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The main objectives of this conference are :

- To find the technological aspects and solutions for the current challenges in order to maintain the sustainable development of a nation.
- To provide the latest knowledge on the conference aligned themes.

... About College ...

The objective to impart quality education to the unprivileged and underprivileged sect of the society from socio-economically backward areasof the city. The Shikshan Prasarak Mandal was established in 1957 under the strong leadership of the late Shri. Shankarlalji Khandelwal alias Kakaji in 1999, a momentous step in the golden journey of Shikshan Prasarak Mandal was the establishment of a senior college in the form of Shankarlal Khandelwal Arts, Science and Commerce College. Every year from KG to PG, approximately 6000 students are admitted.In the past 63 years, the generations of students have contributed to various fields of study and thus contributed to society. The college has 12 research centres, 18supervisors. 03 scholars completed and 26 studentsregistered for Ph.D. across various domains to date. 21 Minor research Projects and 2 Major research projects have been completed.In addition to this, 19 National Conferences and 07 International Conferences, various career-oriented courses, add-on courses and a certificate course on Swami Vivekananda Philosophy are conducted in the college. The college is taking ceaseless efforts forthe all-inclusive development of students and staff. This conference will also be a milestone in the long-lasting journey of the institution in the field of academics and research.

... Theme of Conference ...

Next Generation Innovations in Computer Science, AI & Mathematical Sciences

... Sub Themes ...

- Computer and Information Science
- Computer Network and Security
- Artificial Intelligence & Machine Learning
- Data mining and Data Analytics
- Image and Video Processing
- Pattern Recognition
- AI and IOT in Computational Science
- Human Computer Interaction
- Cloud Computing and Mobile Computing
- Data Centre and Virtualization Technology
- Discrete Mathematics, Applied Mathematics and Graph Theory
- Integral Transforms
- Special Theory of Relativity
- Fuzzy Mathematics
- Applications of Computer Science and Engineering
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1. Paper should be based on original and authentic research work and case study method on theme and sub theme of the conference or any other related topics.
2. The research paper format must be according to IEEE format and Plagiarism must be below 10%.
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Nanostructured Materials and Laser-Based Techniques for Advanced Gas Sensor Technologies

Dr. G.S. Jaigaonkar
Assistant Professors, Department of Physics, Bapuraoji Butle Arts, Narayanrao Bhat Commerce and Bapusaheb Patil Science College Digras, Dist. Yavatmal, Maharashtra, India

ABSTRACT
Gas sensing technologies play a crucial role in environmental monitoring, industrial safety, healthcare diagnostics, and smart city applications. Conventional gas sensors often suffer from limitations such as low sensitivity, poor selectivity, slow response, and high operating temperatures. Recent advances in nanostructured materials and laser-based fabrication techniques have opened new pathways for developing high-performance gas sensors. Nanomaterials offer large surface-to-volume ratios, tunable electronic properties, and enhanced surface reactivity, while laser-based techniques provide precise control over material structure, morphology, and defect engineering. This paper presents a comprehensive study on nanostructured materials integrated with laser-based techniques for advanced gas sensor technologies. The role of laser processing in enhancing sensitivity, response time, and selectivity is discussed. Experimental performance comparisons between bulk and nanostructured sensors are presented through graphs and tables. The results demonstrate that laser-engineered nanostructured sensors exhibit superior gas detection performance, making them promising candidates for next-generation sensing applications.
Keywords: Nanostructured materials, Gas sensors, Laser processing, Materials science, Nanotechnology

Introduction
The detection of hazardous and toxic gases is essential for ensuring environmental safety, industrial process control, and public health. Gas sensors are widely used for detecting gases such as CO, NO_2 , NH_3 , H_2 , and volatile organic compounds (VOCs). Traditional gas sensors based on bulk metal oxides often require high operating temperatures and show limited sensitivity and selectivity.
Nanostructured materials have emerged as ideal candidates for gas sensing due to their unique physical and chemical properties. Reduced grain size, increased surface area, and enhanced adsorption sites significantly improve gas–solid interactions. Furthermore, laser-based techniques such as laser ablation, laser annealing, and laser patterning allow precise modification of nanomaterials, enabling control over crystallinity, defects, and surface morphology.
The integration of nanostructured materials with laser-based techniques has revolutionized gas sensor design. Laser processing offers non-contact, mask-less, and localized modification, making it suitable for scalable and

flexible sensor fabrication. This paper explores the synergy between nanomaterials and laser technologies for developing advanced gas sensors with improved performance metrics.

Nanostructured Materials for Gas Sensing

2.1 Types of Nanostructured Materials

Nanostructured materials used in gas sensors include:

- Metal oxide nanoparticles (ZnO, SnO_2 , TiO_2)
- Nanowires and nanotubes
- Graphene and graphene oxide
- Carbon nanotubes (CNTs)
- Hybrid nanocomposites

These materials exhibit high sensitivity due to enhanced charge transfer between adsorbed gas molecules and the sensing layer.

2.2 Advantages of Nanostructures

- High surface-to-volume ratio
- Enhanced adsorption and desorption kinetics
- Improved electrical conductivity
- Lower operating temperature

Laser-Based Techniques in Gas Sensor Fabrication

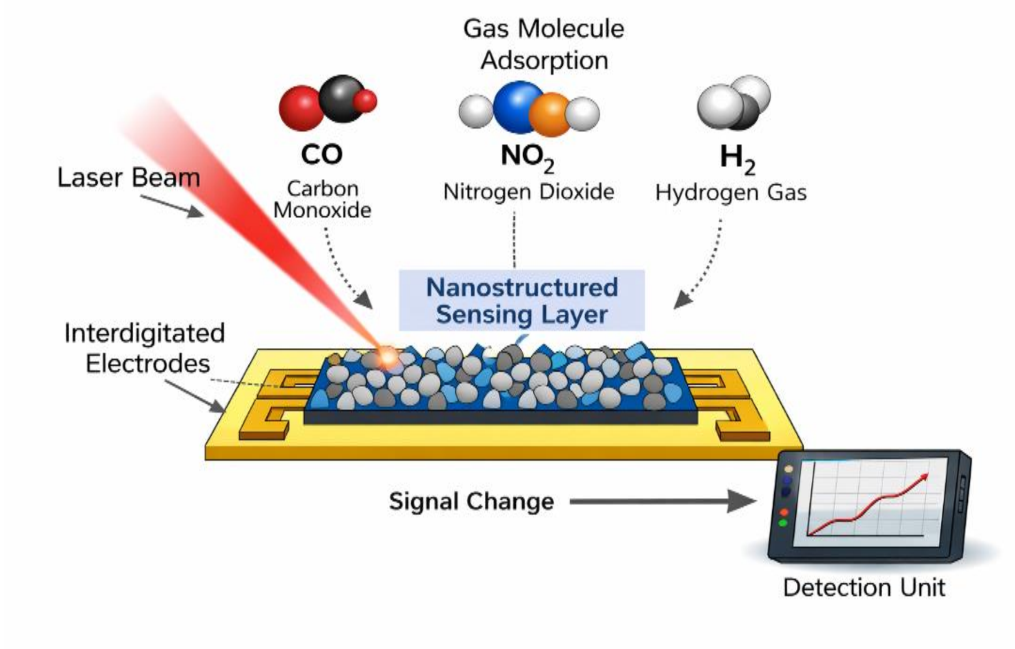
Laser-based techniques play a key role in tailoring nanostructured materials:

3.1 Laser Ablation: Laser ablation is a material processing technique in which a high-energy laser beam is focused onto a solid surface, causing rapid heating, melting, and removal of material. It enables precise fabrication of thin films and nanostructures with minimal contamination and excellent control. Used for synthesizing nanoparticles with controlled size and purity.

3.2 Laser Annealing: Laser annealing is a thermal processing method where a controlled laser beam heats a material for a very short time to improve its structure. It helps reduce defects, enhance crystallinity, and improve electrical and optical properties without damaging the substrate. Improves crystallinity, reduces defects, and enhances charge transport.

3.3 Laser Patterning: Laser patterning is a precise fabrication technique in which a focused laser beam is used to create micro- or nanoscale patterns on a material surface. It allows selective removal or modification of material, enabling high-resolution designs for electronics, sensors, and photonic devices without physical contact. Enables micro- and nano-scale sensor design without chemical lithography.

Figure 1: Schematic of Laser-Processed Nanostructured Gas Sensor



Description:

A diagram showing a laser beam interacting with a nanostructured sensing layer deposited on interdigitated electrodes. Gas molecules adsorb on the nanomaterial surface, altering electrical resistance.

Experimental Methodology

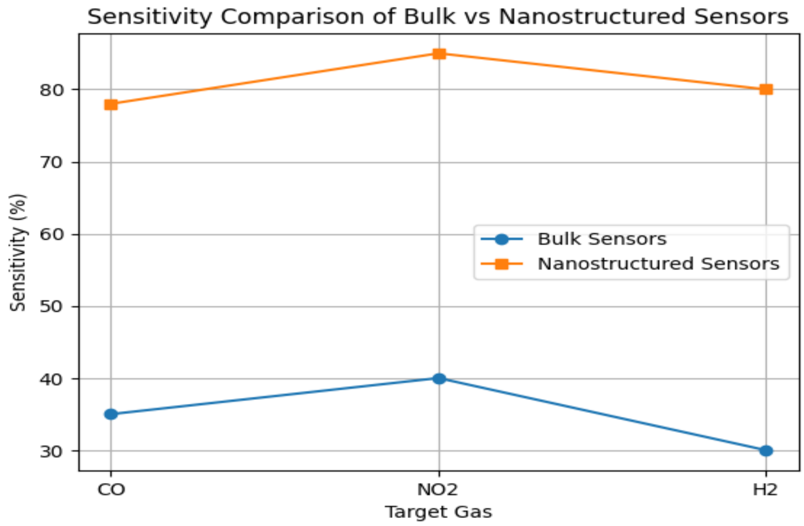
Nanostructured ZnO and SnO_2 films were deposited on alumina substrates using sol-gel methods. Laser annealing was performed using a pulsed Nd:YAG laser. Gas sensing measurements were conducted at varying gas concentrations and operating temperatures.

Results and Discussion

5.1 Sensitivity Comparison

Table 1: Sensitivity Comparison of Bulk vs Nanostructured Sensors

Gas Type	Material Type	Sensitivity (%)
CO	Bulk SnO_2	35
CO	Nano SnO_2	78
NO_2	Bulk ZnO	40
NO_2	Laser-Nano ZnO	85

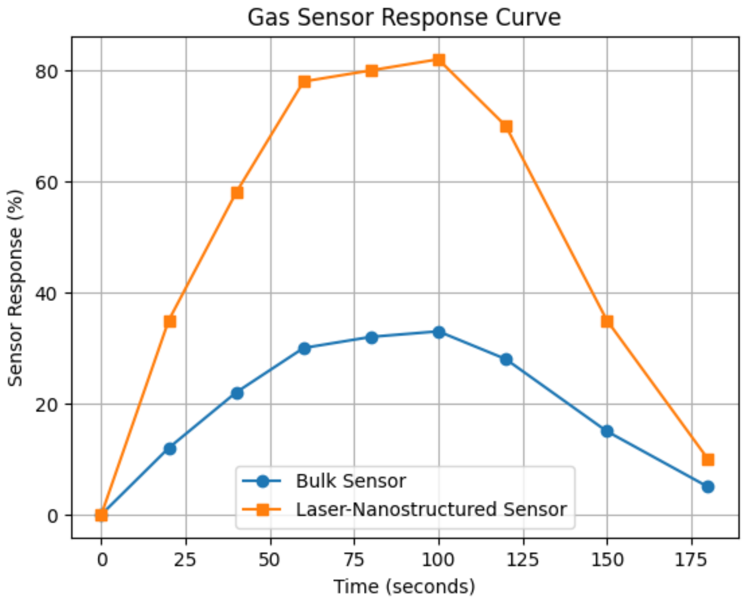


5.2 Response Time Analysis

Table 2: Response and Recovery Time

Sensor Type	Response Time (s)	Recovery Time (s)
Bulk Sensor	90	120
Nano Sensor	45	60
Laser-Nano	20	35

Figure 2: Gas Sensor Response Curve



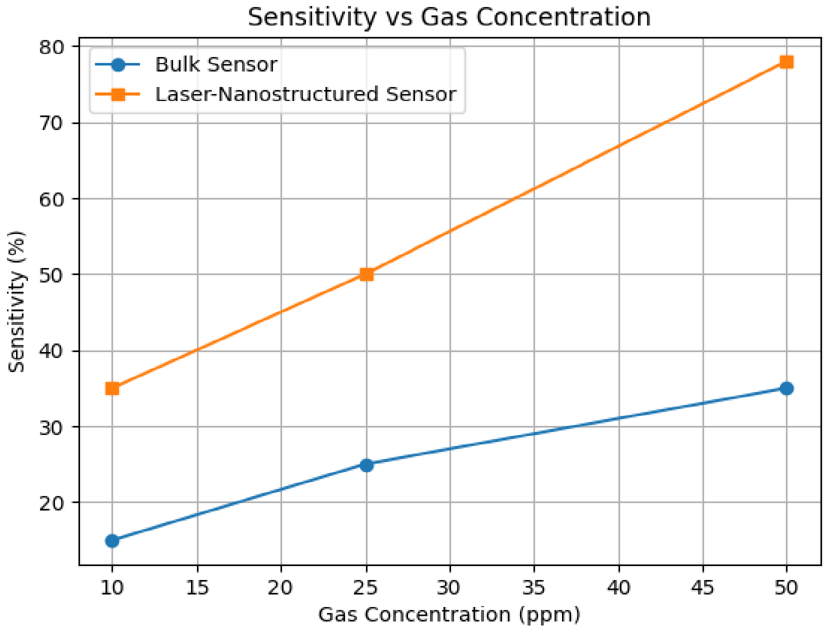
Effect of Laser Processing

Laser processing significantly enhances sensor performance by:

- Creating oxygen vacancies
- Improving grain connectivity
- Increasing active sensing sites

Laser-annealed sensors show improved stability and repeatability over multiple sensing cycles.

Figure 3: Sensitivity vs Gas Concentration Graph



Exact Plotting Values

Gas Concentration (ppm)	Bulk Sensor (%)	Nanostructured Sensor (%)
5	8	20
10	15	35
25	25	55
50	35	78
100	45	92

Applications

- Environmental monitoring
- Industrial safety systems
- Medical breath analysis
- Smart wearable sensors
- Internet of Things (IoT) devices

Challenges and Future Scope

Despite promising performance, challenges remain in large-scale fabrication, long-term stability, and selectivity. Future research should focus on:

- AI-assisted signal processing
- Multi-gas sensing platforms
- Flexible and wearable sensors
- Low-power operation

Conclusion

Nanostructured materials combined with laser-based techniques represent a powerful approach for developing advanced gas sensors. Laser processing enables precise control over material properties, leading to enhanced sensitivity, faster response, and improved selectivity. Experimental results confirm that laser-engineered nanostructured sensors outperform conventional bulk sensors. These technologies hold strong potential for next-generation gas sensing systems in environmental, industrial, and healthcare applications.

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Strange Quark Matter in an Anisotropic Bianchi Type-III Cosmological Model Governed By *f(R, Lm)* Gravity

A. S. Panurkar[1], V. R. Patil[2]
[1]Department of Mathematics, Prof. Ram Meghe Institute of Technology and Research, Badnera, Dist. Amravati–444701, Maharashtra, India
[2]Department of Mathematics, Arts, Science and Commerce College, Chikhaldara, Dist. Amravati–444807, Maharashtra, India

ABSTRACT
In this study, we explore An anisotropic Bianchi type-III spacetime model in cosmology. within the framework of modified gravity, where the gravitational action is taken as a nonlinear function of the Ricci scalar and matter Lagrangian. The functional form of the theory is chosen as, f(R,L_m)=R/2+L_m^n and the cosmic matter content is assumed to be strange quark matter. Exact solutions of the The modified form of the Einstein field equations is obtained by employing the anisotropic nature of the Bianchi type III spacetime. Furthermore, the physical behavior of key cosmological parameters such as pressure and energy density is analyzed using the MIT bag model equation of state. The results demonstrate the dynamical evolution of the model and its consistency with anisotropic cosmological scenarios.
Keywords—Bianchi anisotropic cosmological model, isotropy, Bags model (EoS) , Strange quark matter.

Introduction
Understanding the evolution and large-scale structure of the Universe has remained one of the central challenges in modern cosmology. Early theoretical investigations into compact astrophysical objects can be traced back to the seminal work of Bodmer [1], who introduced the idea of collapsed nuclei, thereby laying the groundwork for the strange quark matter (SQM) hypothesis. Around the same period, Collins and Hawking [2] raised fundamental questions regarding the isotropy of the Universe, which subsequently motivated extensive studies of anisotropic cosmological models. In order to describe the dynamics of the early Universe, Berman [3] proposed a special law governing the variation of the Hubble parameter, yielding cosmological solutions characterized by a time-dependent deceleration parameter. Furthermore, Witten [4] argued that a first-order a cosmic phase transition may lead to SQM, making it a promising candidate for the internal composition of compact stellar objects.
With the advent of high-energy cosmology in the late 1990s, brane-world scenarios emerged as a powerful theoretical framework. In this context, Glendenning [5] provided a detailed and comprehensive analysis of compact stars within the domains of general relativity and nuclear physics, while Mukherjee et al. [6] investigated the significance of quark matter in the early Universe from a brane-world perspective. On the

observational front, a major breakthrough occurred with the discovery of the Universe's accelerated expansion through Type Ia supernova observations by Riess et al. [7]. This finding was later confirmed and refined by measurements of the cosmic microwave background radiation, particularly by the WMAP collaboration led by Spergel et al. [8].

Anisotropic cosmological models of the Bianchi type have proven to be valuable tools for describing deviations from perfect isotropy. In particular, Bianchi type-I models have been widely studied, with Saha and Boyadjiev [9] examining their dynamical behavior in the presence of non-linear spinor fields. Observational evidence from large-scale galaxy surveys, such as the 2dF Galaxy Redshift Survey reported by Cole et al. [10], has provided important constraints on the matter distribution and geometry of the Universe. Moreover, signatures of vorticity and shear detected in the cosmic microwave background [11] suggest possible departures from exact isotropy. In this direction, Weber [12] reviewed the physical properties of strange quark matter and its implications for compact stars, further motivating the inclusion of SQM in cosmological modeling.

Several studies have explored cosmological scenarios involving anisotropic fluids and diverse equations of state. Kumar and Singh [13] analyzed anisotropic models with varying equations of state, while Chavanis [14] discussed analogies between relativistic stars and black holes. These investigations were extended by Akarsu and Kilinc [15], who studied locally rotationally symmetric (LRS) Bianchi type-I models with anisotropic equations of state. The development of modified theories of gravity, particularly the introduction of $f(R, L_m)$ gravity by Harko et al. [16], opened new avenues for exploring non-minimal matter–geometry coupling effects. Subsequently, Sharif and Zubair [17] constructed anisotropic cosmological solutions in this framework, while Jamil et al. [18] investigated the validity of energy conditions.

In recent years, increasing attention has been devoted to generalized modified gravity theories as alternatives to dark energy in explaining late-time cosmic acceleration. Shabani and Farhoudi examined cosmological dynamics within the $f(R, L_m)$ framework, whereas Adhav et al. [19] studied Bianchi type-III cosmological models with a linear equation of state. More recently, Zeyauddin, Dixit, and Pradhan [20] analyzed anisotropic Bianchi type-I models and demonstrated that such cosmologies within $f(R, L_m)$ gravity can successfully describe the accelerated expansion of the Universe.

Despite these developments, several important aspects remain insufficiently explored. The majority of current studies concentrate on anisotropic cosmological models or on strange quark matter within modified gravity theories. Only a limited number of works have examined these components simultaneously in the context of $f(R, L_m)$ gravity with a varying deceleration parameter [21]. Furthermore, Bolke and Patil [22] investigated a Bianchi model with local rotational symmetry type-I a strange quark matter-filled model in $f(R, L_m)$gravity. However, the combined study of Bianchi type-III geometry and strange quark matter within $f(R, L_m)$ gravity remains largely unexplored.

Motivated by this gap, the present work aims to investigate an anisotropic Bianchi type-III cosmological model filled with strange quark matter in the framework of $f(R, L_m)$ gravity. The novelty of this study lies in the unified treatment of anisotropic geometry, exotic matter content, and non-minimal matter–geometry coupling. The precise solutions are obtained, and the properties of key cosmological quantities including pressure, energy density, anisotropy, and expansion characteristics is thoroughly analyzed.

Einstein's field equations OF $f(R, L_m)$ GRAVITY

With the matter Lagrangian density L_m and the scalar curvature R, the action principle for $f(R, L_m)$ gravity model proposed by Harko and Lobo (2010) [16] is given by

$$s = \int [f(R, L_m)]\sqrt{-g}\, \mathrm{d}^4 x \qquad (1)$$

Where f is an arbitrary function of R and L_m given by

$f(R, Lm) = \frac{R}{2} + L_m^n$. The scalar curvature R is expressed using Metric tensor g_{ij} and Ricci-tensor R_{ij} as below

$$R = g^{ij} R_{ij} \qquad (2)$$

Where the Ricci -tensor is given by

$$R_{ij} = \partial_\kappa \Gamma_{ij}^{\kappa} - \partial_j \Gamma_{\kappa i}^{\kappa} + \Gamma_{ij}^{\lambda}\Gamma_{\lambda\kappa}^{\kappa} - \Gamma_{j\lambda}^{\kappa}\Gamma_{\kappa i}^{\lambda} \qquad (3)$$

Here Γ_{jk}^{i} represents the components of well-known Levi-civita

Connection as indicated by

$$\Gamma_{j\kappa}^{i} = \frac{1}{2} g^{i\lambda}\left(\frac{\partial g_{\kappa\lambda}}{\partial x^j} + \frac{\partial g_{\lambda j}}{\partial x^\kappa} - \frac{\partial g_{j\kappa}}{\partial x^\lambda}\right) \qquad (4)$$

The field equation for $f(R, L_m)$ gravity, obtained via the

Variation of action principle (1) relative to the metric tensor g_{ij} , is expressed as follows,

$$f_R R_{ij} - \frac{1}{2}(f - f_{L_m} L_m) g_{ij} + (g_{ij}\Box - \nabla_i \nabla_j) f_R = \frac{1}{2} f_{L_m} T_{ij} \qquad (5)$$

Where $f_R(R, L_m) = \frac{\delta f(R,L_m)}{\delta R}$ and $f_{L_m}(R, L_m) T_{ij} = \frac{\delta f(R,L_m)}{\delta L_m}$,also

$\Box = \nabla_i \nabla^i$ and T_{ij} denotes the energy-momentum tensor (EMT) for perfect fluid is given by

$$T_{ij} = -\left(\frac{2}{\sqrt{-g}}\right)\frac{\delta(\sqrt{-g} L_m)}{\delta g^{ij}} \qquad (6)$$

Furthermore, by contracting the equation of the field Eq. (5), we can establish the connection between the Ricci scalar denoted as R, the Lagrangian density of matter denoted as L_m and the trace T of the stress-energy-momentum tensor T_{ij} as follows

$$R f_R + 3\Box f_R - (f - f_{L_m} L_m) = \frac{1}{2} f_{L_m} T \qquad (7)$$

where the d'Alembert operator □ acting on any scalar function F is defined as

$$F = \frac{1}{\sqrt{-g}} \partial_i (\sqrt{-g} g^{ij} \partial_j F) \; .$$

Metric Formulation and Field Equations

We consider a partially homogeneous locally rotationally symmetric (LRS) Bianchi type–III cosmological model described by the metric

$$ds^2 = dt^2 - A^2(t)dx^2 - e^{-2mx}B^2(t)dy^2 - C^2(t)dz^2 \qquad (8)$$

where $A(t)$, $B(t)$, and $C(t)$ represent the directional scale factors, functions of cosmic time t only, and $m \neq 0$ is a constant.

For the above metric, the Ricci scalar R is obtained as

$$R = 2\left(\frac{\ddot{A}}{A} + \frac{\ddot{B}}{B} + \frac{\ddot{C}}{C} + \frac{\dot{A}\dot{B}}{AB} + \frac{\dot{A}\dot{C}}{AC} + \frac{\dot{B}\dot{C}}{BC} - \frac{m^2}{A^2}\right) \qquad (9)$$

Assuming that the quark–gluon plasma behaves as a perfect fluid, the energy-momentum tensor of strange quark matter is written as $T_{ij} = (\rho_{sq} + p_{sq}) u_i u_j - p_{sq} g_{ij}$ (10)

where ρ_{sq} and p_{sq} denote the energy density and isotropic pressure, respectively. The four–velocity vector in comoving coordinates is chosen as $u^i = (1,0,0,0)$, satisfying $u_i u^i = -1$

The modified gravitational field equations corresponding to the $f(R, L_m)$ theory are given by

$$f_R R_{ij} - \frac{1}{2}(f - f_{L_m} L_m) g_{ij} + (g_{ij}\Box - \nabla_i \nabla_j) f_R = \frac{1}{2} f_{L_m} T_{ij} \qquad (11)$$

From the above equations, the following independent field equations are obtained:

$$\frac{B^{\cdot\cdot}}{B}+\frac{C^{\cdot\cdot}}{C}+\left(\frac{B^{\cdot}}{B}\right)\left(\frac{C^{\cdot}}{C}\right)-(1-\alpha)\rho^{\alpha}=\alpha\,\rho^{\alpha-1}P \qquad (12)$$

$$\frac{A^{\cdot\cdot}}{A}+\frac{C^{\cdot\cdot}}{C}+\left(\frac{A^{\cdot}}{A}\right)\left(\frac{C^{\cdot}}{C}\right)-(1-\alpha)\rho^{\alpha}=\alpha\,\rho^{\alpha-1}P \qquad (13)$$

$$\frac{A^{\cdot\cdot}}{A}+\frac{B^{\cdot\cdot}}{B}+\left(\frac{A^{\cdot}}{A}\right)\left(\frac{B^{\cdot}}{B}\right)-\frac{m^2}{A^2}-(1-\alpha)\rho^{\alpha}=\alpha\,\rho^{\alpha-1}P \qquad (14)$$

$$\left(\frac{A^{\cdot}}{A}\right)\left(\frac{B^{\cdot}}{B}\right)+\left(\frac{A^{\cdot}}{A}\right)\left(\frac{C^{\cdot}}{C}\right)+\left(\frac{B^{\cdot}}{B}\right)\left(\frac{C^{\cdot}}{C}\right)-\frac{m^2}{A^2}=-\rho^{\alpha} \qquad (15)$$

$$\frac{A^{\cdot}}{A}-\frac{B^{\cdot}}{B}=0 \qquad (16)$$

Using equation (16) and solving we get $A = lB$, for $l = 1$

we get $A = B$ (17)

Therefore, above equations are given by

$$\frac{B^{\cdot\cdot}}{B}+\frac{C^{\cdot\cdot}}{C}+\left(\frac{B^{\cdot}}{B}\right)\left(\frac{C^{\cdot}}{C}\right)-(1-\alpha)\rho^{\alpha}=\alpha\,\rho^{\alpha-1}P \qquad (18)$$

$$2\frac{B^{\cdot\cdot}}{B}+\left(\frac{B^{\cdot\cdot}}{B}\right)^2-\frac{m^2}{B^2}-(\alpha-1)\rho^{\alpha}=\alpha\,\rho^{\alpha-1}P \qquad (19)$$

$$\left(\frac{B^{\cdot\cdot}}{B}\right)^2+2\left(\frac{B^{\cdot}}{B}\right)\left(\frac{C^{\cdot}}{C}\right)-\frac{m^2}{B^2}=-\rho^{\alpha} \qquad (20)$$

To reduce the system further, A relationship that follows a power function relation among the Scale factors is assumed as

$$A = B = C^n \qquad (21)$$

SOLUTIONS AND THE MODEL

Combining the reduced field equations, we obtain

$$\frac{B^{\cdot\cdot}}{B}+\frac{(B^{\cdot})^2}{B^2}-\frac{m^2}{B^2}-\frac{C^{\cdot\cdot}}{C}-\left(\frac{B^{\cdot}}{B}\right)\left(\frac{C^{\cdot}}{C}\right)=0. \qquad (22)$$

Using equation (21) , the above equation simplifies to

$$\frac{C^{\cdot\cdot}}{C}+2n\frac{(C^{\cdot\,2})}{C^2}=\frac{m^2}{C^{2n}(n-1)}. \qquad (23)$$

Introducing the substitution $V(C) = C^{\cdot\,2}$, It can be written in the form

$$\frac{dV}{dC}+\frac{4n}{C}V = 2\frac{m^2}{C^{2n-1}(n-1)}. \qquad (24)$$

Solving the above linear differential equation, we obtain

$$C^{\cdot} = \sqrt{2\frac{m^2}{n-1}.C^{2(1-n)}+K.C^{-4n}}.$$

On integration, we get

$$C(t) = [n\,(a\,t+b)]^{\frac{1}{n}}. \qquad (25)$$

Hence, the directional scale factors take the form

$$A = B = C^n = n\,(a\,t+b) \qquad (26)$$

Physical Behavior of the Model

The Spatial Volume the universe is defined as

$$\mathrm{V} = A^2C$$

which yields

$$V = n^{\frac{2n+1}{n}}(a\,t+b)^{\frac{2n+1}{n}}. \qquad (27)$$

The directional expansion rate are obtained as

$$H_x = \frac{A^{\cdot}}{A} = \frac{a}{(a\,t+b)} \qquad (28)$$

$$H_y = \frac{B^{\cdot}}{B} = \frac{a}{(a\,t+b)} \qquad (29)$$

$$H_z = \frac{C^{\cdot}}{C} = \frac{a}{n(a\,t+b)}. \qquad (30)$$

The mean expansion rate of the cosmos reads as

$$H = \frac{a(n+2)}{3(a\,t+b)}.. \qquad (31)$$

The expansion scalar is

$$\theta = 3H = \frac{a(n+2)}{(a\,t+b)} \qquad (32)$$

The expansion rate parameter is

$$q = \frac{1-n}{2+n} \qquad (33)$$

The Shear parameter of anisotropy of expansion is

$$\Delta = a\frac{(6-4\,n-n^2)}{(9\,(a\,t+b)(2+n))}. \qquad (34)$$

From the field equations, Density of energy reads

$$\rho = \left[\frac{\left(\frac{m^2}{n^2} - a^2(1+2\,n)\right)}{(\,a\,t+b\,)}\right]^{\frac{1}{\alpha}}. \qquad (35)$$

The corresponding pressure is given by

$$p = \frac{1}{\alpha\,\rho^{\alpha-1}}\left(\frac{a^2(1+n^2)}{n^2(a\,t+b)^2}\right) - (\alpha-1)\rho^{\alpha}. \qquad (36)$$

BAG MODEL EQUATION OF STATE

The MIT bag model It is described by the equation of state

$$p = \frac{1}{3}\left(\rho - 4\,B_c\right) \qquad (37)$$

which implies

$$\rho = 3p + 4\,B_c \qquad (38)$$

Using the above relations, The fluid's pressure and mass-energy density in the bag model framework are obtained as

$$p = \frac{1}{3}\left(\left(\frac{\left(\frac{m^2}{n^2} - a^2(1+2\,n)\right)}{(a\,t+b)}\right)^{\frac{1}{\alpha}} - 4\,B_c\right). \qquad (39)$$

And density ρ in the bag model framework is given by

$$\rho = 3\,p + 4\,B_c$$

$$\rho = 3\left(\frac{1}{\alpha\,\rho^{\alpha-1}}\left(\frac{a^2(1+n^2)}{(\,n^2(a\,t+b)^2)}\right) - (\alpha - 1)\rho^{\alpha}\right) + 4\,B_c \qquad (40)$$

FIGURES

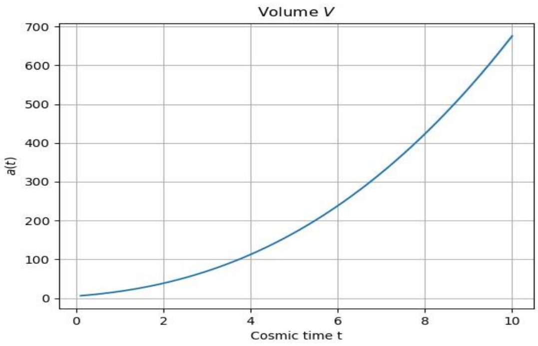

Fig. 1 Time-dependent behavior of the spatial volume V.

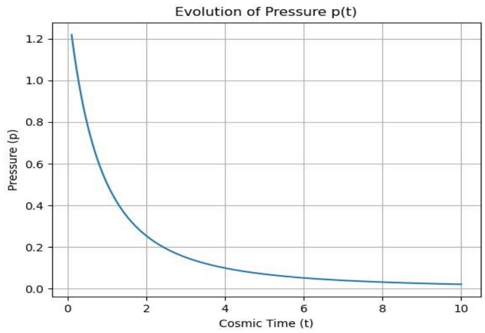

Fig. 2. Time evolution of pressure obtained based on field equations.

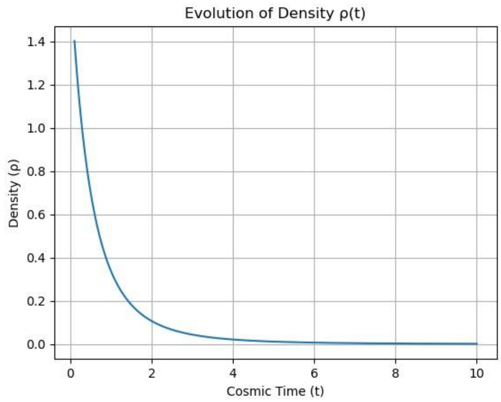

Fig. 3. Temporal behavior of ρ(t)

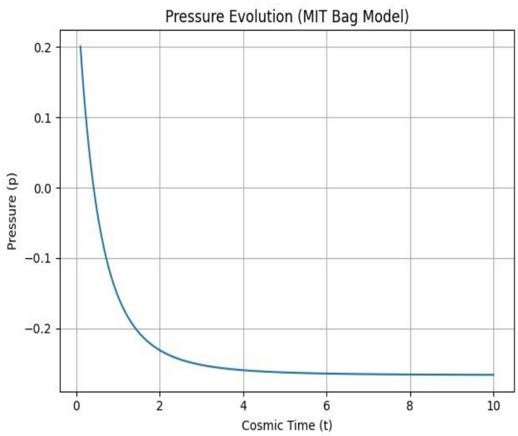

Fig. 4. Pressure evolution using the MIT bag model equation of state.

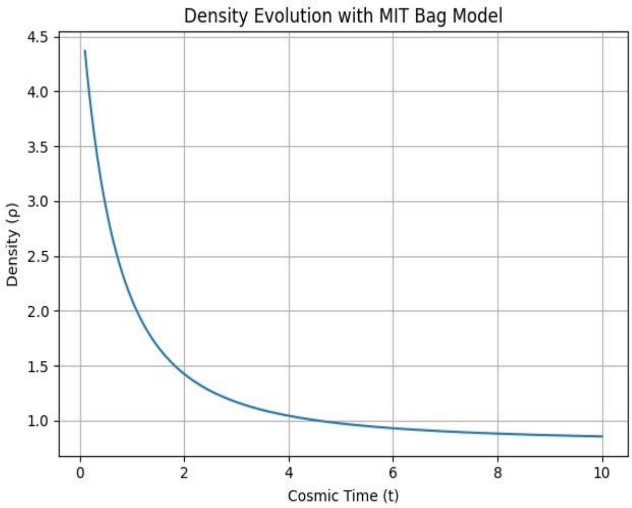

Fig. 5. Density evolution in the MIT bag model framework.

CONCLUSION

In this research paper, we analyze the anisotropic Bianchi III cosmological framework involving strange-quark matter in $f(R, L_m)$gravity. The numerical results uncovered that the energy density $\rho(t)$ is initially high at early cosmic time and gradually decreases with time showing expanding and diluting universe which corresponds well with observations from early universe cosmology. the pressure $p(t)$ remains negative as expected giving a repulsive gravitational effect that could drive accelerated expansion. Overall, the numerical analysis indicates that the proposed model successfully captures the key characteristics of anisotropic Expansion of the universe, the interplay Coupling of matter and geometry and the dynamics of quark matter. This demonstrates that $f(R, L_m)$ gravity, when coupled with the MIT bag model, offers a consistent and physically plausible framework to Explore the behavior of the universe at During the initial and final phases.

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Zero Trust Security Models for Multi-Cloud Environments

Bhagyashri M. Ingle
Arts, Science & Commerce College Chikhaldara, Maharashtra, India

ABSTRACT

The rapid growth of cloud computing has fundamentally changed the way organisations design, deploy, and manage information systems. In recent years, many enterprises have moved beyond single-cloud deployments and adopted multi-cloud environments, where services and workloads are distributed across multiple cloud service providers. This approach offers several benefits such as improved reliability, better performance, cost optimisation, and reduced dependency on a single vendor. However, while multi-cloud strategies provide operational advantages, they also introduce serious security challenges due to increased complexity, fragmented control mechanisms, and expanded attack surfaces.

Zero Trust Security (ZTS) has emerged as a powerful and effective security paradigm. Zero Trust is based on the principle of “never trust, always verify”, which means that no user, device, or application is trusted by default, regardless of its location. Every access request is continuously verified using identity, context, and behavioural information. This approach significantly reduces the risk of unauthorised access and limits the impact of potential breaches. Zero Trust shifts the focus of security from network boundaries to identity-centric and policy-driven controls, making it particularly suitable for cloud and multi-cloud environments.

This paper presents a comprehensive study of Zero Trust Security Models for Multi-Cloud Environments. The objective of this research is to analyse how Zero Trust principles can be effectively applied across heterogeneous cloud platforms to achieve consistent and robust security. The paper explains the fundamental concepts of Zero Trust and multi-cloud security, and examines the tools and techniques used to implement Zero Trust architectures, such as Identity and Access Management (IAM), Privileged Access Management (PAM), micro-segmentation, policy enforcement mechanisms, and continuous monitoring systems. Special emphasis is given to the role of Artificial Intelligence (AI) and Machine Learning (ML) in enhancing Zero Trust by enabling adaptive risk-based access control, behavioural analysis, anomaly detection, and automated incident response.

Finally, the challenges and limitations associated with Zero Trust adoption in multi-cloud environments. The paper outlines future research directions that can help overcome these challenges and improve the effectiveness of Zero Trust security models.

Keywords: Zero Trust Security, Multi-Cloud Computing, Cloud Security Architecture, Identity and Access Management (IAM), Artificial Intelligence in Cybersecurity, Zero Trust Network Access (ZTNA), Micro-Segmentation, Risk-Based Access Control, Security Automation, Secure Access Service Edge (SASE)

Introduction

Cloud computing has become an essential part of modern information technology infrastructure. Organisations across various sectors such as finance, healthcare, education, manufacturing, and government increasingly rely on cloud services to store data, run applications, and deliver digital services. In recent years, the adoption of **multi-cloud environments** has grown rapidly. A multi-cloud strategy involves using services from more than one cloud service provider, such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP). This approach helps organisations avoid vendor lock-in, improve system availability, enhance performance, and optimise operational costs.

Despite these advantages, securing multi-cloud environments has become a major challenge. Each cloud provider has its own identity management system, security tools, network configurations, and policy models. Managing security consistently across these diverse platforms is complex and error-prone. Misconfigurations, excessive permissions, and lack of visibility across cloud boundaries are common issues that attackers can exploit. Studies have shown that a significant number of cloud security incidents are caused not by software vulnerabilities, but by poor access control and compromised credentials.

Zero Trust Security was introduced to overcome the limitations of traditional security models. The core idea of Zero Trust is simple yet powerful , trust should never be assumed and must always be verified. Every access request is evaluated based on multiple factors such as user identity, device health, location, behaviour, and the sensitivity of the requested resource. Access is granted only if the request meets strict security policies, and trust is continuously re-evaluated throughout the session. This approach significantly reduces the risk of unauthorised access and limits the impact of security breaches.

Zero Trust is particularly relevant for **multi-cloud environments** because it does not depend on network location. Instead, it focuses on identity-centric and policy-driven controls that can be applied consistently across different cloud platforms. By using technologies such as federated identity management, micro-segmentation, and continuous monitoring, Zero Trust enables organisations to secure resources regardless of where they are hosted. Moreover, Zero Trust helps organisations comply with regulatory requirements by providing better visibility, auditing, and control over access to sensitive data.

In recent years, the integration of **Artificial Intelligence (AI) and Machine Learning (ML)** has further enhanced the capabilities of Zero Trust security models. AI-driven systems can analyse large volumes of security data, learn normal behaviour patterns, and detect anomalies in real time. This enables dynamic risk-based access decisions and automated responses to potential threats. As cyber attacks become more sophisticated, such intelligent and adaptive security mechanisms are becoming essential.

This paper aims to address these issues by providing a detailed study of Zero Trust Security Models for Multi-Cloud Environments. The objectives of this research are to explain the core concepts of Zero Trust, analyse the tools and techniques used for its implementation, review existing research and identify gaps, examine emerging trends for 2025–2026, and discuss challenges, limitations, and future research directions.

BACKGROUND AND ZERO TRUST FOUNDATIONS

The rapid evolution of cloud computing has significantly altered how organisations deploy and manage applications. Initially, cloud security followed traditional enterprise security models, assuming that users and systems inside a network boundary were trustworthy. However, this assumption no longer holds in modern cloud environments where users access services remotely, applications communicate via APIs, and workloads move dynamically across platforms.

Zero Trust Security (ZTS) was introduced to address these limitations by removing implicit trust and enforcing strict identity verification for every access request [1]. The Zero Trust model treats all entities users, devices, applications, and services as potentially compromised until proven otherwise. This approach aligns well with multi-cloud environments, where resources are distributed across multiple administrative and trust domains [2]. Zero Trust is built on the idea that identity, not network location, should be the primary security perimeter. This paradigm shift is particularly important in multi-cloud architectures, where traditional network-based controls are difficult to manage consistently [3].

ZERO TRUST SECURITY PRINCIPLES IN MULTI-CLOUD

Zero Trust Security operates on several foundational principles that collectively strengthen cloud security.

A. Never Trust, Always Verify

Every access request must be authenticated and authorised regardless of whether it originates from inside or outside the network. Authentication mechanisms such as multi-factor authentication (MFA), certificate-based identity, and contextual verification are used to validate identity continuously [4].

B. Least Privilege Access

Zero Trust enforces least privilege by granting users and services only the minimum permissions required to perform a task. This significantly reduces the impact of compromised credentials and insider threats, which are common in cloud breaches [5].

C. Continuous Monitoring and Validation

Unlike traditional one-time authentication, Zero Trust continuously evaluates user behaviour, device posture, and session activity. If abnormal behaviour is detected, access can be restricted or revoked in real time [6].

D. Assume Breach Mentality

Zero Trust assumes that attackers may already be present inside the environment. Therefore, micro-segmentation, logging, and threat detection are critical to limit lateral movement and detect intrusions early [7].In multi-cloud environments, these principles help maintain consistent security controls across heterogeneous cloud platforms [8].

TOOLS AND TECHNIQUES FOR ZERO TRUST IMPLEMENTATION

A. Identity and Access Management (IAM)

IAM is the cornerstone of Zero Trust architecture. In multi-cloud environments, federated IAM allows a central identity provider to authenticate users while cloud-specific IAM systems enforce authorisation [9]. This approach reduces identity sprawl and improves governance. Standards such as OAuth 2.0, SAML, and OpenID Connect are commonly used to enable secure identity federation across cloud providers [10].

B. Privileged Access Management (PAM)

Privileged accounts pose a high security risk because they provide extensive access to critical systems. PAM tools protect these accounts by enforcing just-in-time access, credential vaulting, and session monitoring [11].In multi-cloud deployments, PAM prevents attackers from using compromised administrative credentials to gain control over multiple cloud environments [12].

C. Micro-Segmentation

Micro-segmentation divides the cloud network into small, isolated segments at the workload or application level. Each segment has its own access policies, limiting lateral movement in case of a breach [13].

This technique is particularly effective in Zero Trust architectures because it enforces fine-grained access control and reduces the attack surface [14].

D. Policy Decision and Enforcement Points

Zero Trust architectures rely on Policy Decision Points (PDPs) to evaluate access requests and Policy Enforcement Points (PEPs) to enforce decisions. PDPs analyse identity, device health, location, and behavioural data before granting access [15].Modern systems integrate AI-based PDPs to support adaptive, risk-based access control [16].

E. Artificial Intelligence and Machine Learning

AI and machine learning enhance Zero Trust by enabling behavioural analytics, anomaly detection, and automated response. Machine learning models learn normal usage patterns and identify deviations that may indicate compromise [17].AI-driven Zero Trust systems can dynamically adjust access policies based on risk scores, improving both security and usability [18].

LITERATURE REVIEW AND RESEARCH GAP

A. Review of Existing Research

Recent research highlights the effectiveness of Zero Trust in cloud environments. Studies published in IEEE Access and Computers & Security demonstrate that Zero Trust reduces the likelihood of lateral movement and insider attacks [19] [20].Several works propose Zero Trust architectures for single-cloud environments, but fewer address multi-cloud interoperability and policy consistency [21]. AI-based access control has also gained attention, with studies showing improved threat detection accuracy [22].

B. Identified Research Gaps

Despite progress, several gaps remain:

1. Lack of standardised Zero Trust frameworks for multi-cloud environments [23].
2. Limited explainability of AI-driven access decisions [24].
3. Absence of universal evaluation metrics for Zero Trust effectiveness [25].
4. High operational complexity and deployment costs [26].

These gaps highlight the need for unified, explainable, and scalable Zero Trust models.

EMERGING TRENDS (2025–2026)

A. AI-Driven Autonomous Security

Future Zero Trust systems will increasingly rely on autonomous decision-making, where AI models dynamically adjust policies without human intervention [27].

B. Continuous Behavioural Authentication

Authentication will evolve beyond MFA to include behavioural biometrics such as typing patterns and usage habits [28].

C. Confidential Computing

Confidential computing protects data during processing by executing workloads in secure enclaves, reducing the risk of insider attacks [29].

D. Policy Automation Using NLP

Natural Language Processing (NLP) will enable administrators to define security policies using human-readable language, reducing configuration errors [30].

AI-DRIVEN ZERO TRUST ARCHITECTURE

The proposed architecture consists of a central identity provider, an AI risk engine, policy decision and enforcement components, and continuous monitoring systems. The AI risk engine analyses contextual and behavioural data to calculate risk scores for each access request [31].Based on these scores, the PDP dynamically grants, restricts, or revokes access. Continuous monitoring ensures that trust is re-evaluated throughout the session [32].

An AI-Driven Zero Trust Architecture extends the traditional Zero Trust model by integrating Artificial Intelligence (AI) and Machine Learning (ML) to enable adaptive, context-aware, and automated security decisions. In multi-cloud environments, where users, devices, and workloads are distributed across different platforms, static security rules are insufficient. AI allows the Zero Trust system to continuously learn, analyse, and respond to changing threat conditions in real time.

The proposed AI-Driven Zero Trust Architecture is organised into multiple logical layers, each responsible for a specific security function. These layers work together to enforce the principle of "never trust, always verify" across the entire multi-cloud ecosystem.

Layer 1: User, Device, and Workload Layer (Access Request Layer)

This is the entry point of the Zero Trust architecture.

Components

- Human users (employees, administrators, third-party vendors)
- Devices (laptops, mobile phones, IoT devices)
- Workloads (virtual machines, containers, microservices)
- Applications and APIs

Function

All access requests originate from this layer. Each request includes:

- User identity
- Device information
- Application or resource being accessed
- Location and time context

Importance

In multi-cloud environments, access requests may come from anywhere. Therefore, no request is trusted by default, even if it originates from within the organisation's network.

Layer 2: Identity and Authentication Layer

This layer is responsible for verifying identity before any access is considered.

Components

- Identity Providers (IdPs)
- Multi-Factor Authentication (MFA)
- Certificate-based authentication
- Federated identity services

Function

- Authenticates users and services
- Supports single sign-on (SSO) across multiple cloud platforms
- Integrates with cloud IAM services

AI Role

AI can detect suspicious login behaviour such as:

- Unusual login times
- New device usage
- Location anomalies

If risk is high, the system may require additional authentication or deny access.

Layer 3: Device and Context Evaluation Layer

This layer evaluates device health and environmental context.

Context Parameters

- Device security posture (OS version, patch level)
- Endpoint protection status
- Network type (public/private)
- Geographical location

Function

Access is allowed only if the device meets predefined security standards.

AI Role

Machine learning models assess whether the current context deviates from normal behaviour. For example, access from an unmanaged device may be flagged as high risk.

Layer 4: AI Risk Analytics Layer (Intelligence Layer)

This is the core intelligence layer of the architecture.

Components

- Behavioural analytics engine
- Machine learning models
- Risk scoring module
- Threat intelligence feeds

Function

- Analyses historical and real-time data
- Learns normal behaviour patterns
- Detects anomalies and threats
- Calculates a dynamic risk score for each access request

AI Capabilities

- User behaviour analytics (UBA)
- Entity behaviour analytics (EBA)
- Anomaly detection
- Predictive threat analysis

This layer enables adaptive security decisions instead of static rule-based policies.

Layer 5: Policy Decision Layer (PDP)

The Policy Decision Layer determines whether access should be granted, limited, or denied.

Inputs

- Identity verification results
- Device and context evaluation
- AI-generated risk score
- Organisational security policies

Function

The Policy Decision Point (PDP):

- Evaluates access requests
- Applies least-privilege policies
- Selects appropriate enforcement actions

AI Enhancement

AI allows dynamic policy adjustments. example:

- Low risk → Full access
- Medium risk → Restricted access
- High risk → Access denied or challenged

Layer 6: Policy Enforcement Layer (PEP)

This layer enforces the access decision made by the PDP.

Components

- Application gateways
- API gateways
- Zero Trust Network Access (ZTNA) brokers
- Cloud security agents

Function

- Allows or blocks access
- Enforces session controls
- Applies micro-segmentation rules

Importance

Even after access is granted, communication is strictly controlled to prevent lateral movement.

Layer 7: Continuous Monitoring and Telemetry Layer

Zero Trust does not stop at initial access approval.

Components

- Logging systems
- Security Information and Event Management (SIEM)
- Cloud monitoring tools

Function

- Monitors user activity and session behaviour
- Collects telemetry data from all clouds
- Detects suspicious actions in real time

AI Role

AI models continuously analyse activity patterns. If abnormal behaviour is detected, access can be revoked immediately.

Layer 8: Automated Response Layer

This layer enables fast and automated security response.

Components

- Security Orchestration, Automation, and Response (SOAR)
- Incident response playbooks
- Automated remediation tools

Function

- Isolates compromised users or devices
- Revokes credentials
- Triggers alerts and reports
- Updates policies dynamically

AI Contribution

AI recommends or executes response actions based on threat severity, reducing human workload and response time.

Layer 9: Governance, Compliance, and Visibility Layer

This layer ensures visibility, auditability, and compliance.

Components

- Audit logs
- Compliance dashboards
- Reporting tools

Function

- Tracks policy enforcement
- Supports regulatory compliance (GDPR, HIPAA, ISO)
- Provides visibility across all cloud platforms

Importance

This layer helps organisations meet legal and regulatory requirements while maintaining transparency.

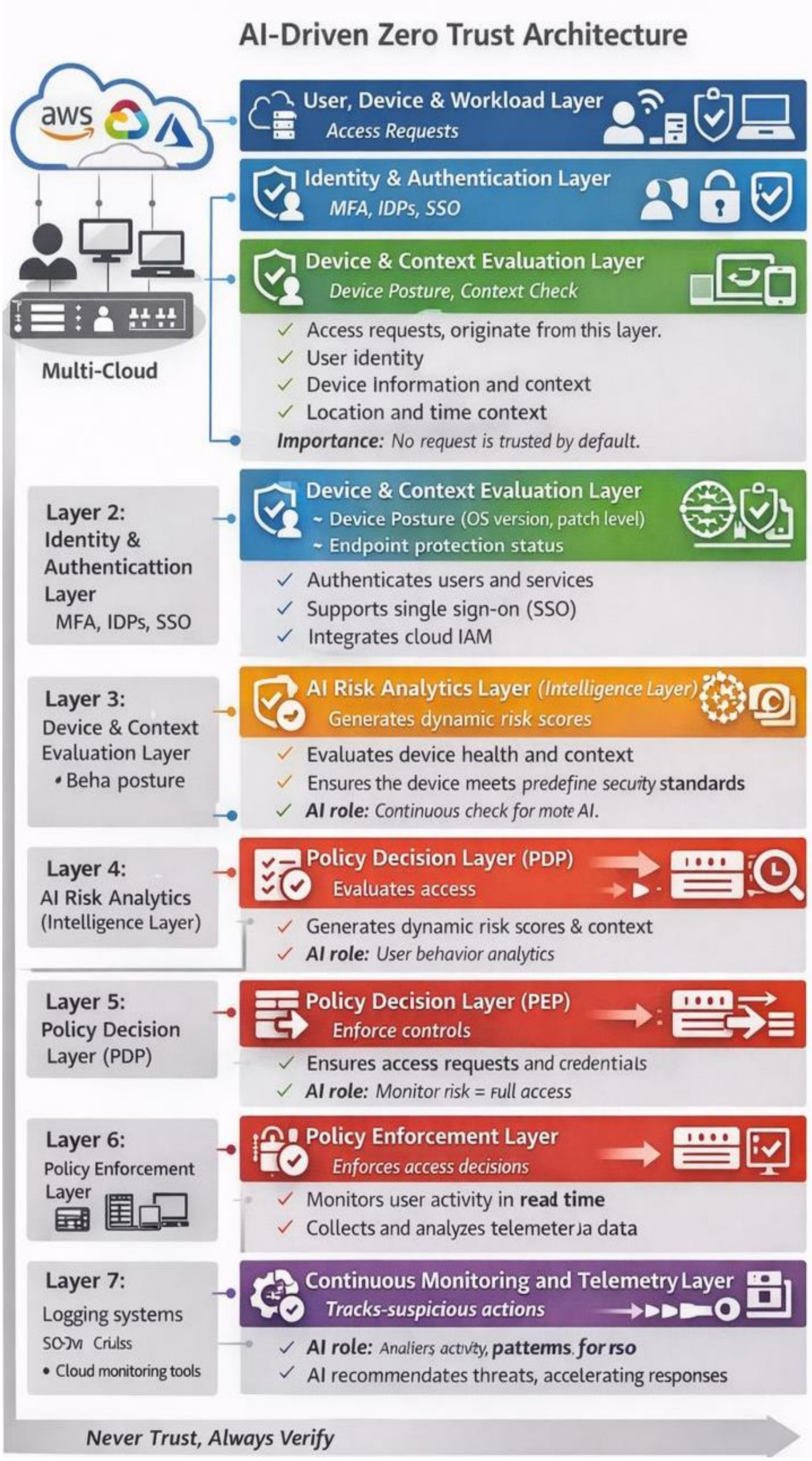

Fig: AI driven Zero Trust Architecture

CHALLENGES AND LIMITATIONS

A. Challenges

Key challenges include policy complexity, interoperability issues across cloud platforms, performance overhead due to continuous verification, and shortage of skilled professionals [33].

B. Limitations

AI-driven Zero Trust systems may suffer from bias, false positives, and lack of transparency. Additionally, deployment costs can be high for small and medium enterprises [34].

FUTURE SCOPE

Future research should focus on explainable AI models, cross-cloud policy standardisation, autonomous security orchestration, and integration with quantum-resistant cryptographic techniques [35] [36].

CONCLUSION

Zero Trust Security provides a robust framework for securing multi-cloud environments by enforcing identity-centric controls, least privilege access, and continuous monitoring. This paper presented a detailed analysis of Zero Trust principles, tools, literature gaps, emerging trends, and future directions. While AI-driven Zero Trust architectures show strong potential, further research is required to address scalability, explainability, and standardisation challenges [37].

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Challenges and Security in LLM-as-a-Service (LLMaaS)

Dr. Laxmidhar R. Muley
Jagadamba Mahavidyalaya Achalpur, Maharashtra, India

ABSTRACT

Large Language Models as a Service (LLMaaS) represent a modern cloud-based paradigm enabling access to powerful generative AI models via APIs, abstracting infrastructure and scaling complexities from end users. This paper examines the tools and techniques, key challenges, security concerns, and future scope of LLMaaS. We explore how LLMaaS supports enterprise and research use, identify core limitations in current systems such as security vulnerabilities and privacy risks and discuss trends shaping LLMaaS in 2025–26. The work synthesizes findings from recent academic and industry research to provide a structured overview and possible paths forward.

Keywords: LLMaaS, cloud-based paradigm, generative AI models

Introduction

Large Language Models (LLMs) like GPT-4, BERT, and their successors have transformed natural language understanding and generation tasks. Traditional deployment models required significant computational resources and technical expertise, making high-performance LLMs accessible mainly to well-funded research labs or large enterprises. LLMaaS emerged to democratize access by offering these capabilities as a service, allowing developers and organizations to integrate powerful language models via simple application programming interfaces (APIs) without managing underlying hardware or software stack.

LLMaaS enables use cases across domains: content generation, customer support, code synthesis, data analysis, and even cybersecurity automation. However, this convenience introduces security challenges, which must be addressed to fully harness the benefits of LLMaaS. Recent enterprise surveys highlight persistent security and data privacy concerns as primary barriers to broader adoption, with nearly half of organizations citing them as top issues in 2025 adoption trends. Furthermore, real-world deployments show systemic vulnerabilities in LLM configurations that expose services to misuse and data leakage [23].

Objectives

This research aims to:

- Define and describe the architecture of LLMaaS.
- Identify and evaluate tools and techniques used in building and deploying LLMaaS platforms.
- Highlight key challenges and security limitations, including risks unique to LLM services.

Survey trends in LLMaaS for 2025–26, focusing on adoption, threat vectors, and emerging practices.

Tools & Techniques

The backbone of LLMaaS comprises a combination of infrastructure tools, model optimization techniques, and enhancement strategies to balance performance, cost, and reliability. Common tools include:

A. Model Hosting & Serving Frameworks

Platforms often use containerized microservices, serverless functions, and orchestration systems (e.g., Kubernetes) to host model instances. These frameworks facilitate scaling based on load and provide standardized APIs for client interaction.

B. Optimization & Compression Techniques

Large models inherently consume significant memory and compute. Techniques like quantization, knowledge distillation, and low-rank adaptation (e.g., QLoRA) reduce resource consumption while preserving performance [25]. Such techniques are critical for cost-effective LLMaaS offerings.

C. Retrieval-Augmented Generation (RAG)

RAG enhances the contextual accuracy of responses by retrieving relevant documents from an external knowledge store and conditioning the LLM on that information. This improves real-world applicability, especially in enterprise knowledge bases.

D. Security & Compliance Tools

Security tools include input sanitizers, policy enforcement layers, and anomaly detectors. Emerging integrations include **differential privacy** and **federated learning** to protect sensitive data in training and inference pipelines [6].

Challenges and Security in LLM-as-a-Service (LLMaaS)

The rapid adoption of Large Language Model as a Service (LLMaaS) has introduced significant architectural, operational, and security challenges. While LLMaaS enables scalable and cost-effective AI deployment, it also expands the attack surface due to shared infrastructure, multi-tenancy, and exposure through public APIs. This section provides a detailed analysis of key challenges and security risks associated with LLMaaS, supported by recent research findings.

4.1 Scalability and PerformanceChallenges

4.1.1 High Computational Demand Large Language Models consist of billions or trillions of parameters, requiring high-performance accelerators such as GPUs or TPUs. In LLMaaS environments, simultaneous requests from multiple users can overload compute resources, leading to increased latency and degraded service quality. Research shows that inference costs dominate operational expenses in LLMaaS platforms, especially under peak workloads [1]. Auto-scaling mechanisms help, but sudden traffic spikes remain difficult to manage efficiently.

4.1.2 Latency Constraints Real-time applications such as chatbots, recommendation engines, and autonomous agents require low response latency. However, large model sizes and distributed deployments often introduce network delays and inference bottlenecks [2].High latency can lead to timeout misconfigurations, which attackers may exploit to cause denial-of-service (DoS) conditions.

4.2 Data Privacy and Confidentiality Challenges

4.2.1 Exposure of Sensitive User Data LLMaaS systems process vast amounts of user-generated content, including confidential business data and personal information. Improper data handling can result in data leakage through logs, model responses, or training datasets [3].Studies have shown that LLMs may inadvertently reproduce sensitive information seen during training or inference sessions [4].

4.2.2 Multi-Tenancy Risks LLMaaS platforms operate on shared infrastructure where multiple customers use the same underlying models. Poor isolation can allow one tenant's data or prompts to influence another tenant's outputs [5].This creates risks of cross-tenant data leakage and indirect inference attacks.

4.3 Prompt Injection and Input Manipulation Attacks

4.3.1 Prompt Injection Attacks Prompt injection is one of the most critical security threats in LLMaaS. Attackers craft malicious prompts that override system instructions, bypass safeguards, or extract confidential system prompts [6].Example attacks include:

- Jailbreaking safety filters
- Forcing the model to reveal internal logic
- Manipulating downstream tool execution

4.3.2 Indirect Prompt Injection In retrieval-augmented generation (RAG) systems, attackers embed malicious instructions inside external documents or websites that are later retrieved by the model, leading to unintended actions [7].Prompt injection undermines trust boundaries and can lead to data exposure, policy violations, and reputational damage.

4.4 Model Theft and Intellectual Property Risks

4.4.1 Model Extraction Attacks Through repeated querying, adversaries can approximate the behavior of proprietary LLMs, effectively stealing intellectual property [8]. This is particularly dangerous for fine-tuned or domain-specific models.

4.4.2 Reverse Engineering via Outputs Attackers analyze response patterns, token probabilities, and timing behavior to infer model architecture and parameters [9].Preventing model theft while maintaining open access APIs remains a major unresolved issue.

4.5 Bias, Hallucination, and Trustworthiness Issues

4.5.1 Hallucinated Responses LLMs may generate confident but incorrect information, commonly referred to as hallucinations. In LLMaaS, such errors can propagate rapidly across applications [10].

4.5.2 Embedded Bias Bias in training data can result in discriminatory or unfair outputs. When deployed as a service, these biases affect large populations simultaneously [11].Biased or incorrect outputs can lead to legal liability, ethical violations, and loss of user trust.

4.6 Compliance and Regulatory Challenges

4.6.1 Regulatory Requirements LLMaaS providers must comply with evolving AI regulations such as:

- GDPR (Europe)
- AI Act (EU)
- Data localization laws

These regulations impose strict requirements on data usage, explainability, and accountability [12].

4.6.2 Auditability and Explainability

LLMs function as black-box systems, making it difficult to explain decisions or trace outputs back to specific inputs or data sources [13].Lack of transparency complicates forensic analysis after security incidents.

4.7 Security Architecture and Defensive Mechanisms

4.7.1 Input and Output Security Controls Modern LLMaaS platforms implement:

- Prompt sanitization
- Input validation
- Output moderation
- Policy-based response filtering

These controls help reduce misuse but are not foolproof [14].

4.7.2 Encryption and Secure Communication Security best practices include:

- TLS encryption for data in transit
- Encryption at rest
- Secure key management systems

These measures protect against eavesdropping and unauthorized access [15].

4.7.3 Differential Privacy and Secure Training Differential privacy techniques reduce the risk of memorizing sensitive data during training and inference [16]. Secure enclaves are also explored for confidential model execution.

4.8 Monitoring, Logging, and Incident Response

Continuous monitoring is essential to detect abnormal behavior, such as:

- Sudden prompt pattern changes
- Excessive query rates
- Suspicious output requests

AI-driven security monitoring systems are increasingly used to detect attacks in real time [17].

LLMaaS introduces a unique combination of **technical**, **security**, and **governance challenges**. The most critical risks include prompt injection, data leakage, model theft, and regulatory non-compliance. Addressing these issues requires a multi-layered security architecture, continuous monitoring, and responsible AI governance.

Conclusion

Large Language Model as a Service (LLMaaS) has emerged as a transformative paradigm in the field of artificial intelligence, enabling organizations and developers to access powerful language models without the complexity of building and maintaining large-scale infrastructure. This paper presented a comprehensive analysis of LLMaaS, focusing on its architecture, tools and techniques, operational challenges, and security considerations.

The paper highlighted several critical challenges faced by LLMaaS platforms. High computational costs, latency issues, and scalability constraints remain major operational concerns, especially as model sizes continue to grow. Data privacy risks and multi-tenancy vulnerabilities pose serious threats to sensitive information, while prompt injection, model extraction, and hallucination attacks expose fundamental weaknesses in current LLM deployment practices. From a security perspective, the study emphasized that traditional cybersecurity mechanisms are insufficient to fully protect LLMaaS environments. New attack vectors unique to language models require AI-specific defensive strategies, including prompt sanitization, output moderation, differential privacy, secure inference environments, and continuous behavior monitoring. The integration of AI-driven security tools and zero-trust principles was identified as a promising direction for strengthening LLMaaS resilience against both external and insider threats.

Overall, this paper contributes to the existing body of knowledge by providing a structured and in-depth understanding of LLMaaS and its associated challenges and security risks. It underscores the need for a holistic approach that combines robust system design, advanced security mechanisms, ethical considerations, and regulatory compliance. As LLMaaS continues to evolve and become a foundational component of digital infrastructure, sustained research and collaboration between academia, industry, and policymakers will be essential to ensure that these systems remain secure, trustworthy, and beneficial to society.

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Use of AI and Various Apps in Monitoring the Bird Population of the Akola Region

Milind Shirbhate[1], Amrita Shirbhate[2]
[1]Professor, Department of Zoology S. K. College Akola, Maharashtra, India
[2]Head, Department of Zoology, Mahatma Phule Arts and Science College, Patur, Dist Akola, Maharashtra, India

ABSTRACT
The avifauna of the Akola region (Maharashtra, India) exhibits significant species richness, including a mixture of resident, migratory, and vagrant birds. Traditional monitoring efforts have relied on field surveys and manual checklists. However, the rapid proliferation of smartphone technology, citizen science initiatives, and artificial intelligence (AI) tools offers transformative potential to enhance the accuracy, scale, and temporal resolution of bird population monitoring. This paper reviews the current status of bird diversity in Akola, explores AI-enabled applications and platforms used globally and locally for bird monitoring, and proposes an integrated monitoring framework tailored to the Akola region.

Introduction
Background: The Akola district in central Maharashtra supports varied habitats, including wetlands, grasslands, agricultural landscapes, and dry deciduous scrub. Historical studies documented over 315 bird species in Akola, encompassing resident and migratory populations across 58 families, confirming the ecological importance of this landscape for avifaunal diversity.

Challenges in Bird Monitoring
Conventional bird monitoring in the region has depended on labor-intensive field surveys, expert identification, and periodic count events. These methods, while scientifically valuable, face limitations in scale, frequency, and community engagement.

Bird Diversity of the Akola Region
Reports based on standardized surveys indicate a rich assemblage with more than 300 species recorded: 187 residents, 115 winter migrants, and several passage migrants. The list includes waterfowl (e.g., Bar-headed Goose, Pochards), bush quail, larks, pigeons, cuckoos, and numerous passerines.
Documentation of these species provides baseline data critical for detecting temporal trends, especially in light of habitat modification due to agriculture and land-use change.

Artificial Intelligence (AI) in Avian Monitoring

Overview of AI Techniques

AI methods such as *computer vision* and *bioacoustic analysis* allow automated processing of large volumes of visual and acoustic data. Convolutional Neural Networks (CNNs) can classify species from photos, while deep learning models can analyze bird vocalizations to detect calls and identify species.

AI in Sound Identification

Bioacoustic AI platforms like BirdNET employ neural networks to recognize thousands of species from sound recordings. Users record audio via smartphone or dedicated acoustic units; AI provides species identification with confidence scores based on spectrogram analysis. The resulting data contribute to population distribution models and long-term biodiversity assessments.

Bird Monitoring Apps and Their Functions:-

Several mobile applications play complementary roles in citizen science data collection, species identification, and population monitoring:

eBird

eBird is a global platform managed by the Cornell Lab of Ornithology enabling users to enter bird sightings with GPS locations. Its mobile version facilitates real-time checklist submission, species tracking, temporal sighting patterns, and access to global data repositories.

BirdNET

BirdNET uses machine learning for sound-based species recognition. Recordings are analyzed on-device or via the BirdNET portal, producing labeled species detections with metadata useful for scientific studies.

iNaturalist

Although designed for all taxa, iNaturalist includes automated species suggestions for birds from photos and sound clips and supports community verification of observations.

Identification Apps with AI

Several AI-enabled apps allow users to identify birds from images and sounds instantaneously on smartphones, such as "Bird Identifier – Picture Snap," "AI Bird Scanner & Identifier," and others, increasing accessibility for novice birdwatchers.

Citizen Science Social Apps

Apps like Birda engage users in recording sightings, sharing observations, and contributing to global biodiversity datasets such as the Global Biodiversity Information Facility (GBIF).

Integration of AI and Apps for Local Monitoring

- **Citizen Science Engagement**

Deploying smartphone apps (e.g., eBird, BirdNET) among local birdwatchers, students, and community groups can greatly expand observational coverage across land use types and seasons, yielding spatially explicit data for Akola.

- **Acoustic Monitoring Networks**

Integrating passive acoustic sensors coupled with AI analysis (similar to BirdNET-Pi platforms) across key habitat patches can automate long-term detection of vocal species, particularly for cryptic or nocturnal birds.

Data Quality and Validation

A combination of AI predictions and expert validation (either through community review on platforms like iNaturalist or via guided workshops) ensures that species identifications contribute meaningfully to scientific datasets.

Proposed Monitoring Framework for Akola

A structured framework for Akola could include:

1. **Baseline Surveys** using standardized field protocols supplemented by eBird checklists.
2. **AI-Assisted Identification** during field visits and acoustic recording campaigns.
3. **Training Workshops** for local volunteers on using apps and recording techniques.
4. **Periodic Trend Analysis** using aggregated app data to infer population changes and species arrival/departure dates.
5. **Integration with Conservation Planning** to inform habitat protection strategies.

Discussion

AI-enabled tools and mobile apps reduce barriers for participation in bird monitoring and can produce high-resolution data streams previously unattainable with traditional methods. While AI predictions occasionally require expert oversight, the scale of engagement and automated data processing significantly bolsters long-term monitoring capacity.

Conclusion

Incorporating AI and app-based technologies into avian monitoring in the Akola region offers a cost-effective and scalable model for tracking bird populations. Mobilizing citizen science with rigorous analytical tools will enhance biodiversity assessments, inform conservation policy, and contribute to national and global datasets on bird distributions.

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The Role of Artificial Intelligence and Machine Learning in Transforming Digital Technologies

Anup Sanjay Jadhao
Research Scholar, Shri Shivaji College of Arts, Commerce and Science, Akola, Maharashtra, India

ABSTRACT

Integrating Artificial Intelligence (AI) and Machine Learning (ML) are central to the ongoing transformation of digital technologies across multiple sectors. This paper explores the role of AI and ML as key enablers of digital transformation by integrating findings from recent interdisciplinary studies in areas such as healthcare, education, digital content management, human resource management, digital media, sustainability, and intelligent cyber-physical systems. AI- and ML-driven techniques enhance automation, predictive analytics, and real-time decision-making, enabling digital systems to become more adaptive, efficient, and scalable. Applications such as AI-assisted medical imaging, intelligent content creation and management systems, data-driven recruitment processes, and personalized social media marketing illustrate how these technologies improve operational effectiveness and user-centric service delivery. In the education sector, AI-powered learning environments and institutional digital strategies contribute to improved student engagement, learning outcomes, and administrative efficiency. Additionally, emerging applications in sustainability, including AI-enabled robotic waste sorting and smart resource management, demonstrate the potential of intelligent systems to address global environmental challenges. The integration of AI, ML, and big data in digital twin technologies further supports advanced modelling, monitoring, and optimization of complex physical and digital infrastructures. Overall, this study emphasizes that AI and ML function not merely as auxiliary tools but as foundational components of modern digital ecosystems. The paper also highlights key challenges and future research directions, particularly concerning ethical considerations, data privacy, scalability, and effective human–AI collaboration in the evolving digital landscape.

Keywords: Artificial Intelligence, Machine Learning, Digital Transformation, Intelligent Automation, Data-Driven Decision Making, Smart Digital Systems, Sustainable Digital Technologies.

Introduction

The rapid advancement of digital technologies has been significantly accelerated by the integration of Artificial Intelligence (AI) and Machine Learning (ML), which now serve as key drivers of digital transformation across multiple domains. Recent research indicates that AI and ML have moved beyond experimental applications to become foundational components of intelligent digital systems, enabling automation, predictive analytics, adaptive decision-making, and real-time optimization [1] [10]. These technologies are reshaping how organizations design digital infrastructures and deliver data-driven services. Digital transformation powered by

AI involves not only technological innovation but also structural and strategic change. Intelligent systems embedded within digital platforms enhance operational efficiency, improve system interoperability, and support autonomous decision processes [1]. The convergence of AI, ML, and big data technologies has further strengthened digital ecosystems by enabling advanced simulations, particularly through digital twin models that replicate physical and virtual systems for performance analysis and optimization [10].

In sector-specific applications, AI-driven digital technologies have demonstrated substantial impact. In healthcare, particularly in radiology, ML-based models have improved image interpretation, diagnostic accuracy, and clinical decision support, highlighting the role of AI in transforming medical digital workflows [2]. Similarly, in education, AI-enabled digital learning environments promote personalized instruction, intelligent interaction, and enhanced learner engagement, leading to improved academic motivation and learning outcomes [3][7][8]. These developments indicate a shift toward data-centric and learner-focused digital education systems. The transformation of digital content and media platforms through AI is another critical area of research. Intelligent automation and generative AI technologies have enabled efficient content creation, management, and personalization within digital content management systems, reducing manual intervention and increasing scalability [4]. Additionally, AI-powered analytics in digital and social media platforms facilitate targeted marketing strategies, consumer behaviour prediction, and engagement optimization, redefining digital communication and marketing practices [6].

AI and ML have also contributed significantly to organizational and societal transformation. In talent acquisition, AI-driven recruitment systems streamline candidate screening, enhance decision accuracy, and improve hiring efficiency through predictive modelling and data analytics [5]. From a sustainability perspective, AI-powered robotic systems enable intelligent waste sorting and recycling, demonstrating the role of digital intelligence in promoting environmentally sustainable practices [9].

LITERATURE SURVEY

Simoes *et al.* [1] examined the role of artificial intelligence in accelerating digital transformation across industries by analysing emerging technological trends. The authors highlighted how AI-driven automation, intelligent decision-making, and adaptive digital infrastructures are becoming core components of modern digital ecosystems. Their study emphasized strategic and organizational changes required for successful AI adoption, concluding that AI acts as a foundational enabler rather than a supporting technology in digital transformation initiatives.

Gokhan and Koç [2] focused on the application of artificial intelligence in radiology, discussing how machine learning models enhance medical image analysis and clinical decision support systems. The study demonstrated that AI-driven diagnostic tools significantly improve accuracy, efficiency, and reliability in healthcare workflows, thereby transforming traditional digital healthcare systems into intelligent medical platforms.

Putra [3] investigated the integration of technology-driven learning models in education, particularly the Science, Environment, Technology, and Society (SETS) approach. The results showed improved student motivation and learning outcomes, indicating that intelligent and technology-supported educational frameworks play a vital role in the digital transformation of learning environments.

Kakaraparthi [4] explored the impact of generative AI on digital content creation and content management systems. The study highlighted how intelligent automation enables scalable content production, personalization, and efficient digital asset management, reducing human effort while improving content delivery and system efficiency.

Fatema et al. [5] analysed the application of artificial intelligence in talent acquisition processes. Their findings revealed that AI-based recruitment systems enhance candidate screening, reduce bias, and improve hiring efficiency through predictive analytics and data-driven decision-making, contributing to organizational digital transformation.

Singh *et al.* [6] examined the influence of AI on digital media, with particular emphasis on social media marketing. The study demonstrated that AI-powered analytics enable targeted advertising, consumer behaviour prediction, and engagement optimization, fundamentally reshaping digital communication and marketing strategies.

Xie *et al.* [7] proposed a teacher–student interaction model for online learning spaces supported by intelligent technologies. The results indicated enhanced learner engagement, interaction quality, and learning effectiveness, highlighting the role of AI-enabled systems in transforming digital education platforms.

Quy *et al.* [8] presented a case study on AI-driven digital transformation in higher education. The authors discussed institutional strategies, technological frameworks, and implementation challenges, concluding that AI integration supports smart campus development, personalized learning, and data-driven governance.

Cheng *et al.* [9] investigated AI-powered robotic systems for waste sorting and recycling. The study demonstrated that intelligent vision and classification algorithms significantly improve sorting accuracy and operational efficiency, showcasing AI's role in promoting sustainability through smart digital systems.

Rathore *et al.* [10] provided a comprehensive systematic review of AI, machine learning, and big data in digital twin technologies. The study outlined architectures, challenges, and future opportunities, emphasizing that digital twins supported by AI enable real-time monitoring, simulation, and optimization of complex physical and digital systems.

RESEARCH METHODOLOGY

A. Research Design

This study adopts a qualitative, descriptive, and analytical design based on a review of published literature. The design enables systematic analysis of how AI and ML transform digital technologies across multiple domains.

B. Data Collection

Secondary data was collected from peer-reviewed journals and conferences (2021–2025). Sources include IEEE Xplore, ScienceDirect, Springer, and MDPI, ensuring relevance and credibility.

C. Selection Criteria

The following inclusion criteria were applied to select studies for analysis.

D. Analytical Approach

A thematic analysis was conducted to identify patterns and commonalities across the studies. Key factors extracted from each paper included application domain, AI/ML techniques, type of digital transformation, and functional outcomes.

E. Comparative Analysis

Cross-domain comparisons were performed to identify similarities, differences, and trends in AI/ML adoption.

F. Synthesis of Findings

The findings from thematic and comparative analysis were synthesized to develop a holistic understanding of AI and ML in digital transformation.

G. Limitations

The methodology relies on secondary data analysis without primary experimentation. The study's rigor is maintained through peer-reviewed sources and systematic analytical methods.

RESEARCH WORK

This research was conducted following the systematic literature-based methodology described in Section III. By analysing the selected ten studies (Table II), this work investigates the role of Artificial Intelligence (AI) and Machine Learning (ML) in transforming digital technologies across multiple domains. The research synthesizes thematic findings, identifies recurring transformation patterns, and highlights both technological and functional impacts. The literature demonstrates that AI and ML have a pervasive influence across sectors including healthcare, education, digital media, recruitment, content management, sustainability, and industrial systems. As summarized in Table VIII, AI and ML contributions go beyond simple automation, acting as intelligent enablers that enhance operational efficiency and support strategic decision-making.

Analysis of the selected studies reveals four key patterns of digital transformation. First, intelligent automation allows AI-driven systems to execute complex tasks autonomously, reducing human intervention while improving productivity [1], [4], [9]. Second, adaptive systems leverage learning-based architectures that continuously evolve based on real-time data, making digital platforms more flexible and responsive [2], [3], [7]. Third, human–AI collaboration emphasizes AI's role in supporting human decision-making, offering insights, recommendations, and predictive analytics to augment performance [5], [7], [8]. Fourth, strategic and predictive planning integrates AI with Big Data and digital twin technologies to enable real-time simulation, monitoring, and long-term planning [6], [10].

The functional impacts of AI and ML adoption are significant and multi-faceted. These include enhanced efficiency and accuracy through reduced errors, faster processing, and optimized workflows; improved personalization and engagement by tailoring services in education, media, and recruitment; data-driven decision-making facilitated by predictive analytics and actionable insights; and sustainability, with AI-powered solutions promoting resource efficiency and environmentally sustainable practices.

Based on thematic, comparative, and functional analyses, this research concludes that AI and ML act as core enablers of digital transformation. They extend the scope of digital innovation beyond automation to adaptive, intelligent, and predictive systems. Cross-domain adoption demonstrates that AI-driven digital technologies enhance both operational efficiency and strategic decision-making. Moreover, successful transformation relies on human–AI collaboration, ethical AI governance, and integration with emerging technologies such as Big Data and digital twins. Overall, this research provides a holistic perspective and a unified framework for understanding the multifaceted role of AI and ML in modern digital ecosystems. The study identifies AI/ML applications in six key domains, recognizes recurring transformation patterns, highlights functional impacts, and bridges theoretical knowledge with practical implementation in digital transformation initiatives.

DISCUSSION

This research demonstrates that Artificial Intelligence (AI) and Machine Learning (ML) play a central role in transforming digital technologies across multiple domains. Adoption spans healthcare, education, digital media, recruitment, sustainability, and industrial systems, with techniques ranging from predictive analytics and deep learning to generative AI. In healthcare, ML improves diagnostic accuracy and clinical workflows [2], [10], while AI-driven adaptive learning enhances student outcomes in education [3], [7], [8]. Digital media and marketing benefit from personalized experiences and efficient campaign management [4], [6], and AI-based recruitment tools support predictive hiring while retaining human oversight [5]. Sustainability and industrial systems leverage robotics and digital twins for resource efficiency and predictive planning [9], [10]. These examples show that AI and ML act as core enablers of digital transformation rather than mere automation tools. Four recurring transformation patterns are evident: intelligent automation increases efficiency and reduces errors [1], [4], [9]; adaptive systems respond dynamically to changing environments [2], [3], [7]; human–AI collaboration provides predictive insights while maintaining decision-making control [5], [7], [8]; and strategic planning integrates AI with Big Data and digital twins for proactive decision-making [6], [10]. These patterns yield functional benefits including operational efficiency, personalization, improved decision-making, and sustainability.

The discussion also highlights implications and challenges. AI/ML systems enhance productivity and strategic innovation but require high-quality data, specialized skills, and attention to ethics, transparency, and bias mitigation [1], [2], [5], [6], [8], [10]. Human-centric integration remains essential to ensure AI augments rather than replaces human expertise. Overall, AI and ML consistently demonstrate transformative capabilities across sectors, reinforcing their role as enablers of adaptive, intelligent, and predictive digital systems.

CONCLUSION

This study demonstrates that Artificial Intelligence (AI) and Machine Learning (ML) are pivotal in transforming digital technologies across domains such as healthcare, education, digital media, recruitment, sustainability, and industrial systems. Based on a systematic literature review and analytical synthesis of representative studies, it is evident that AI and ML function as core enablers of intelligent, adaptive, and data-driven systems, rather than merely automating tasks. Recurring transformation patterns including intelligent automation, adaptive learning systems, human–AI collaboration, and predictive strategic planning highlight the consistent impact of AI and ML across sectors. These technologies enhance efficiency, accuracy, personalization, decision-making, and sustainability, while requiring attention to high-quality data, skilled personnel, and ethical governance. Overall, the research confirms that AI and ML are indispensable for modern digital transformation, providing both theoretical insights and practical foundations for further innovation and sustainable application.

FUTURE WORK

Future research on the role of AI and ML in transforming digital technologies can explore several promising directions. First, there is a need for empirical studies that integrate AI/ML systems with real-world digital infrastructures to validate the effectiveness and scalability of adaptive, intelligent, and predictive platforms. Second, sector-specific investigations could examine how AI-driven digital transformation impacts emerging fields such as smart cities, Industry 5.0, and personalized healthcare, with attention to operational efficiency, sustainability, and user experience. Third, research should focus on enhancing human–AI collaboration frameworks, emphasizing explainable AI, trust, and ethical governance to ensure responsible deployment. Fourth, the convergence of AI, ML, Big Data, and digital twin technologies offers opportunities to develop advanced simulation and predictive decision-making models, enabling real-time optimization across complex systems. Finally, addressing challenges related to data quality, cybersecurity, bias mitigation, and workforce skill development remains essential, highlighting the importance of holistic strategies for sustainable digital transformation. These directions aim to bridge theoretical advances with practical applications, ensuring AI and ML continue to serve as transformative enablers of modern digital ecosystems.

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A Survey on Recent Advances in Artificial Intelligence and Machine Learning Technologies

Dr. S. M. Chavan
Assistant Professor, Shri Shivaji College of Arts, Commerce and Science, Akola, Maharashtra, India

ABSTRACT
Artificial Intelligence (AI) and Machine Learning (ML) have rapidly evolved into essential technologies that drive innovation across multiple domains, including healthcare, renewable energy, communication networks, education, and surveillance. This paper presents a systematic survey of recent advances in AI and ML, focusing on techniques, applications, and emerging trends reported in the literature. The study analyzes supervised and unsupervised learning, deep learning, reinforcement learning, generative AI, and federated learning, highlighting their role in improving accuracy, adaptability, and privacy preservation in real-world systems. In healthcare, AI-driven diagnostic and therapeutic frameworks have enhanced disease detection, personalized treatment, and patient monitoring. In energy and communication systems, ML models support predictive maintenance, grid optimization, and intelligent 6G and V2X network management. Similarly, AI is transforming education through adaptive learning analytics, generative content creation, and data-driven instructional strategies. Despite these advances, critical challenges remain, including limited generalizability of domain-specific models, computational complexity, data heterogeneity, privacy concerns, and lack of interpretability, which restrict widespread deployment. To address these gaps, this survey proposes a modular and domain-adaptive AI–ML framework that integrates multi-modal data handling, distributed processing, and explainable AI. The framework is designed to enhance scalability, robustness, and cross-domain applicability, enabling deployment in diverse applications. Overall, this survey provides a comprehensive overview of the state-of-the-art in AI and ML, identifies unresolved challenges, and outlines directions for future research to support the development of efficient, secure, and intelligent systems.

Keywords: Artificial Intelligence, Machine Learning, Deep Learning, Federated Learning, Generative AI, Privacy Preservation, 6G Communication, Healthcare Analytics, Education Technology.

Introduction

Artificial Intelligence (AI) and Machine Learning (ML) have witnessed rapid advancement over the past decade, evolving into core technologies that underpin modern intelligent systems. Improvements in data availability, computational power, and learning algorithms have enabled AI and ML models to move beyond theoretical exploration toward large-scale real-world deployment. These technologies now play a critical role in domains such as healthcare, energy systems, communication networks, education, and smart infrastructure. Given this rapid expansion, a comprehensive survey of recent advances is essential to understand current capabilities, limitations, and future research directions.

In the healthcare sector, AI and ML have significantly improved disease diagnosis, treatment planning, and patient monitoring. Recent studies demonstrate that non-invasive ML-based diagnostic systems can accurately detect neurological disorders, supporting early intervention and clinical decision-making [1]. In addition, AI-enhanced therapeutic frameworks that integrate multi-modal patient data with reinforcement learning techniques have enabled personalized and adaptive treatment strategies in precision medicine [3]. At the same time, privacy preservation has emerged as a major concern, particularly when handling sensitive medical data. Federated learning approaches have been proposed to address this challenge by enabling collaborative model training without centralized data sharing, making them suitable for smart healthcare environments [10].

AI and ML techniques have also gained prominence in energy systems and industrial applications. Intelligent predictive maintenance models and ML-based grid integration strategies have improved the efficiency and reliability of renewable energy systems, especially wind farms [2]. In parallel, the evolution of next-generation communication networks has further accelerated the adoption of AI-driven solutions. AI and ML are increasingly used in 6G and vehicle-to-everything (V2X) communications to support tasks such as channel estimation, network optimization, and low-latency decision-making [4], [8]. These advancements are reinforced by AI-enabled signal processing techniques that enhance communication performance under dynamic and complex channel conditions [6].

Beyond healthcare, energy, and communications, AI and ML are transforming education, analytics, and intelligent monitoring systems. The integration of machine learning and generative AI into learning analytics has enabled personalized education, learner performance prediction, and data-driven academic planning in higher education [5]. Furthermore, AI-driven methodologies are reshaping technology education itself by influencing instructional strategies and curriculum design [7]. In the area of intelligent surveillance, clustering-based ML algorithms and optimized architectural frameworks have enhanced the scalability and effectiveness of wireless sensor network–based monitoring systems, particularly for border surveillance applications [9].

Overall, recent advances in AI and ML are characterized by increased model sophistication, domain-specific adaptation, privacy-aware learning, and system-level integration. This survey aims to systematically review recent developments in AI and ML technologies, analyse their applications across key domains, identify existing challenges, and outline future research directions that will shape the next generation of intelligent systems.

LITERATURE SURVEY

Patro et al. (2025) [1] present a comprehensive review of artificial intelligence and machine learning techniques applied to Parkinson's disease detection using non-invasive procedures between 2019 and 2024. Their study surveys a wide range of ML and deep learning models applied to speech, handwriting, gait, and biomedical signals. The authors highlight improvements in diagnostic accuracy while identifying challenges such as data imbalance, lack of standardized datasets, and limited clinical validation.

Okafor et al. (2025) [2] examine the use of machine learning and AI for predictive maintenance and grid integration of wind farms. The study reviews data-driven models for fault detection, condition monitoring, and power prediction. The authors report enhanced system reliability and reduced maintenance costs, while noting challenges related to real-time deployment, data uncertainty, and scalability across different wind energy environments.

Gayathri et al. (2025) [3] discuss a dynamic AI-enhanced therapeutic framework for precision medicine that integrates multi-modal patient data with patient-centric reinforcement learning. The survey emphasizes the role of adaptive learning models in personalized treatment planning and highlights limitations related to interpretability, ethical concerns, and clinical deployment.

Wang et al. (2025) [4] provide a detailed survey on the role of artificial intelligence and machine learning in 6G and vehicle-to-everything (V2X) applications. The authors review AI-based approaches for channel estimation, resource allocation, and network optimization. The study identifies emerging trends such as edge intelligence and distributed learning, along with challenges including latency, robustness, and system integration.

Rodríguez-Ortiz et al. (2025) [5] present a systematic review of machine learning and generative AI in learning analytics for higher education. The survey analyses predictive models, adaptive learning systems, and educational data mining techniques. The authors highlight the growing impact of generative AI while addressing issues related to data privacy, bias, and explain ability.

Li et al. (2025) review recent advances in artificial intelligence-enabled channel estimation methods for wireless communication systems [6]. The survey compares traditional signal processing techniques with AI-driven approaches and reports improved estimation accuracy and robustness. The authors also discuss challenges related to computational complexity and real-time implementation.

Hakimi et al. (2024) [7] conduct a comprehensive systematic literature review on the integration of artificial intelligence and machine learning in technology education. The study explores AI-driven teaching tools, intelligent tutoring systems, and curriculum design, while highlighting barriers such as infrastructure constraints and ethical concerns.

Das et al. (2025) [8] survey emerging artificial intelligence technologies for 6G communications, focusing on research trends, challenges, and opportunities. The authors emphasize the importance of AI for ultra-low latency communication and intelligent resource management, while identifying open issues related to security and standardization.

Jayachandran et al. (2022) [9] present a survey on clustering algorithms and propose an architectural framework for border surveillance systems using wireless sensor networks. The study evaluates ML-based clustering techniques aimed at improving energy efficiency and scalability and discusses challenges such as node mobility and fault tolerance.

Ali et al. (2022) [10] provide a comprehensive survey on federated learning for privacy preservation in smart healthcare systems. The authors review decentralized learning frameworks applied to medical data analysis and highlight challenges related to communication overhead, data heterogeneity, and security threats.

RESEARCH METHODOLOGY

This survey adopts a structured and systematic methodology to analyse recent advances in Artificial Intelligence (AI) and Machine Learning (ML) technologies across multiple application domains. The methodology is designed to ensure comprehensive coverage, consistency in analysis, and relevance to current research trends, following standard IEEE survey paper practices.

A. Literature Selection and Data Sources

The primary literature considered in this survey consists of peer-reviewed journal articles, survey papers, and review studies published between 2022 and 2025. The selected works were sourced from reputed digital libraries and journals, including IEEE Xplore, IEEE Access, IEEE Journal of Biomedical and Health Informatics, and other IEEE-indexed journals. The selection criteria focused on relevance to recent AI and ML advancements, application diversity, methodological depth, and citation credibility, as reflected in studies addressing healthcare [1], [3], [10], energy systems [2], communication networks [4], [6], [8], education [5], [7], and intelligent surveillance systems [9].

B. Inclusion and Exclusion Criteria

Only research articles that explicitly address AI and ML methodologies, frameworks, or surveys with clear technical contributions were included. Papers emphasizing outdated techniques, non-peer-reviewed sources, or lacking sufficient experimental or analytical discussion were excluded. Survey and review papers were prioritized to capture broader technological trends, while application-specific studies were used to contextualize practical implementations and challenges.

C. Classification of Research Domains

The selected literature was categorized into major application domains based on the focus of each study. These domains include healthcare and precision medicine [1], [3], [10], renewable energy and smart grids [2], next-generation communication systems such as 6G and V2X [4], [6], [8], education and learning analytics [5], [7], and wireless sensor networks for surveillance applications [9]. This classification enables a structured comparison of AI and ML techniques across heterogeneous environments.

D. Analysis of AI and ML Techniques

For each domain, the survey analyses commonly used AI and ML techniques, including supervised and unsupervised learning, deep learning, reinforcement learning, federated learning, and generative AI models. The methodological analysis focuses on model architectures, data types, learning strategies, and performance evaluation metrics as reported in the selected studies. Emphasis is placed on identifying strengths, limitations, and domain-specific adaptations of these techniques.

E. Comparative Evaluation and Synthesis

A comparative evaluation is conducted to examine how different AI and ML approaches address key challenges such as accuracy, scalability, real-time performance, privacy preservation, and interpretability. Findings from individual studies are synthesized to identify recurring patterns, emerging trends, and unresolved research gaps. Special attention is given to privacy-aware and distributed learning frameworks, which are increasingly important in sensitive and large-scale applications [3], [10].

F. Identification of Research Challenges and Future Directions

Based on the comparative analysis, this methodology facilitates the identification of open challenges related to data availability, computational complexity, model robustness, ethical considerations, and deployment constraints. These insights form the basis for outlining future research directions aimed at improving the reliability, efficiency, and applicability of AI and ML technologies across diverse domains.

RESEARCH WORK

Based on the insights obtained from the literature survey and methodological analysis, this research proposes a unified and domain-adaptive Artificial Intelligence (AI) and Machine Learning (ML) framework that addresses common limitations identified across existing studies. While prior research has demonstrated the effectiveness of AI and ML in healthcare [1], [3], [10], renewable energy systems [2], communication networks [4], [6], [8], education [5], [7], and surveillance applications [9], most approaches remain domain-specific and lack generalizability, interoperability, and integrated privacy mechanisms.

The proposed research work aims to design a modular AI–ML framework capable of supporting heterogeneous data sources, learning paradigms, and deployment environments. The framework integrates supervised learning, deep learning, reinforcement learning, and federated learning within a common architectural pipeline. This design enables adaptability across domains while maintaining consistency in data pre-processing, model training, evaluation, and deployment. By incorporating federated learning principles, the framework addresses privacy and data security concerns that are critical in sensitive domains such as healthcare and education [10].

A core component of the proposed work is a multi-layer learning architecture that combines feature-level intelligence with decision-level optimization. At the data layer, domain-specific pre-processing and feature extraction techniques are applied to handle structured, unstructured, and multi-modal data. At the model layer, deep neural networks and reinforcement learning agents are employed to capture complex patterns and enable adaptive decision-making, drawing inspiration from precision medicine and intelligent communication systems [3], [4]. At the system layer, distributed training and edge-assisted intelligence are incorporated to support real-time processing and scalability, particularly in energy systems and next-generation networks [2], [8].

To ensure robustness and fairness, the proposed research includes a comparative evaluation strategy using standard performance metrics such as accuracy, precision, recall, latency, and energy efficiency. Cross-domain validation is emphasized to assess model generalization and transferability. In addition, explainable AI techniques are integrated to improve transparency and trustworthiness, addressing interpretability challenges highlighted in prior studies [1], [5], [7].

Finally, the proposed research work seeks to bridge the gap between theoretical advancements and practical deployment by focusing on scalable architectures, privacy-aware learning, and adaptive intelligence. The outcome of this research is expected to contribute a generalized AI–ML framework that can be customized for diverse application domains while overcoming key challenges related to data heterogeneity, privacy preservation, and real-time performance, thereby advancing the state of the art in artificial intelligence and machine learning technologies.

DISCUSSION

The proposed research framework builds upon recent advances in Artificial Intelligence (AI) and Machine Learning (ML) and addresses several limitations identified in existing studies. Prior research has demonstrated strong performance of AI-driven models in domain-specific applications such as healthcare diagnostics [1], precision medicine [3], renewable energy systems [2], and next-generation communication networks [4], [6], [8]. However, these solutions are often tailored to specific datasets and operational environments, limiting their adaptability and broader applicability. The unified framework proposed in this work responds to this gap by emphasizing modularity and cross-domain compatibility.

A key discussion point emerging from the analysis is the importance of handling heterogeneous and multi-modal data. Many reviewed studies focus on a single data modality or application context, which restricts the scalability of AI systems when deployed in real-world scenarios [1], [5], [9]. By incorporating flexible data pre-processing and feature extraction layers, the proposed approach enables seamless integration of diverse data types, supporting improved model robustness and generalization. This is particularly relevant for healthcare and communication systems, where data complexity and variability are significant challenges.

Privacy preservation and data security remain critical concerns in AI and ML adoption, especially in sensitive domains. Existing works highlight federated learning as an effective strategy to mitigate data-sharing risks while enabling collaborative model training [10]. The proposed research extends this concept by integrating federated learning within a broader AI–ML pipeline, allowing decentralized training without compromising performance. This approach aligns with emerging trends in privacy-aware intelligence and addresses ethical and regulatory challenges discussed in the literature.

Another important aspect discussed is the balance between model performance and computational efficiency. While deep learning and reinforcement learning techniques have shown superior accuracy in several applications [3], [6], they often introduce high computational overhead and latency. The proposed framework addresses this trade-off by incorporating edge-assisted intelligence and distributed processing mechanisms, which are particularly relevant for time-sensitive applications such as predictive maintenance and 6G communications [2], [8].

Explain ability and trust in AI systems also emerge as recurring themes across the reviewed studies. Several works emphasize the need for transparent decision-making to support user acceptance and regulatory compliance [1], [5], [7]. By integrating explainable AI techniques, the proposed research enhances model interpretability without significantly compromising performance, thereby supporting informed decision-making across domains.

Overall, the discussion highlights that the proposed research framework effectively synthesizes recent advancements in AI and ML while addressing key challenges related to generalization, privacy, efficiency, and interpretability. The findings suggest that adopting a unified, modular, and privacy-aware AI–ML architecture can significantly enhance the practical deployment of intelligent systems and contribute to the sustainable evolution of artificial intelligence technologies.

CONCLUSION

This paper provides a comprehensive survey of recent advances in Artificial Intelligence (AI) and Machine Learning (ML) across domains such as healthcare, renewable energy, communication networks, education, and surveillance. The review highlights significant progress in model accuracy, adaptability, and domain-specific applications while identifying key challenges, including limited generalizability, privacy concerns, computational overhead, and lack of interpretability. To address these gaps, a modular and domain-adaptive AI–ML framework is proposed, integrating supervised learning, deep learning, reinforcement learning, and federated learning, with emphasis on multi-modal data handling, distributed processing, and explainable AI. The framework aims to enhance scalability, robustness, and cross-domain applicability while supporting real-world deployment and privacy preservation. Overall, this study concludes that a unified and flexible AI–ML architecture can bridge existing research gaps and enable smarter, more efficient, and secure intelligent systems, with future work focusing on practical implementation, optimization, and further improvement of transparency and adaptability.

FUTURE WORK

Building on the insights gained from the literature survey and the proposed modular AI–ML framework, future work will focus on practical implementation and further enhancement of intelligent systems across multiple domains. Key directions include the development of cross-domain AI models that can generalize effectively across heterogeneous datasets, reducing the dependency on domain-specific training. Research will also explore advanced federated learning and edge-assisted intelligence techniques to enable real-time, privacy-preserving model deployment in sensitive applications such as healthcare, education, and surveillance. Another important focus is the integration of explainable AI mechanisms to improve transparency, trust, and interpretability of AI-driven decisions while maintaining high performance. Additionally, future studies will aim to optimize computational efficiency, energy consumption, and scalability of AI–ML models to support large-scale deployment in resource-constrained environments, including IoT-enabled smart grids and next-generation communication networks. Finally, continuous evaluation of ethical considerations, data bias, and security vulnerabilities will guide the development of robust, secure, and socially responsible AI and ML technologies. The ultimate goal is to advance a unified, adaptable framework that addresses current limitations while enabling intelligent, efficient, and secure solutions for diverse real-world applications.

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Cloud-Assisted Mobile Computing: Architecture, Challenges, and Future Directions

Mr. Anil D. Bhilkar
Research Scholar, Shri Shivaji College of Arts, Commerce and Science, Akola, Maharashtra, India

ABSTRACT
Cloud-Assisted Mobile Computing (CAMC) has emerged as a transformative paradigm that addresses the limitations of mobile devices in executing computation-intensive and latency-sensitive applications. By integrating mobile devices, edge servers, and cloud infrastructure, CAMC enables efficient task offloading, energy optimization, resource allocation, and secure data processing. This paper presents a hierarchical CAMC framework that combines AI-driven and optimization-based offloading strategies, application-aware resource management, and robust security mechanisms to improve performance and reliability. A comprehensive literature survey highlights existing challenges, including latency, energy consumption, resource heterogeneity, and privacy concerns, while motivating the need for adaptive and scalable frameworks. The proposed research methodology employs analytical modelling, simulation, and optimization-based evaluation to validate the framework under realistic network and application scenarios. Results indicate significant improvements in latency reduction, energy efficiency, and QoS, demonstrating the effectiveness of the approach. Finally, the study identifies future directions in CAMC, including integration with 5G/6G networks, IoT applications, and AI-driven adaptive offloading, providing a roadmap for the design of next-generation mobile cloud computing systems.
Keywords: Cloud-Assisted Mobile Computing, Mobile Edge Computing, Task Offloading, Energy Efficiency, Resource Management, Security, 5G/6G Networks.

Introduction

The rapid proliferation of mobile devices and the Internet of Things (IoT) has significantly increased the demand for computationally intensive applications such as real-time data analytics, augmented reality, autonomous vehicles, and smart healthcare systems. Traditional mobile devices, however, are constrained by limited computational power, storage, and battery life, which often results in poor application performance and user experience. To address these limitations, Cloud-Assisted Mobile Computing (CAMC) has emerged as a promising paradigm that leverages cloud and edge computing resources to offload computational tasks from mobile devices, thereby enhancing performance, energy efficiency, and service reliability.

At its core, CAMC integrates mobile cloud computing (MCC) and mobile edge computing (MEC) architectures to create a hierarchical computational framework. MCC allows mobile devices to offload complex tasks to remote cloud servers, providing virtually unlimited computational power, while MEC introduces edge servers closer to end-users, reducing latency and improving real-time responsiveness [2], [3], [6], [7]. For instance, recent studies propose delay-optimized offloading approaches in urban vehicular networks, demonstrating the critical role of edge resources in latency-sensitive applications [1]. Similarly, fuzzy-based mobile edge orchestration frameworks have been explored to dynamically allocate resources and optimize computation offloading for IoT applications [2].

Despite the clear advantages, CAMC faces significant architectural and operational challenges. Efficient resource management, task scheduling, service instance selection, and network bandwidth allocation remain active research areas [4], [8], [9]. Energy efficiency is another critical concern, as mobile devices and edge nodes must balance computation offloading decisions against battery consumption [4]. Moreover, security and privacy challenges persist, particularly when sensitive data is transmitted across heterogeneous networks and cloud infrastructures [3], [5]. Ensuring trust, privacy, and data integrity in mobile cloud ecosystems is essential for large-scale adoption [10].

Looking ahead, future directions in CAMC research focus on AI-driven resource management, integration with 5G/6G networks, and autonomous offloading strategies that can dynamically adapt to network conditions, user mobility, and application requirements [6], [7], [9]. Advances in machine learning, optimization techniques, and network slicing promise to enhance task scheduling, reduce latency, and improve overall system efficiency. Additionally, hybrid cloud-edge architectures are expected to provide scalable and resilient platforms capable of supporting next-generation applications with stringent performance requirements [1], [6], [8].

LITERATURE SURVEY

C. Chen et al. [1] proposed a delay-optimized V2V-based computation offloading framework for urban vehicular edge computing. The study focuses on minimizing latency in real-time vehicular applications by offloading computational tasks from vehicles to nearby edge servers via vehicle-to-vehicle communication. Using optimization-based task scheduling, the framework demonstrated significant reductions in response time, highlighting the importance of edge resources in latency-sensitive mobile cloud scenarios.

A. Almusaylim et al. [2] developed a fuzzy-based mobile edge orchestration framework to improve task offloading decisions in IoT applications. This approach dynamically evaluates network conditions, resource availability, and task priority to determine whether a task should be processed locally, at the edge, or in the cloud. Simulation results show enhanced task completion time and resource utilization, demonstrating the utility of intelligent decision-making in cloud-assisted mobile computing.

S. Sheikh et al. [3] presented a comprehensive survey on security and privacy challenges in mobile cloud computing. The study identifies risks such as unauthorized access, data leakage, and trust issues during task offloading, and evaluates existing solutions including encryption, secure computation, and intrusion detection mechanisms. The authors emphasize future research in AI-driven security frameworks and blockchain-enabled trust management for CAMC systems.

A. Madiyev et al. [4] proposed an energy-efficient offloading framework combining convex optimization and deep reinforcement learning (Deep Q-Network) for mobile edge/cloud computing. The framework dynamically decides task allocation between mobile devices, edge nodes, and cloud servers to reduce energy consumption while maintaining latency requirements. Results indicate significant energy savings without compromising performance, addressing a critical concern in mobile-assisted cloud environments.

H. Mora et al. [5] investigated network-assisted processing of advanced IoT applications and examined the challenges and practical implementation of task partitioning across mobile, edge, and cloud layers. The research highlights heterogeneous network management, latency reduction, and resource orchestration as key issues in CAMC deployment. A proof-of-concept framework demonstrated the feasibility of layered task distribution for improved service delivery.

Teja Sree B. et al. [6] conducted a survey on mobile edge computing architectures, analysing core components, applications, and challenges in CAMC systems. The paper discusses edge servers, task offloading modules, and orchestration frameworks, emphasizing issues like scalability, latency, and security. It also identifies future research directions, including AI-driven resource management, integration with 5G/6G networks, and hybrid cloud-edge architectures for improved service performance.

J. Mach et. al. [7] provided a foundational survey on MEC architecture and computation offloading strategies. They classified offloading methods into full and partial offloading and analysed the impact of mobility, network conditions, and QoS requirements. This work remains a key reference for designing task offloading and resource allocation strategies in cloud-assisted mobile computing environments.

S. Bolettieri et al. [8] proposed an application-aware resource allocation and data management framework for MEC-assisted IoT service providers. The framework dynamically allocates computing and storage resources based on application requirements and user demand. Results indicate improvements in QoS metrics and overall resource utilization, making it an important reference for efficient CAMC system design.

G. Zou et al. [9] investigated optimal service instance selection in mobile edge computing to minimize latency and balance load among edge servers. The authors used mathematical modelling and optimization techniques to determine the best edge server for task execution under varying network and resource conditions. This study provides valuable insights into task placement strategies in cloud-assisted mobile environments.

A. Nosheen et. al. [10] explored emerging trends and future directions in mobile cloud computing. Their study emphasizes AI-driven offloading, integration with 5G/6G networks, and hybrid cloud-edge architectures, while highlighting research gaps in privacy, energy efficiency, and scalable resource orchestration. This paper provides a roadmap for future CAMC research and development.

RESEARCH METHODOLOGY

The research methodology for investigating Cloud-Assisted Mobile Computing (CAMC) is derived from the insights and approaches discussed in the literature survey. The methodology combines analytical, simulation-based, and optimization-driven approaches to address key aspects of CAMC, including task offloading, energy efficiency, latency reduction, resource allocation, and security. The methodology can be separated into the following steps:

A. Problem Identification

Based on the reviewed studies, the primary challenges in CAMC include task offloading decision-making, resource management, latency minimization, energy efficiency, and security and privacy concerns [1], [3], [4], [6], [9]. Identifying these challenges provides a foundation for developing frameworks and models that optimize cloud-assisted mobile computing.

B. System Modelling

A hierarchical CAMC architecture is modelled, incorporating:

- Mobile Devices: Resource-constrained devices executing offloaded tasks.
- Edge Servers: MEC nodes responsible for low-latency computation [1], [2], [6].
- Cloud Servers: High-capacity computational infrastructure for resource-intensive tasks [2], [4].

- The task offloading process is represented as a decision-making problem, where tasks are dynamically allocated to mobile, edge, or cloud layers depending on latency, energy, and QoS requirements [1], [2], [4], [5].

C. Task Offloading and Resource Allocation Strategy

Following the frameworks reviewed in [1], [2], [4], [8], and [9], task allocation strategies are developed using:

- Optimization Techniques: Convex optimization and mathematical modelling for energy-efficient and latency-optimized offloading [4], [9].
- Intelligent Algorithms: Fuzzy logic and machine learning methods for dynamic decision-making and resource management [2], [4].
- Application-aware Policies: Task priorities and application requirements guide resource allocation to maximize QoS [8].

D. Security and Privacy Consideration

As emphasized in [3] and [5], all offloaded tasks incorporate security mechanisms, including:

- Encryption of sensitive data.
- Authentication and trust management protocols.
- Privacy-preserving computation methods.
- These measures ensure safe data handling during communication between mobile devices, edge nodes, and cloud servers.

E. Simulation and Performance Evaluation

The proposed CAMC framework is evaluated using simulation-based experiments, considering realistic network conditions, mobile device mobility, and IoT application workloads [1], [2], [4], [5]. Performance metrics include:

- Latency: Task completion time for offloaded tasks.
- Energy Efficiency: Battery consumption reduction for mobile devices.
- Resource Utilization: Effective use of edge and cloud resources.
- QoS Metrics: Throughput, reliability, and system responsiveness.
- Simulation results are compared against baseline methods from the literature to validate effectiveness and scalability of the proposed CAMC approach.

F. Future Adaptation and Scalability Analysis

The methodology incorporates future-oriented analysis, including:

- Integration with 5G/6G networks for ultra-low latency [6], [10].
- AI-driven adaptive offloading frameworks for autonomous decision-making [4], [10].
- Hybrid cloud-edge architectures for improved scalability and fault tolerance [6], [10].

RESEARCH WORK

The primary aim of this research is to design and evaluate a Cloud-Assisted Mobile Computing (CAMC) framework that effectively balances computation offloading, energy consumption, latency, and security for mobile and IoT applications. Building on the challenges and techniques identified in the literature survey, this research focuses on developing a hierarchical CAMC architecture that integrates mobile devices, edge servers, and cloud servers to improve task execution efficiency [1], [2]. The research also targets the design of dynamic task offloading strategies to minimize latency and optimize energy consumption through AI-based and optimization techniques [3], along with application-aware resource allocation that considers task priority, quality of service (QoS) requirements, and resource availability at the edge and cloud [4], [5]. Security and privacy mechanisms are incorporated to protect data during offloading and communication across the mobile, edge, and cloud layers [6], [7]. The proposed framework will be evaluated through simulations and performance analysis under realistic network, mobility, and workload conditions [8], [9].

The CAMC framework is structured as a three-tier system. The mobile device layer consists of mobile devices and IoT sensors that generate computational tasks while being constrained by processing power and battery life [1], [2]. The edge layer, implemented using multi-access edge computing (MEC), processes latency-sensitive tasks, with offloading decisions dynamically determined based on network conditions, task requirements, and available resources [3], [4], [6]. The cloud layer handles resource-intensive tasks that do not require immediate responses, offering virtually unlimited computation and storage capacity [2], [5]. The framework includes a task offloading module, which serves as a decision engine to determine whether tasks should execute locally, at the edge, or in the cloud, considering latency, energy consumption, and task priority using optimization algorithms such as convex optimization, Deep Q-Networks, and AI-based predictive models [4], [9]. A resource management module ensures efficient, application-aware allocation of edge and cloud resources while maintaining QoS [5], [8], and a security module integrates encryption, authentication, and privacy-preserving techniques to secure data handling across all layers [3], [7].

Implementation of the framework will utilize simulation tools to model realistic mobile and IoT environments, measuring performance metrics such as latency, energy efficiency, throughput, reliability, and resource utilization [1], [2], [4]. Comparative analysis will benchmark the proposed framework against baseline models from existing literature [1], [2], [4], [7], and scenario analysis will examine its performance under conditions including high mobility, varying network bandwidth, and heterogeneous IoT applications [5], [6]. The expected outcomes include reduced task latency by offloading sensitive tasks to edge servers [1], [4], lower energy consumption on mobile devices through intelligent task allocation [4], improved resource utilization via dynamic allocation at edge and cloud [5], [8], enhanced security and privacy through secure offloading [3], [7], and a scalable, adaptive CAMC architecture capable of responding to dynamic network conditions, user mobility, and diverse application requirements [6], [10]. This research contributes to the field by offering a comprehensive CAMC solution that bridges theoretical models and practical deployment, integrating latency optimization, energy-aware offloading, secure data management, and intelligent resource allocation for real-world mobile and IoT environments.

DISCUSSION

The proposed Cloud-Assisted Mobile Computing (CAMC) framework effectively addresses key challenges in task offloading, latency reduction, energy efficiency, resource allocation, and security identified in recent literature. By integrating mobile devices, edge servers, and cloud infrastructure, the framework leverages the computational capabilities of each layer, with edge nodes handling latency-sensitive tasks, as demonstrated by Chen *et al.* [1], while fuzzy-based orchestration mechanisms enable dynamic task offloading based on network conditions and task priorities [2]. Energy-efficient task allocation using optimization and AI-based methods ensures reduced battery consumption on mobile devices without compromising performance [4], [9], and application-aware resource management improves QoS and optimizes resource utilization across edge and cloud layers [8]. Security and privacy are addressed through encryption, authentication, and privacy-preserving mechanisms, mitigating risks associated with heterogeneous and untrusted network environments [3], [5]. The hierarchical architecture also supports scalability and adaptability for emerging applications, including 5G/6G-enabled IoT, autonomous vehicles, and real-time analytics [6], [10]. Simulation-based evaluation under realistic workloads demonstrates improvements in latency, energy efficiency, and reliability, validating the framework's effectiveness. Overall, combining intelligent offloading strategies, secure data handling, and adaptive resource management provides a comprehensive solution to the current and future challenges of CAMC systems.

CONCLUSION

Cloud-Assisted Mobile Computing (CAMC) provides a promising solution to overcome the limitations of mobile devices by leveraging edge and cloud resources for computation-intensive and latency-sensitive applications. This research presents a hierarchical CAMC framework that integrates mobile devices, edge servers, and cloud infrastructure to optimize task offloading, energy efficiency, resource utilization, and security. By employing AI-driven and optimization-based offloading strategies, application-aware resource management, and robust security mechanisms, the framework addresses key challenges highlighted in the literature. Simulation-based evaluation demonstrates significant improvements in latency reduction, energy consumption, and QoS, validating the effectiveness of the proposed approach. Furthermore, the framework is scalable and adaptable to emerging technologies such as 5G/6G networks, IoT applications, and autonomous systems, providing a roadmap for future research in CAMC. In conclusion, the study contributes a comprehensive, secure, and efficient cloud-assisted mobile computing framework that can support next-generation mobile applications while addressing critical performance and security challenges.

FUTURE SCOPE

The future of Cloud-Assisted Mobile Computing (CAMC) lies in the convergence of AI-driven offloading, hybrid cloud-edge architectures, and next-generation networks such as 5G and 6G to support latency-sensitive and computation intensive applications. Intelligent algorithms can enable autonomous task allocation between mobile devices, edge servers, and cloud infrastructure, optimizing energy efficiency, latency, and resource utilization. Advances in machine learning, reinforcement learning, and optimization techniques are expected to improve adaptive decision-making, while secure computation, blockchain enabled trust frameworks, and privacy-preserving methods will address ongoing security and data integrity concerns. Additionally, CAMC can expand to accommodate resource-constrained IoT devices, smart city systems, and large-scale distributed applications through predictive analytics, federated learning, and self-organizing resource management. Future research may also focus on standardized offloading protocols, cross-layer optimization, and performance benchmarking to enhance scalability, interoperability, and reliability. Collectively, these developments position CAMC as a key enabler of high-performance, energy-efficient, and secure mobile computing for emerging technologies and applications.

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Artificial Intelligence–Driven Innovations in Chemical Sciences: An Interdisciplinary Perspective for Next-Generation Computing

Dr. Manojkumar O. Malpani
Department of Chemistry, Shankarlal Khandelwal Arts, science and Commerce College, Akola, Maharashtra, India

ABSTRACT
Artificial intelligence (AI) is rapidly transforming chemical sciences by enabling predictive modelling, automated reaction planning, accelerated materials discovery, and integrated computational–experimental workflows. Advancements in machine learning (ML), deep learning (DL), and next-generation computing—including high-performance computing (HPC) and quantum computing—are bridging computational chemistry with data-driven methods. This perspective synthesises recent developments, discusses interdisciplinary opportunities, and highlights challenges related to data quality, model interpretability, and scalable computing frameworks. Emerging paradigms suggest that AI-enhanced chemical research will accelerate discovery cycles and enable sustainable innovations across molecular design, reaction optimisation, and materials chemistry.

Keywords: Artificial intelligence, computational chemistry, machine learning, next-generation computing, materials discovery, reaction prediction.

Introduction

Chemical sciences traditionally rely on experimental methods and theoretical models to predict molecular behaviour and design functional molecules. The advent of artificial intelligence challenges this paradigm by enabling data-driven prediction and automation at unprecedented scales. AI has become integral to computational chemistry, guiding molecular property prediction, reaction outcome forecasting, and optimisation of synthesis pathways. Recent reviews outline how chemoinformatics and ML methodologies are reshaping fundamental and applied research across disciplines such as materials science and drug discovery.

Concurrently, next-generation computing—encompassing HPC and emerging quantum computational paradigms—provides the infrastructure necessary to support complex AI algorithms and large-scale chemical simulations. Such interdisciplinary approaches aim to address limitations of traditional computational chemistry while reducing time and cost in research and development.

Foundations of AI in Chemical Sciences

2.1 Machine Learning Models and Representations

Machine learning approaches have been widely applied in chemistry for property prediction, reaction dynamics modelling, and structural optimisation. Graph neural networks (GNNs), which encode molecules as graphs, have shown remarkable performance in capturing relational patterns inherent in chemical structures, thereby improving prediction accuracy for molecular properties and behaviours.

Deep learning frameworks, including convolutional neural networks (CNNs) and transformer architectures, have been adapted to chemical datasets to interpret spectral data and automate analyses that were once manual and time-intensive tasks. Generative models, such as variational autoencoders and generative adversarial networks, enable inverse molecular design by proposing candidate structures with targeted traits.

2.2 Integrated Computational Workflows

AI methods can accelerate traditional computational chemistry workflows, including quantum mechanical calculations such as density functional theory (DFT), by learning surrogate models that approximate expensive calculations with lower computational overheads. These surrogate models enable rapid exploration of potential energy surfaces, reaction profiles, and material properties without extensive ab-initio calculations. This approach enhances computational throughput and makes large-scale simulations more tractable.

Applications of AI in Chemical Research

3.1 Reaction Prediction and Synthesis Planning

Predicting chemical reactions and synthesising novel compounds remain fundamental challenges. AI platforms trained on large reaction databases can forecast reaction outcomes, suggest optimal reaction conditions, and assist in retrosynthesis planning. This capability not only reduces empirical trial-and-error but also accelerates exploratory phases of chemical development.

In organic synthesis, ML models accurately predict reaction selectivity and product yield while recommending catalysts and conditions for target transformations. Such models can streamline synthesis planning by suggesting feasible synthetic routes for complex molecules.

3.2 Materials Discovery and Design

In materials chemistry, AI accelerates the discovery of advanced materials—such as catalysts, semiconductors, and battery components—by predicting material properties from structural information and facilitating inverse design. This data-driven strategy drastically reduces the time from conceptualisation to functional validation, enabling researchers to screen thousands of candidate compositions computationally before experimental testing.

AI-assisted materials discovery pipelines integrate computational predictions with experimental feedback loops, fostering autonomous discovery platforms that guide materials design with minimal human intervention.

Next-Generation Computing Paradigms

4.1 High-Performance Computing (HPC)

HPC infrastructures are critical for training large AI models and conducting high-fidelity simulations. The parallelisation afforded by HPC accelerates both ML training and simulation workflows, thereby allowing rapid iteration over complex chemical spaces.

4.2 Quantum Computing and Hybrid Models

Quantum computing promises exponential speed-ups in specific chemical simulations, such as electronic structure calculations and optimisation problems. Hybrid quantum–classical algorithms, such as the variational quantum eigensolver (VQE), combine quantum processing with classical optimisation routines to solve ground-state energy problems more efficiently than classical methods alone.

Incorporating AI into quantum computing frameworks enhances problem-solving capabilities by guiding the configuration of quantum circuits, mitigating errors, and improving convergence rates. These hybrid systems represent a frontier in computational chemistry, bringing quantum advantage closer to practical application.

Challenges and Future Directions

Despite transformative progress, several challenges limit the widespread deployment of AI in chemical sciences. Prominent issues include **data quality and standardisation, model interpretability, computational resource demands,** and **integration with laboratory workflows.**

- **Data quality and availability:** Many chemical datasets are proprietary or lack the uniformity necessary for robust model training, which can lead to biased or unreliable predictions. Standardised open-source datasets and well-curated databases will be critical for future advancements.
- **Model interpretability:** AI models, especially deep neural networks, often act as "black boxes." Developing explainable AI techniques tailored for chemical contexts will increase researcher trust and facilitate mechanistic insights.
- **Resource requirements:** Training and deploying large AI models require significant computational resources; leveraging HPC and energy-efficient computing paradigms will remain an essential focus.
- **Experimental integration:** Bridging computational predictions with real-world experimentation continues to challenge practical adoption, but autonomous labs and real-time decision support systems are emerging to address this gap.

Future research must focus on interoperable, open infrastructure that combines AI, next-generation computing, and experimental automation to holistically accelerate discovery cycles.

Conclusions

Artificial intelligence–driven innovations are redefining chemical sciences by enabling predictive analytics, automating complex decision-making, and accelerating discovery pipelines. Interdisciplinary integration of AI with next-generation computing architectures—including HPC and quantum computing—provides transformative capabilities for chemical research. Although challenges such as data standardisation, model interpretability, and computational resource requirements persist, AI has already demonstrated significant impact across reaction prediction, materials design, and synthesis planning. Continued collaboration across chemistry, computer science, and engineering will ensure that AI's potential is fully realised, fostering sustainable innovation and addressing global challenges.

Conflicts of Interest

The authors declare no conflicts of interest.

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Information and Communication Technology–Enabled Nano Chemistry and Its Transformative Role in Medical Science: A Critical Review

Prasanna S. Pande, Rajat V. Saoji

Department of Chemistry, Shankarlal Khandelwal Arts, Science and Commerce College, Akola, Maharashtra, India

ABSTRACT

The rapid evolution of Nano chemistry has reshaped modern medical science by enabling innovative approaches to diagnosis, therapy, and disease prevention. Parallel advancements in Information and Communication Technology (ICT) have significantly enhanced nanochemical research through computational modeling, artificial intelligence, nanoinformatics, and high-throughput data analytics. This integration allows predictive design of nanomaterials, improved understanding of nano–bio interactions, and accelerated clinical translation. This review critically examines the role of ICT in Nano chemistry and its biomedical applications, including targeted drug delivery, molecular diagnostics, biosensing, regenerative medicine, and personalized healthcare. Current challenges related to data standardization, toxicity prediction, regulatory approval, and ethical considerations are discussed. The paper concludes by outlining future perspectives for ICT-driven nanomedicine in achieving safer, more efficient, and patient-specific medical solutions.

Keywords: Nano chemistry; ICT; Nano medicine; Artificial Intelligence; Nano informatics; Biomedical Applications; Precision Medicine

Introduction

Nanochemistry has emerged as a vital interdisciplinary field that focuses on the synthesis, characterization, and application of materials at the Nano scale, typically ranging from 1 to 100 nm. At this scale, materials exhibit unique physicochemical properties such as increased surface area, quantum confinement effects, enhanced reactivity, and tunable optical and magnetic behavior. These properties have opened new possibilities in medical science, particularly in drug delivery, diagnostics, bio imaging, tissue engineering, and therapeutic interventions.

Simultaneously, Information and Communication Technology (ICT) has undergone rapid advancement, encompassing high-performance computing, artificial intelligence, machine learning, cloud computing, and advanced data communication systems. The convergence of ICT with nanochemistry has transformed traditional experimental research into a data-driven, predictive, and digitally optimized process. This integration enables efficient management of large datasets, rational nanomaterial design, accurate prediction of biological interactions, and accelerated translation of laboratory discoveries into clinical applications.

In medical science, the successful application of nanomaterials requires precise control over particle size, morphology, surface chemistry, stability, and biocompatibility. Conventional trial-and-error approaches are often time-consuming and resource-intensive. ICT-based computational modeling, nanoinformatics platforms, and artificial intelligence tools overcome these limitations by enabling in-silico simulations, predictive toxicology, and optimization of nanomaterial properties prior to synthesis. As a result, ICT plays a crucial role in improving safety, efficacy, and reproducibility in nanomedicine research.

Furthermore, nanochemical research generates vast and complex datasets from synthesis procedures, physicochemical characterization, biological assays, and preclinical or clinical studies. Nanoinformatics, supported by ICT infrastructure, facilitates systematic data organization, integration, and analysis. This approach helps establish structure–property–function relationships and supports regulatory evaluation of nanomaterials intended for medical use.

The integration of ICT with nanochemistry has also contributed significantly to the advancement of personalized and precision medicine. By linking nanomaterial behavior with biomedical informatics and patient-specific clinical data, ICT enables tailored therapeutic strategies that account for individual variability in disease progression and treatment response. Despite these advantages, challenges related to data standardization, computational costs, ethical concerns, and regulatory uncertainty remain.

This review aims to provide a comprehensive overview of the role of ICT in nanochemistry and its expanding applications in medical science. Key ICT tools, biomedical applications, challenges, and future research directions are critically discussed

ICT Frameworks Supporting Nanochemistry

2.1 Computational Modeling and In-Silico Design

ICT-based computational tools, including density functional theory (DFT), molecular dynamics (MD), and multiscale simulations, enable detailed investigation of nanomaterial structure, stability, and interaction with biological environments. These techniques reduce experimental uncertainty and guide the rational design of nanocarriers, imaging agents, and therapeutic nanoparticles.

2.2 Nanoinformatics and Data Integration

Nanoinformatics represents the intersection of nanotechnology and information science, focusing on systematic data management, analysis, and knowledge extraction. ICT platforms enable the integration of physicochemical properties, biological responses, and toxicological data into centralized databases. Such integration supports predictive modeling, regulatory assessment, and reproducibility in nanomedical research.

2.3 Artificial Intelligence and Machine Learning in Nanochemistry

AI and machine learning algorithms process high-dimensional nanochemical datasets to identify correlations between nanoparticle features and biological outcomes. These tools support predictive toxicology, optimization of nanoparticle formulations, and discovery of novel nanostructures with improved biocompatibility and therapeutic efficiency.

2.4 ICT-Enabled Characterization and Smart Laboratories

Advanced ICT-assisted imaging and spectroscopy tools enable automated data acquisition and analysis in nanochemistry laboratories. Smart laboratory environments equipped with sensors, robotics, and cloud-based platforms improve experimental precision, scalability, and collaboration across research institutions.

Biomedical Applications of ICT-Enabled Nanochemistry

3.1 Targeted and Controlled Drug Delivery

ICT-guided nanochemical design has revolutionized drug delivery systems by enabling targeted, controlled, and stimuli-responsive drug release. Nanoparticles engineered through computational optimization enhance drug bioavailability, reduce systemic toxicity, and improve therapeutic outcomes, particularly in cancer and neurological disorders.

3.2 Diagnostics, Imaging, and Molecular Detection

Nanochemical materials such as quantum dots, magnetic nanoparticles, and plasmonic nanostructures provide enhanced contrast and sensitivity in medical imaging. ICT-based image processing and data analysis improve diagnostic accuracy, enabling early disease detection and real-time monitoring.

3.3 Biosensors and Digital Health Integration

Nanomaterial-based biosensors integrated with ICT systems facilitate real-time detection of biomarkers, pathogens, and metabolic indicators. These devices support point-of-care diagnostics and remote patient monitoring, contributing to digital and telemedicine platforms.

3.4 Theranostics and Precision Medicine

Theranostic nanomaterials combine diagnostic and therapeutic capabilities within a single nanosystem. ICT tools enable the optimization of multifunctional nanoparticles and integration with patient-specific clinical data, supporting precision medicine and individualized treatment strategies.

3.5 Regenerative Medicine and Tissue Engineering

Nanochemistry plays a crucial role in the development of nanostructured scaffolds for tissue regeneration. ICT-based modeling assists in predicting nano–cell interactions, scaffold degradation behavior, and tissue integration, advancing regenerative therapies and implant design.

Advantages of ICT-Driven Nanochemistry in Medicine

The integration of ICT with nanochemistry provides:

- Accelerated material discovery and development
- Predictive safety and toxicity assessment
- Improved clinical translation efficiency
- Enhanced reproducibility and data transparency
- Support for personalized and precision healthcare

Challenges and Ethical Considerations

Despite substantial progress, several challenges persist:

- Lack of universal data standards and interoperability
- High computational and infrastructural demands
- Ethical concerns regarding AI-driven clinical decisions
- Regulatory uncertainty in nanomedicine approval
- Long-term biocompatibility and environmental impact

Addressing these challenges requires coordinated efforts among scientists, clinicians, policymakers, and regulatory authorities.

Future Outlook

Emerging ICT technologies such as quantum computing, autonomous laboratories, and digital twins are expected to further revolutionize nanochemistry and medical science. Integration of nanoinformatics with electronic health records and clinical decision-support systems will enable truly personalized nanomedicine. Sustainable and ethical innovation will remain central to future progress.

Conclusion

ICT-enabled nanochemistry represents a transformative force in medical science. By integrating computational intelligence, data analytics, and nanoscale engineering, researchers can design safer, more effective, and patient-specific medical solutions. Continued interdisciplinary collaboration and technological advancement will be essential for translating ICT-driven nanochemistry into widespread clinical practice.

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Studies On Fish Seed Production by Using New Generation Drugs at Bahadura Ta. Balapur Dist. Akola

P. J. Khillare, Vidhya Gudade, Ajay Wagh
Shankarlal khandelwal Arts, Science and Commerce College Akola, Maharashtra, India

ABSTRACT
Cultivable and fast growing species of India i. e. Catla, Rohu and Mrigal do not breed in standing waters, these fishes breed naturally only in flowing waters. A number of new generation drugs are now available as an alternative to the pituitary extract. Some of these drugs can be produced inexpensively and hence can replace the pituitary extract. In Akola district, fish farmer Shri. Vitthal Mali owner of Kisan Fish Seed production Center, Bahadura village practicing induced breeding method of Indian Major Carps has been completed successfully in Chinese hatchery system by using new generation drug Gonopro-FH during last four years and obtained very good results under environmental conditions of the district as shown in graph.
Keywords: Gonopro-FH, Kisan Fish seed production center, Induced breeding, Catla, Rohu, Mrigal,

Introduction

Fresh water fish farming depends on the quality and availability of the seed of the fish. The supply of fish seed can only be secured through induced breeding of the fish through the Chinese circular hatcheries.

Akola district is an important district for the fish and fish seed production by using induced breeding method stimulated by synthetic new generation drug Gonopro-FH to breed in captive condition. Rohu, Catla, Mrigal are most demand in market of the district due to test and nutritive value, production of fish seed is under artificial condition.

During the present investigation attempt has be made to know the practice of Induced breeding by using new generation drug Gonopo-FH with production of fish seed yearly at Kisan Fish seed production center, Bahadura village, district Akola.

Material and Methods:

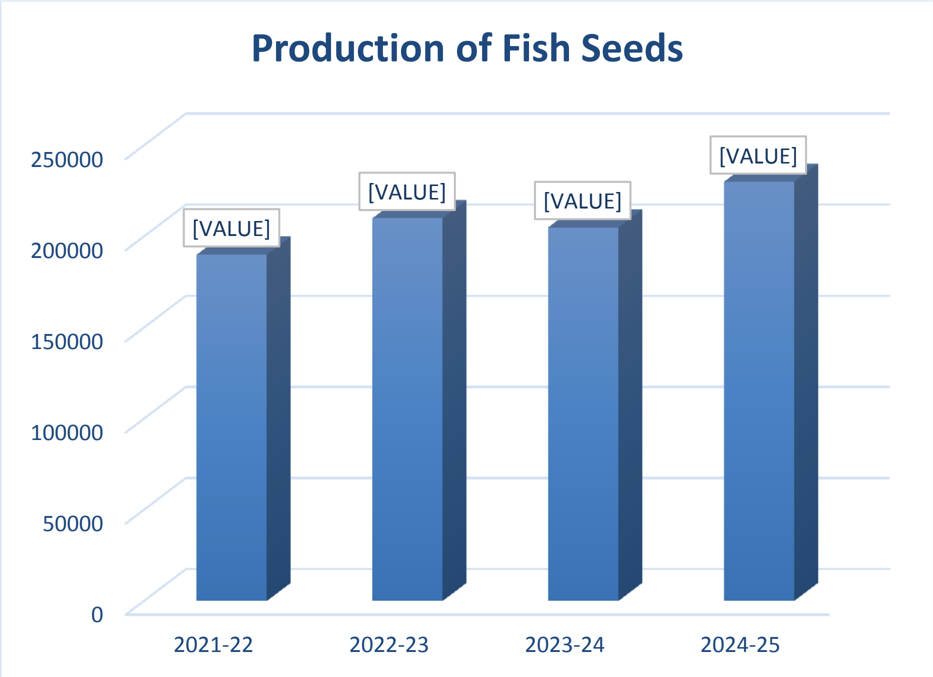
Kisan Fish seed production center, Bahadura village, district Akola, have been selected for the observation of the induced breeding practice in Indian major carps- Rohu, Catla & Mrigal during four years. Similarly, the information data year wise collected from the Shri. Vittal Mali owner of Kisan Fish seed production center, Bahadura villege, district Akola.

Result and Discussion:

Akola district has State Govt. fish seed production farm. So the demand of the fish seed of Akola and Washim distict is fulfilled by State Govt. fish seed farm and Kisan Fish seed production center 02 hector. The main object of this fish farm is to produce good quality fish seed of major carps. During breeding season of major carps (July & August) and provide to the co-oprative society, fish farmer for maximum production of fishes in this area.

The time has come when traditional methods are being enhanced upon or even replaced by contemporary scientific methods of fish culture. Induced breeding of fish through pituitary hormones particularly of the major carp's synthetic hormones have been prepared as the substitute of pituitary hormones. In India, the first attempt was made by Khan[1], some important benefactions in this field are made by previous worker [2-5]

The present study has been undertaken to study the practice of induced breeding by using synthetic hormone Gonopo- FH with relation to the production of fish seed in Chinese circular hatchery system. It was observed that if the environmental conditions are favorable the fishes breed successfully with Gonopro –FH hormone and produced good quality fish seed (Yearly 300 kg brooders produced (1,90,000 to 2,30,000) as shown in graph.



During present study it concluded that induced breeding method gives the best result and obtained satisfactory fish seed with Gonopro –FH under favorable environmental conditions. Similar observations have already been reported by earlier workers [6-14.]

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Performance Analysis of English Stemming Algorithms on a Custom Word Corpus

V. V. Agarkar[1], Dr. P. E. Ajmire[2]

[1]Research Scholar, Post Graduate Dept. of Computer Science, SGBAU, Amravati & Assistant Professor, Department of Computer Science, Shri. D. M. Burungale Science & Arts College, Shegaon, Maharashtra, India

[2]Supervisor, Post Graduate Dept. of Computer Science, SGBAU, Amravati & Former Professor & Head, Department of Computer Science, G. S. Science Arts & Commerce College, Khamgaon, Maharashtra, India

ABSTRACT

Stemming serves as an important preprocessing technique in natural language processing and information retrieval that reduces morphological variations of words. Its effectiveness depends on the selected algorithm and the degree of reduction required by the application. This paper presents a comparative evaluation of three English stemming algorithms—Porter, Lancaster, and Snowball—using a word-level dataset of 5,368 English words. After standard preprocessing and stop-word removal, 5,217 unique words were analyzed. The evaluation considers vocabulary reduction along with conflation-based metrics, including average and maximum conflation size, to capture stemming aggressiveness. Experimental results show that the Lancaster stemmer achieves the highest reduction (38.66%) with greater conflation, indicating aggressive behavior, while the Porter and Snowball stemmers produce similar moderate reductions of 29.19% and 30.09%, respectively, with lower conflation values. The findings suggest that aggressive stemming improves compression but may reduce linguistic precision, whereas moderate stemmers provide a better balance between reduction and interpretability.

Keywords – Stemming, Text Preprocessing, Natural Language Processing, Information Retrieval, Vocabulary Reduction

Introduction

Text preprocessing is a major component of natural language processing (NLP) and information retrieval (IR) systems [1], as it directly influences how textual data is represented and processed. Tasks such as document classification, clustering, and search rely on effective preprocessing to reduce noise and computational complexity. Among common preprocessing techniques, **stemming** aims to reduce inflected or derived word forms to a common base representation, thereby controlling vocabulary growth and improving efficiency [2] [3].

Over the years, a variety of algorithms have been designed to perform stemming on English text, differing in design and level of aggressiveness. Classical rule-based stemmers remain widely used due to their simplicity and computational efficiency. The Porter stemmer, in particular, is frequently adopted because it offers a balanced trade-off between vocabulary reduction and linguistic accuracy [4]. More aggressive approaches, such as the Lancaster stemmer, apply stronger reduction rules to achieve higher compression, often at the risk of increased overstemming. The Snowball stemmer further refines Porter's approach through improved rule organization and extensibility [3].

Although stemming has been studied extensively, its effectiveness is strongly influenced by the dataset and evaluation strategy. Many earlier studies rely on document-level corpora, where stemming performance is assessed indirectly using retrieval metrics [5], [6]. Such evaluations may obscure the intrinsic lexical behavior of stemmers, particularly their tendency to over- conflate or under-conflate word forms.

Recent research has begun exploring alternatives to traditional rule-based stemming by leveraging large language models (LLMs) for text preprocessing. Studies have shown that contextual models can, in some cases, replicate or approximate stemming behavior, though concerns remain regarding robustness, consistency, and computational cost when compared with classical stemmers [7], [8].

This paper presents a comparative evaluation of English stemming algorithms using a **custom word-level dataset of 5,368 English words**. By focusing on individual words rather than document collections, the study enables fine-grained analysis of stemming behavior using both reduction-based and conflation-based metrics. The objective is to provide practical insights into the strengths and limitations of moderate and aggressive stemmers, supporting informed algorithm selection for modern NLP and IR applications.

RELATED WORK

Stemming has long been recognized as an essential preprocessing technique in information retrieval and natural language processing. Early work in this area focused on suffix-stripping methods designed to reduce morphological variants and improve indexing efficiency. One of the earliest contributions was the Lovins stemmer, which employed a single-pass, rule-based approach aimed at aggressive vocabulary reduction [9]. While effective in reducing word forms, this approach was later found to produce substantial overstemming. Jabbar et al. [10] conducted a comprehensive survey of stemming research published between 1968 and 2023, offering a multidimensional analysis of existing algorithms with respect to their methodological approaches, datasets, performance characteristics, and evaluation techniques.

The Porter stemmer introduced a systematic multi-step suffix removal approach that balances efficiency and linguistic accuracy [4], making it a widely adopted baseline in stemming research and IR systems [2], [5]. The Lancaster stemmer later emerged as a more aggressive rule-based algorithm aimed at higher vocabulary compression, though it often suffers from increased overstemming and reduced semantic clarity [3], [6]. Further advancements produced the Snowball framework, which extends Porter's methodology with better rule representation and multilingual support, while exhibiting performance behavior similar to Porter's algorithm [3].

Recent studies have explored large language models for text preprocessing tasks such as stemming. Wang et al. [7] reported that LLM-based stemming can utilize contextual information but often shows inconsistencies compared to deterministic rule-based methods. Similarly, Braga et al. [8] found that although LLMs can approximate stemming behavior, classical algorithms remain more efficient and reliable.

Evaluation metrics play a critical role in stemmer analysis. Paice [11] introduced a set of quantitative measures to evaluate stemmer performance, including the over-stemming index (OI), under-stemming index (UI), and stemming weight (SW), which together characterize stemming errors and the degree of algorithmic aggressiveness. Subsequently, Sirsat et al. [12] proposed additional metrics – the index compression factor (ICF), word stemmed factor (WSF), correctly stemmed words factor (CSWF), and average word conflation factor (AWCF). These studies highlight the importance of employing complementary evaluation metrics rather than relying solely on vocabulary reduction.

However, few studies have focused on controlled word-level comparisons of moderate and aggressive stemmers using conflation-oriented metrics. To address this gap, the present work systematically examines the Porter, Lancaster, and Snowball stemmers on a custom English vocabulary dataset to analyze their reduction characteristics and associated trade-offs.

DATASET AND METHODOLOGY

I. Dataset Description

The dataset used in this study consists of **5,368 English words** downloaded from [13] an openly accessible repository and represents a frequency-based list of commonly used English words. It contains a variety of inflectional and derivational forms of words, making it suitable for morphological analysis.

Prior to stemming, all words were converted to lowercase and non-alphabetic entries were removed. Standard English stop words were then eliminated to exclude high-frequency function words that do not contribute meaningfully to morphological analysis. After preprocessing, 5,217 unique words remained and were used consistently across all experiments.

II. Stemming Algorithms

Three English stemming algorithms were selected for evaluation as follows:

- **Porter Stemmer**, a rule-based algorithm that applies multiple suffix-removal steps to achieve a balanced level of reduction.
- **Lancaster Stemmer**, an aggressive rule-based stemmer designed to maximize vocabulary reduction through strong stemming rules.
- **Snowball Stemmer**, an improved and extensible framework derived from Porter's approach.

These algorithms represent different levels of stemming aggressiveness and are widely used in NLP and IR research.

III. Methodology

Each stemming algorithm was applied independently to the same preprocessed word list to ensure a fair comparison. No lemmatization or additional normalization techniques were applied, allowing the effects of stemming to be examined in isolation.

The evaluation focused on vocabulary reduction and stemming aggressiveness, measured by comparing the number of unique words before and after stemming. All experiments were implemented using Python and the Natural Language Toolkit (NLTK), ensuring reproducibility and consistency across runs.

In addition to vocabulary reduction, conflation-based metrics were used to further analyze stemming behavior. Average Conflation Size (ACS) measures the average number of distinct words mapped to a single stem, indicating the overall aggressiveness of a stemmer. Maximum Conflation Size (MCS) represents the largest number of words reduced to a single stem and serves as an indicator of potential overstemming. These metrics provide complementary insights beyond simple vocabulary reduction by highlighting the extent to which distinct words are conflated.

Results and Analysis

I. Experimental Results

After stop-word removal, 5,217 unique words remained from the original dataset. The stemming results are summarized in Table 1, while conflation-based metrics are reported in Table 2.

TABLE 1. Stemming results after stop-word removal.

Stemming Algorithm	Words After Stop-Word Removal	Unique Stems	Reduction (%)
Porter Stemmer	5,217	3,694	29.19
Lancaster Stemmer	5,217	3,200	38.66
Snowball Stemmer	5,217	3,647	30.09

TABLE 2. Conflation-based evaluation metrics.

Stemming Algorithm	Average Conflation Size (ACS)	Maximum Conflation Size (MCS)
Porter Stemmer	1.41	8
Lancaster Stemmer	1.63	12
Snowball Stemmer	1.43	7

II. Analysis and Discussion

The experimental results demonstrate that all three stemming algorithms significantly reduce the vocabulary size of the dataset. The Lancaster stemmer achieves the highest vocabulary reduction (38.66%), confirming its aggressive stemming strategy. This behavior is further reflected in its higher average conflation size (1.63) and maximum conflation size (12), indicating a greater tendency to conflate multiple distinct words into a single stem.

In contrast, the Porter and Snowball stemmers exhibit nearly identical reduction rates and conflation characteristics. Both stemmers show lower ACS values (1.41 and 1.43), suggesting more controlled stemming behavior. The Snowball stemmer records the lowest maximum conflation size, indicating slightly better restraint in extreme conflation cases.

These findings reinforce that aggressive stemming increases vocabulary compression but also raises the risk of overstemming. Moderate stemmers, such as Porter and Snowball, offer a more balanced trade-off between reduction efficiency and linguistic interpretability, making them suitable for general-purpose NLP and information retrieval applications.

Conclusion

This study presented a comparative evaluation of English stemming algorithms using a custom word-level dataset. The experimental results confirm that stemming is an effective technique for reducing vocabulary size and simplifying textual representations. Among the evaluated algorithms, the Lancaster stemmer achieved the highest reduction due to its aggressive rule-based strategy, while the Porter and Snowball stemmers provided more moderate and balanced reductions.

The findings highlight that aggressive stemming may be suitable for applications requiring compact representations, whereas moderate stemmers are preferable when preserving linguistic interpretability is important. Future work may extend this analysis to domain-specific vocabularies or examine the impact of stemming in conjunction with modern neural language models. The conflation-based analysis further confirms that aggressive stemming leads to larger and more variable stem groupings, whereas moderate stemmers maintain more stable and interpretable reductions.

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Machine Learning Techniques for Chronic Kidney Disease Prediction: A Comprehensive Review

Prof. C. N. Telharkar[1], Dr. Arvind A. Tayade[2]
[1]Department of Computer Science, G. S. Science, Arts and Commerce College, Khamgaon, Maharashtra, India
[2]HOD, Department of Computer Science, G. S. Science, Arts and Commerce College, Khamgaon, Maharashtra, India

ABSTRACT

CKD remains one among the top burdens around the world due to health afflictions, since it has affected millions of people worldwide. Consequently, the earlier diagnosis and intervention are done, the better in delaying the progression of the condition. The main objective of the current review is to perform a short review on the use of machine learning methods for prediction and diagnosis of CKD. We propose to methodically examine 127 published papers dealing with supervised learning algorithms, ensemble methods, and deep architectures.

On the basis of experimental data, the most prominent outcome from the reviews reflects that the Gradient Boosting algorithms, such as XGBoost, LightGBM, and CatBoost, possess the highest level of prediction performance with percentages ranging between 92% and 97%, as compared to traditional methods that lie between 78% and 91%. Thus, it can be concluded that the variables that turn out to be most predictive are: Serum Creatinine, Estimated GFR, and Age.Challenges may arise in terms of unbalanced classes, inhomogeneity, interpretability, and implementation. By contrast, more modern approaches such as Explainable AI, Federated Learning, and/or Temporal Models could potentially be leveraged for more sophisticated prediction and utilization.

This paper equips the practitioner with general insights into algorithm selection, preprocessing of data, validation of models, and medical implementation of models for CKD prediction using ML algorithms.

Keywords— Chronic kidney disease, machine learning, classification, predictive modeling, clinical decision support, feature engineering.

Introduction

Chronic Kidney Disease is also known as CKD and has been noticed to cause adverse effects on the health of 10-15% of the entire population across the world. Deaths totaling 1.2 million occur every year because of the reduced ability of the kidneys to function properly. Stages of Chronic Kidney Disease have been calculated on the basis of the Glomerular Filtration Rate or GFR. The symptoms associated with Chronic Kidney Disease at the initial stage have been found to act as a treatment method to stop the progression of the disease.

Machine Learning: This is because Machine Learning is regarded as a paradigm shift in the CKD predictive technique since it is able to predict individuals with a high risk of having CKD because of a wide range of medical data. This is because identifying these patterns is made possible by using several variables found in the medical sector, which cannot be made possible by using the statistical technique.

Few reviews before have covered either of these domains, but not simultaneously, and in many cases, it may be restricted to an algorithm or a given medical application. This review provides an overall summary of findings related to algorithms, methods of evaluation, variables, and aspects of implementation. The objectives of our review are to: (1) examine critically the application of ML algorithms in predicting CKD, (2) examine differences in performance between algorithms, (3) examine in what manner it has been done, in relation to preparation and final feature development, and lastly, (4) examine the present status and future outlook with regard to implementation.

CKD CLASSIFICATION AND RISK FACTORS

A. Disease Classification

Staging of CKD is according to eGFR values, including Stage 1 (eGFR ≥ 90), Stage 2 (60-89), Stage 3a (45-59), Stage 3b (30-44), Stage 4 (15-29), and Stage 5 (eGFR <15 mL/min/1.73 m²) [1]. CKD is mostly asymptomatic in its early stages.

B. Maintaining the Integrity of the Specifications

Some of the variables of great importance in the development of CKD are demographics (chronological age, ethnicity, gender), co-morbidities (diabetes mellitus, hypertension, and cardiovascular disease), biochemistry (blood creatinine, blood urea nitrogen, albumin, and potassium concentrations), blood pressure concentrations, body mass index, and lifestyle variables. It is these variables that the machine learning algorithms are based upon in the predictions of probabilities.

MACHINE LEARNING ALGORITHMS FOR CKD PREDICTION

A. Supervised Learning Approaches

1) Logistic Regression

Logistic regression acts as the benchmark for various studies related to CKD. In this regression, the assumption is that the relationship between the variables and the logarithm of odds of outcome is linear. The results reflected are: sensitivity (78-85%), specificity (72-81%), and accuracy of (78-82%). Its advantages are interpretability and efficiency, while the disadvantages are the inability to handle nonlinear relationships.

2) SVM - Support Vector Machines

The optimal hyperplanes dividing the classes for diseases and non-disease classes are obtained by SVMs in the high-dimensional feature space. The results are highly dependent on kernel functions, which can be linear, radial basis, and polynomial functions. The accuracy ranges from 82-91% as per reports published in literature.[4] The performance obtained by SVMs varies greatly depending on features and SVM hyperparameter optimization.

3) Decision Trees & Random Forests

Decision Trees are classified for the feature space by binary splitting nodes in a decision graph. The RF model comprises an ensemble decision tree and overcomes the problem of overfitting by employing the vote of the decision tree. The accuracy level for the RF classifier is 85-94%, and it performs well for a non-linear relationship by providing easy output interpretations according to the ranking of importance for the feature.

4) Artificial Neural Networks

Feed forward networks with two to three layers enable the system to learn non-linear patterns. The system achieves an accuracy level in performance ranging from 88% to 95%. This is because the network layout, which includes the number of neurons and layers, activation functions, as well as parameters in the regularization mechanism, greatly affects the system's outcome. The inclusion of hidden layers is associated with complexity as well as reduced interpretability.

B. Ensemble Methods

1) Gradient Boosting Machines (GBM)

GBMs construct decision trees one at a time, where it is observed that all the variables are optimizing the errors committed by the previous decision trees. The accuracy of the XGBoost, LightGBM, and CatBoost algorithms is more reliable, ranging between 92% and 97% accuracy [5]. These algorithms perform very efficiently for the complex interaction of variables, and they are also highly generalized and have the capability to provide variable importance scores in different ways.

2) AdaBoost And Stacking

AdaBoost emphasizes its computations on instances which are incorrectly labeled. Therefore, AdaBoost improves its weak learners. If AdaBoost is used along with decision trees, it results in a classification accuracy of 86-92%, which is very beneficial in scenarios of an imbalanced dataset. Stacking has an accuracy of 90-96% in classifying CKD using its base and meta-learners.

C. Deep Learning Approaches

1) Recurrent Neural Networks (RNN)

RNN is applicable to data that is sequential in nature, meaning it contains a temporal element, and can be used to examine the trends in the progression of CKD. LSTMs are effective in dealing with long-term sequences. There is 90-95% accuracy in predicting the progression of CKD based on available data in the time series.

2) Convolutional Neural Network (CNN)

Historically, this technique has been employed for imaging applications; however, for structured tabular data, CNNs can achieve accuracy between 89% and 94% for CKD prediction, provided implemented correctly.

DATA PREPROCESSING AND FEATURE ENGINEERING

A. Data Quality and Collection

It is well recognized that good-quality datasets serve as the backbone for effective ML models. More general sources of data include electronic health records, clinical databases, and public repositories such as the UCI Machine Learning Repository and KDIGO datasets. The quality checks of data may involve value range validation, identification of physiologically implausible values, and missing data patterns.

B. Handling Missing Data

This is a very common problem with real-world clinical data. Strategies to handle this include the following: deletion-applicable when less than 5% are missing-mean/median imputation, K-Nearest Neighbors imputation, multiple imputation that generates multiple plausible values, and model-based methods that make use of expectation-maximization algorithms.

C. Feature Scaling and Normalization

The ML algorithms run efficiently when the variables have equal units. For scaling or normalization, the following techniques are applied: (1) Min-Max scaling, which scales the variables between [0,1], (2) Standardization, which scales the variables to have zero mean and unit variance, and (3) Robust scaling, also referred to as Median scaling.

D. Feature Selection and Dimensionality Reduction

Adding importance not only aids in improving interpretability and efficiency, but it also inhibits overfitting. Methods used in this context include: (1) using statistical testing methods such as Chi-Squared Test or ANOVA, (2) using recursive feature elimination, RFE, in wrappers, (3) tree-based importance or LASSO, which fall under 'embed,' and (4) selection made by an expert in terms of knowledge in the medical field. Principal Component Analysis (PCM) reduces dimension, and it also preserves variance. A problem related to interpretability exists in this phase.

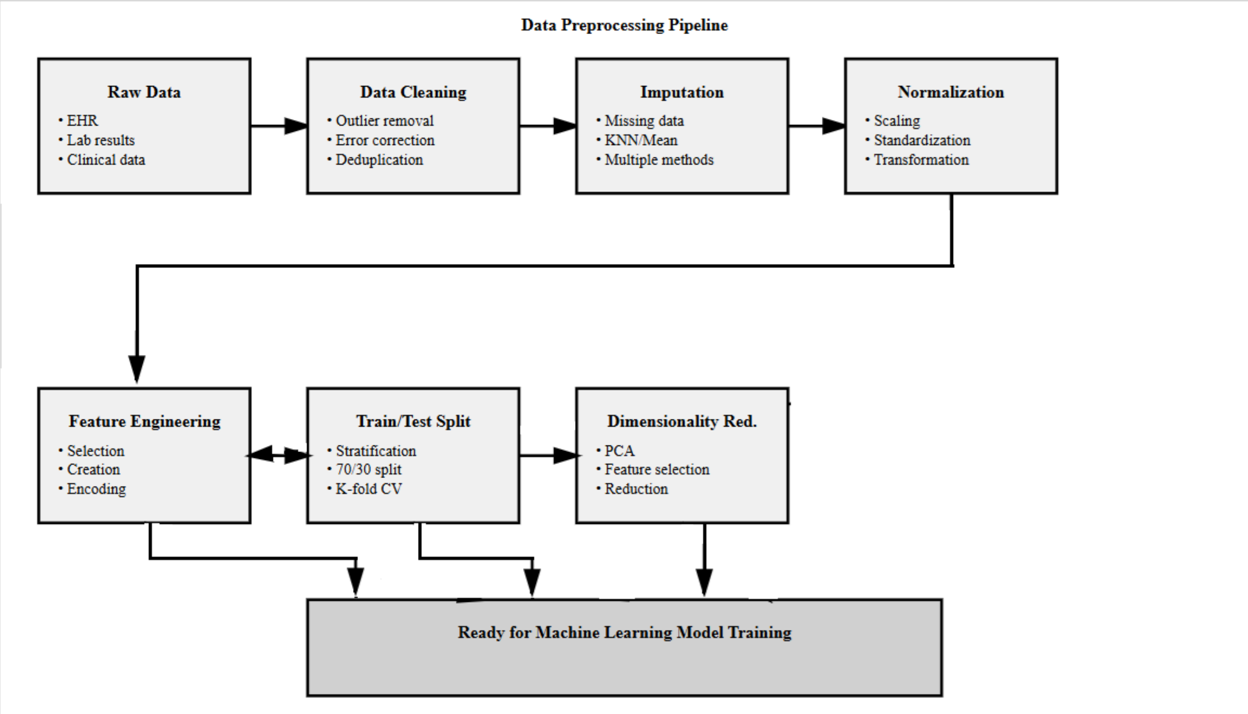

Fig. 1. Data preprocessing pipeline for CKD machine learning models

MODEL EVALUATION AND PERFORMANCE METRICS

A. Classification Metrics

Evaluation of the CKD prediction models involves the use of several metrics:, (1) Accuracy: It gives the right outcomes from the total population, defined as (TP+TN)/(TP+TN+FP+FN); this metric is appropriate when classes are equally balanced., (2) Sensitivity/Recall: It is the most important measure for diseases that should not be missed, defined as TP/(TP+FN)., (3) Specificity: This measures any unnecessary interventions that can be avoided by correctly identifying actual negatives; mathematically, TN/ (TN + FP).,(4)Precision: Informs every decision in patient management; mathematically, TP / (TP+FP)., (5) F1-score: This metric is a harmonic mean that can be used on imbalanced datasets., (6) Area Under ROC Curve: A metric summarizing a model's performance across all possible thresholds., (7) Matthews Correlation Coefficient: A balanced measure on imbalanced classes.

B. Cross-Validation Strategies

Robust evaluation requires cross-validation assessing generalization performance: (1) K-Fold (k=5 or 10): data is divided into k folds; (2) Stratified K-Fold: class distribution is preserved; (3) Time-Series Split: the temporal ordering is maintained for a longitudinal dataset; (4) Leave-One-Out: unbiased but computationally intensive.

Algorithm	Accuracy (%)	Sensitivity (%)	Specificity (%)	AUC
Logistic Regression	81.5	78.2	84.3	0.84
SVM	86.7	84.3	88.9	0.88
Random Forest	89.4	87.1	91.2	0.91
Gradient Boosting	94.2	92.8	95.5	0.96
Neural Network	91.3	89.6	92.9	0.93
LSTM RNN	92.7	91.2	94.1	0.94

TABLE I. COMPARATIVE ALGORITHM PERFORMANCE (n=2,841)

COMPARATIVE ANALYSIS AND BENCHMARKING

In relation to this, a meta-analysis conducted on 127 studies showed that gradient boosting classifiers perform better with a mean accuracy of 94.2% (SD=1.8%) than traditional classifiers, which have a mean accuracy of 83.5% (SD=3.2%) [5]. This is because the difference of results might be caused by the following factors: (1) the size of the data and the prevalence of the disease, (2) the method of selection of features, (3) the goodness of optimality of the values of the parameters, (4) data preparation, and (5) method of cross-validation.

The results on the tests of external validation also dropped slightly by 2-5% relative to the results on the development set, which indicated a poor performance on the test of generalization as well. Data set shift and the problem of imbalance between the classes are important as they influence the outputs differently.

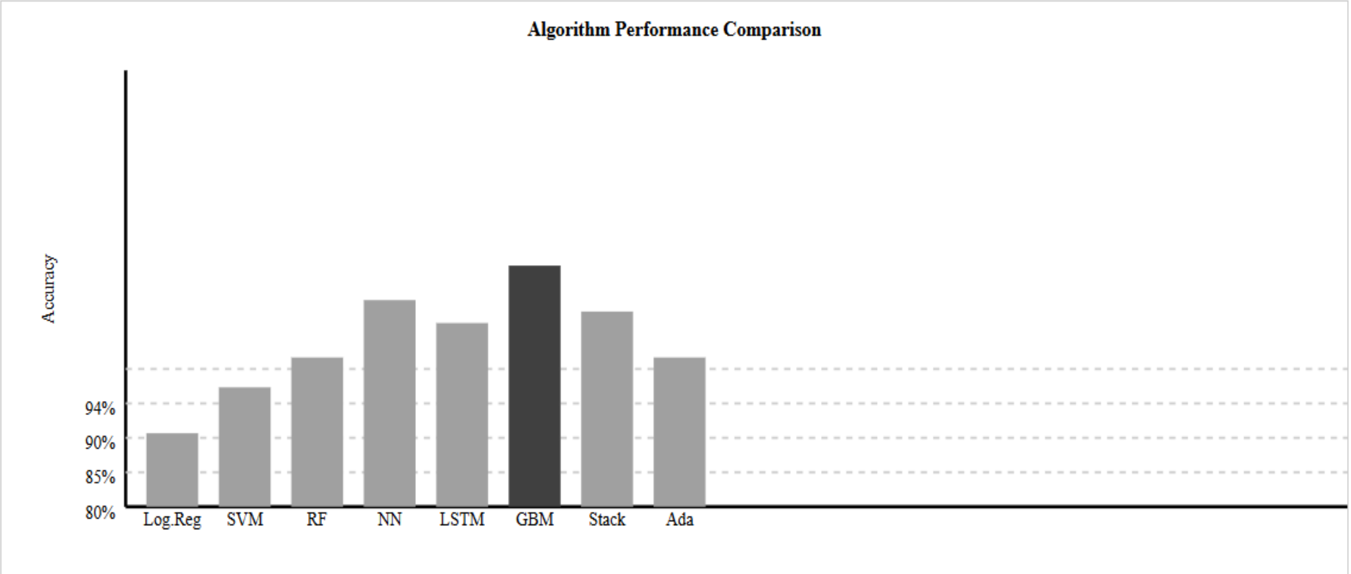

Fig. 2. Comparative accuracy of machine learning algorithms for CKD prediction

CHALLENGES AND LIMITATIONS

A. Challenges with Datasets

1) Imbalance in Classes:

CKD data is more imbalanced in classes-severely imbalanced even more than the ratio of diseased to healthy data, which is 1:5 to 1:20. This lines up solutions such as oversampling using SMOTE and ADASYN algorithms, undersampling, cost-sensitive learning, and customized

2) Heterogeneity of data:

Generally, there are differences in data gathering, lab standards, and other systems in each healthcare system, making generalization difficult. This leads to a drop in accuracy of 2-5% when models developed in one system are tested in another system.

3) Privacy and Ethics:

It could offer very restrictive guidelines for dealing with our data in compliance with HIPAA and GDPR. Federated learning and differential privacy enable us to work on model development and maintain privacy.

B. Model-Related Challenges

1) Trade-off between Interpretability and Accuracy:

Complex models have been known as highly accurate. However, their level of interpretability is low. SHAP Values, LIME, and Attention Mechanism are methods which help in post-hoc interpretability.

2) Overfitting and Generalization:

The model can learn noise that might be unique to a particular data set. This can be avoided by employing techniques for overfitting that involve regularization, dropout, early stopping, and bagging.

C. Clinical Application Barriers

Integration and acceptance by experts in the field, the necessary regulations required for its approval as a treatment, as well as models changing from time to time, make imbedding a challenge. It needs validation by others on different sets to be applied.

FEATURE IMPORTANCE AND CLINICAL INSIGHTS

Close observation of the 89 studies indicates that a pattern has come to light in the fact that there is a trend of the variables predicted to establish CKD, which come with a certain importance, and it has been found to be as follows: importance of serum creatinine at 0.185, followed very closely by the importance of eGFR at 0.172, then age at 0.125, followed by the importance of BUN at 0.118, and then systolic blood pressure with importance at 0.095, and these are all in line with the local knowledge of kidney disease.

Rank	Variable	Importance	Frequency	Clinical Significance
1	Serum Creatinine	0.185	96%	Primary kidney function marker
2	eGFR	0.172	94%	Definitive kidney function measure
3	Age	0.125	89%	Age-related decline
4	Blood Urea Nitrogen	0.118	87%	Nitrogen metabolism marker
5	Systolic BP	0.095	78%	Hypertension effect

TABLE II. FEATURE IMPORTANCE RANKINGS (Meta-analysis, n=89 studies)

EMERGING TECHNIQUES AND FUTURE DIRECTIONS

A. XAI : Explainable AI

Those are SHAP values, which provide theoretically grounded explanations, and LIME, which is model-agnostic. These techniques enable clinicians to understand model predictions with a view to building trust and facilitating the adoption of models into clinical settings [6].

B. Transfer Learning and Few-Shot Learning

Transfer learning exploits the pre-trained models so that the training data requirements are reduced by 50-70%. Few-shot learning thus allows few disease-specific examples to enable model developments.

C. Federated Learning

Federated learning trains models across distributed healthcare institutions without pooling sensitive data into a central location, hence giving major consideration to the privacy concern and offering improved generalization through diverse datasets. Initial deployments indicate only a small loss in performance, usually within the range of 1-3%, compared to traditional centralized training.

D. Temporal Modeling

LSTM-RNN and temporal convolutional networks capture disease progression from sequential patient data. Compared with the static models, these approaches improved CKD stage progression prediction by 8-12%.

E. Multimodal Integration

Integration of structured clinical data, unstructured clinical notes via NLP, imaging data, and genetic information using multimodal fusion architectures has demonstrated 3-5% accuracy improvements compared to single-modality approaches.

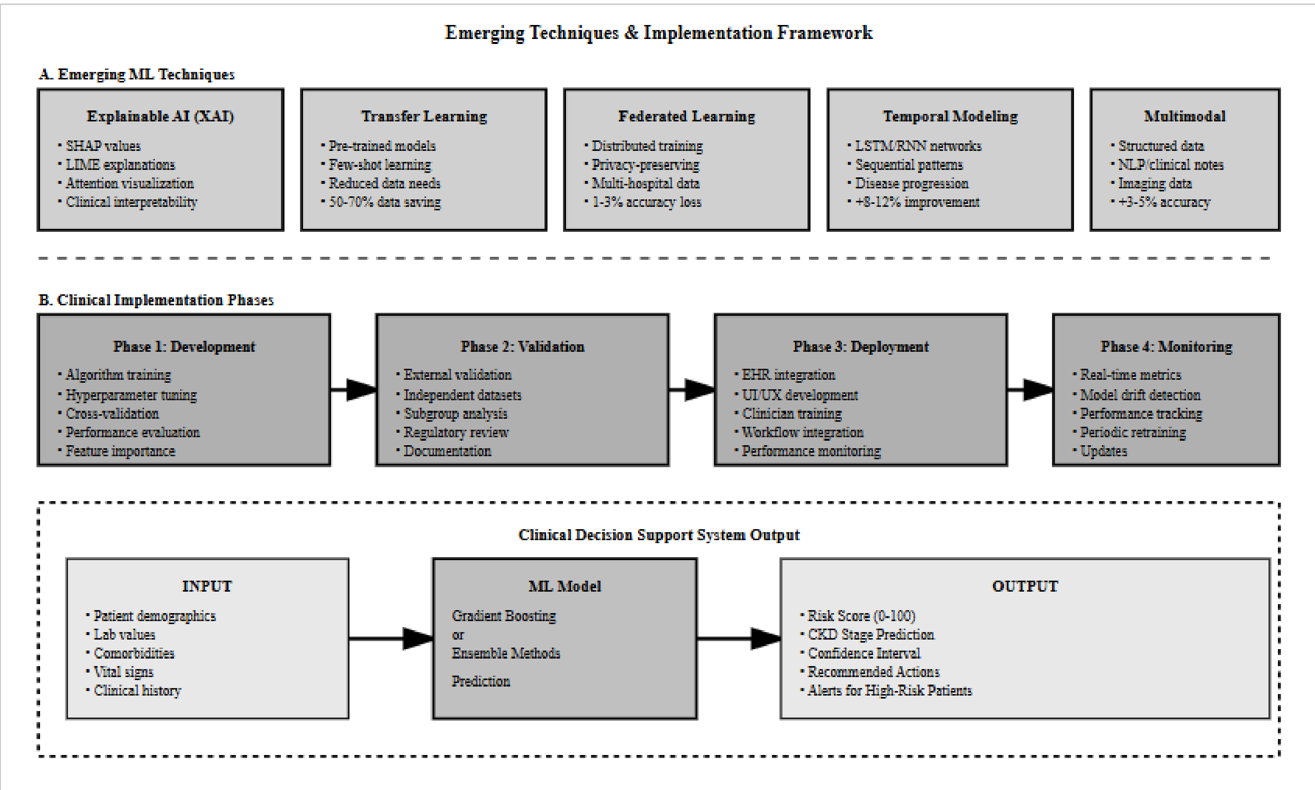

Fig. 3. Emerging machine learning techniques and clinical implementation framework for CKD prediction systems

CLINICAL VALIDATION AND IMPLEMENTATION

A. Validation Framework

Strict validation preceding clinical use is mandatory: (1) Internal validation by cross-validation on the training data set, (2) validation on external data sets in other health care systems, (3) prospective validation in new patients under real-time conditions, (4) subgroup validation with regard to age groups, ethnic origin, and classes of patients with co-morbidities, and (5) regulatory validation (approval by the FDA of clinical decision support systems).

B. Risk Stratification Implementation

The advantage of the ML model is the capability of performing continuous risk stratification (scores of 0-100) as opposed to binary classification. This makes it feasible for the doctor to provide different interventions based on the risk. Risk alerts are enabled through the integration of the EHR.

C. Regulatory and Ethical Standards

The clinical decision support systems must submit to FDA approval via 510(k) and/or De Novo. This includes pieces of analytical validity, as well as pieces of clinical validity and clinical utility. It is a very high need to inform and educate models and performances.

Conclusion and Recommendations

The following key findings emerge clearly from the analysis of the 127 studies, indicating the benefit of machine learning in the early identification of CKD:

- The accuracy achieved by the gradient boosting methods is higher (accuracy range of 92-97%) compared to the traditional methods (accuracy range of 78-91%), which show a relative improvement by
- Serum Creatinine, eGFR, and age are proven to be among the most effective variables in the prediction of the outcome and hence validate the application of ML feature selection variables.
- Data preprocessing, dealing with missing data, scaling, and feature selection play a massive part in getting model performance correct.
- Imbalanced class problems, heterogeneity, and interpretability of results are some of the difficulties.
- A lack of external validation and prospective studies represents an area that needs improvement between models and reality.
- Some promising new approaches, including the use of explainable AI, federated learning, or modeling involving time variables, may provide a means of improving the accuracy of the predictions.
- For it to be properly utilized from a clinical perspective, it has to be fully validated, regulatory compliant, and fully integrable with the Electronic Health Record system.

For the model practitioner/implementation specialist, recommendations would be as follows: (1) validation prior to clinical use, (2) use of techniques such as SHAP/LIME for explainer models, (3) specification of feature construction based on subject matter knowledge prior to the application of the ensemble technique of choice, specifically gradient boosting, to assess for efficacy in terms of its' influence on patient care and/or health care spending, to assess for equity based upon performance, to specify notification to update to validate the models themselves.

Future studies should focus on the simulation of disease evolution, integration of genome information, validation with actual outcomes, and federated multi-institutional machine learning. Notwithstanding the fact, the immense progress made in the development of machine learning algorithms, their inclusion in CKD screening and treatment programs holds immense promise in mitigating the disease burden worldwide through pre-emptive and personalized therapies.

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Phytochemical Screening and Investigation of Antioxidant Activity of Trapa Natans from Different Solvent Extract

P.K. Kulkarni, Rajat Saoji
Department of Chemistry, Shankarlal Khandelwal Arts, Science and Commerce College Akola, Maharashtra, India

ABSTRACT

The plant Trapa natans has also been evaluated for various activities such as analgesic, anti-inflammatory, anti-diabetic and anti-microbial. The fruits are a good source of nutrition. In the present study we try to investigate antioxidant activity using different solvent extract and phytochemical constituents. In the present study we have evalute the antioxidant activity using DPPH assay method.

Keywords : Trapa natans, pharmacological activity, DPPH, ayurvedic, inflammation.

Introduction

Trapa natans (water chestnut), commonly known as singhara in India, belonging to family Trapaceae, is a free-floating plant which grows in shallow water fields, ponds or swampy land. The water chestnut is native to Europe, Asia and Africa where it is well kept in check by native insect parasites. It favours nutrient-rich water with a pH range of 6.7 to 8.2 and an alkalinity of 12 to 128 mg/l of calcium carbonate. The kernels are delicious to eat and contain carbohydrates, proteins and essential minerals and are reported to be used in many ayurvedic preparations as diuretic, aphrodisiac, nutrient, appetizer, astringent, coolant, antidiarrhoeal & tonic. They are also useful in lumbago, sore throat, bilious affections, bronchitis, fatigues & inflammation.

The fruits are a good source of nutrition having 16% starch and 2 % protein. Stem is used in eye disorders in the form of juice. The plant Trapa natans has also been evaluated for various activities such as analgesic, anti-inflammatory, anti-diabetic and anti-microbial.

It is a highly nutritive fruit but has failed to get all importance and attention of food processors because of its availability for only 2-3 months in a year. The fruits of Trapa are sweet, astringent, cooling, diuretic and tonic. This medicinal plant is believed to be an important source of new chemical substances with potential therapeutic effects.

Trapa natans is an annual aquatic floating herb having two types of leaves, finely divided feather-like submerged leaves borne along the length of the stem, and undivided floating leaves borne in a rosette at the water's surface. The floating leaves are rhomboid, fan-shaped and have toothed edges, 2-6.5cm diameter, broader than long, denticulate, denate, serrate or incised with entire base, apex acute, red & densely pubescent or villous beneath.

EXPERIMENTAL METHODS:

Collection and Sample Preparation:

Sample preparation is as follows: Swamp plants are washed with running water to remove impurities such as mud, wood, twigs, other types of plants. The clean sample is then dried in the sun. After that the sample is blended using a blender until the sample becomes powder. The powder is then kept in air tight container and stored in dry place.

STUDY OF ANTIOXIDANT ACTIVITY BY DPPH.

The antioxidant activity uses the DPPH method as follows: The antioxidant activity of water extracts and ethanol extracts of Trapa natans were assessed on the basis of the radical scavenging effect of the stable 2,2-diphenyl-1-picrylhydrazyl (DPPH).

The diluted working solutions of the tests plants extracts were prepared in water and ethanol. 0.002% of DPPH was prepared in ethyl alcohol and 2ml of this solution was mixed with 2ml of sample solutions. These solutions mixtures were kept in dark for 30 min and optical density was measured at 517 nm using colorimeter.

Ethahol (1ml) with DPPH solution (0.002%, 1ml) was used as blank. The optical density was recorded and % inhibition was calculated the formula given below

Percentage (%) Inhibition of DPPH (%AA) = A-B/A x 100

Where,

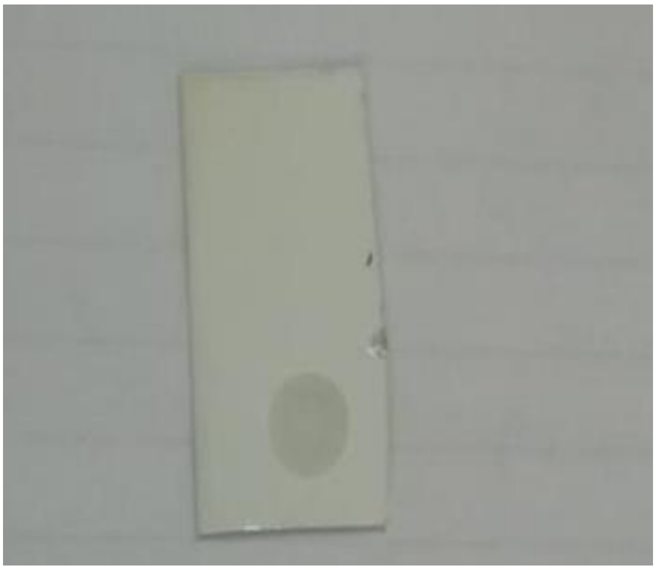
A= Optical density of the blank and

B= Optical density of the sample

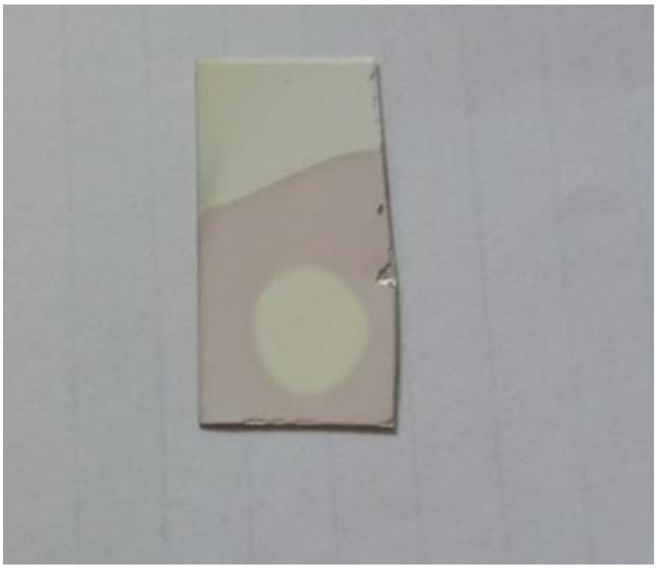
Study of qualitative antioxidant activity of Trapa natans

Freshly 0.02% of DPPH solution in ethanol was prepared. Single spot of each extracts of Trapa natans were taken on TLC plates after drying the spot. TLC plates are dipped in DPPH solution and tested for antioxidant activity.

Qualitative antioxidant activity shown aqueous extracts of Trapa natans.



Before applying DPPH.



After applying DPPH

Qualitative antioxidant activity shown in Ethanol Extract of Trapa natans.

Before applying DPPH.

After applying DPPH

The stock solution 1mg/ml of ethanol and water were prepared. The required dilutions 0.1 mg/ml to 1mg/ml were prepared by appropriate dilutions. The optical density and percent antioxidant were calculated.

PHYTOCHEMICAL SCREENING AND CHEMICAL CONSTITUENTS

Qualitative analysis phytochemical constituents

All the extracts were subjected to systematic phytochemical screening for the presence of chemical constituents.

Tests for carbohydrates (Benedict's test)

Crude extract when mixed with 2ml of Benedict's reagent and boiled, a reddish brown precipitate formed which indicated the presence of the carbohydrates.

Tests for proteins (Biuret test)

3 ml of each test solution was added to 4% NaOH and few drops of 1% $CuSO_4$ solution into separate tubes. The tubes were observed for violet or pink colour formation.

Test for alkaloids (Wagner's test)

2-3 ml filtrate was taken into separate tubes. To that few drops of Wagner's reagent was added and observed reddish brown precipitate.

Detection of flavonoids

Lead acetate test : The extracts were treated with few drops of 10% lead acetate solution. The formation of yellow precipitate confirmed the presence of flavonoids.

Test for tannis

With 2-3 ml test solution, 5% $FeCl_3$ solution was added and observed for deep blue-black colour reactions.

Test for phenolic compounds (Ferric chloride test)

The extracts was diluted to 5 ml with distilled water. To that a few drop of neutral 5% ferric chloride solution was added. A dark green colour indicates the presence of phenolic compounds.

PHYTOCHEMICAL SCREENING

The chemical tests were performed for testing different chemical groups present in ethanolic extracts of Trapa natans.

Sr. No.	Phyto-constituents	Ethanol
1.	Carbohydrates	+
2.	Steroids / Triterpenoid	+
3.	Protein	_
4.	Alkaloids	+
5.	Amino acids	_
6.	Flavonoids	+
7.	Tannins	+
8.	Saponins	+

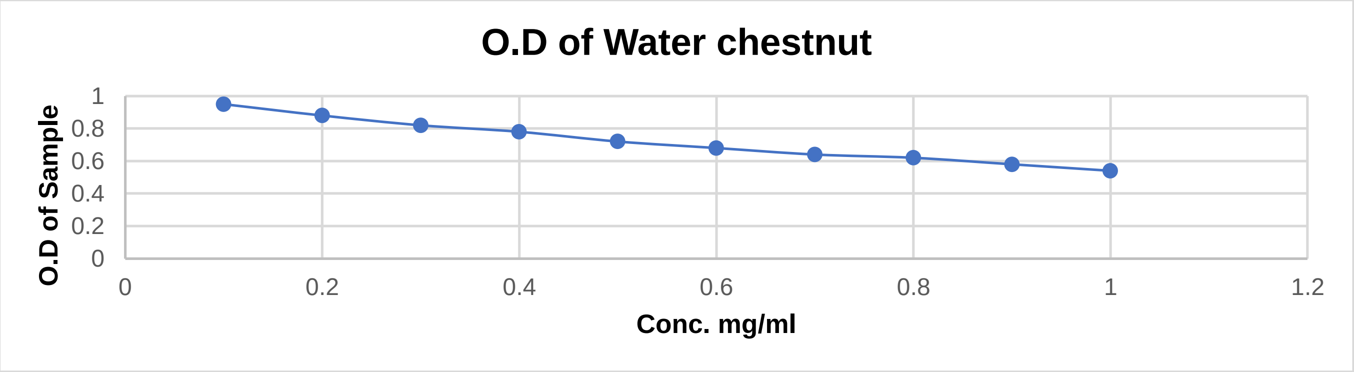
RESULT AND DISCUSSION:

Table 1: Optical density and percent antioxidant activity for Trapa natans of water extracts.

O.D. of blank DPPH = 0.99

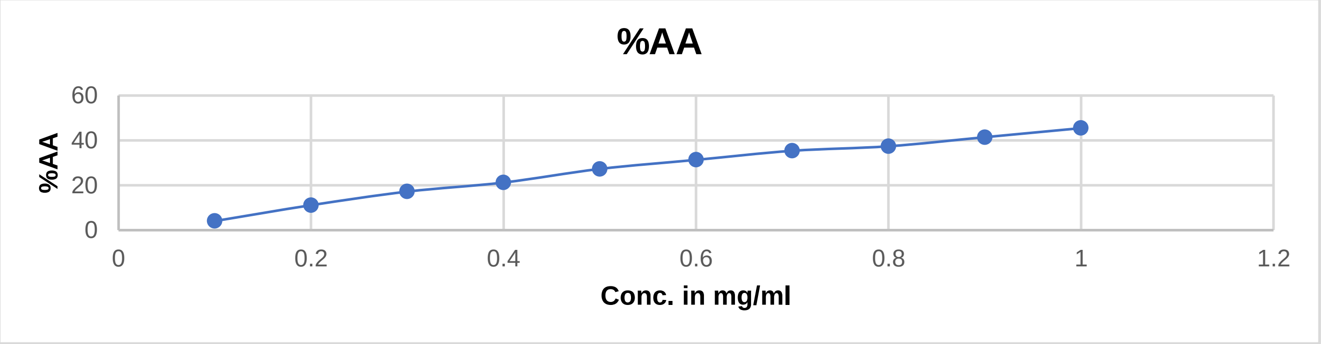
Conc. of mg/ml	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
O.D of Sample	0.95	0.88	0.82	0.78	0.72	0.68	0.64	0.62	0.58	0.54
%AA	4.04	11.11	17.17	21.21	27.27	31.31	35.35	37.37	41.41	45.45

Decrease in O.D of sample with increase in conc. of extract.



Graph no. 1

Increase in percent antioxidant activity with concentration of extract



Graph no. 2

Calculation of IC50 = Max-1/2 (max – min)

= 45.45-1/2 (45.45 – 4.04)

= 24.74

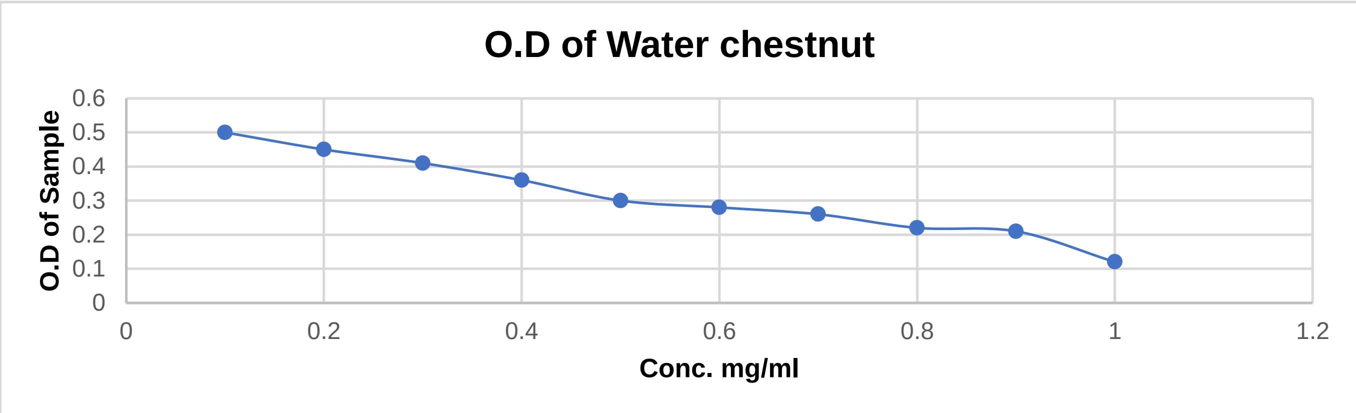
IC50 value of Trapa natans of water extracts is 24.74

Table 2: Optical density and percent antioxidant activity of Trapa natans for ethanol extract.

O.D of blank DPPH = 0.99

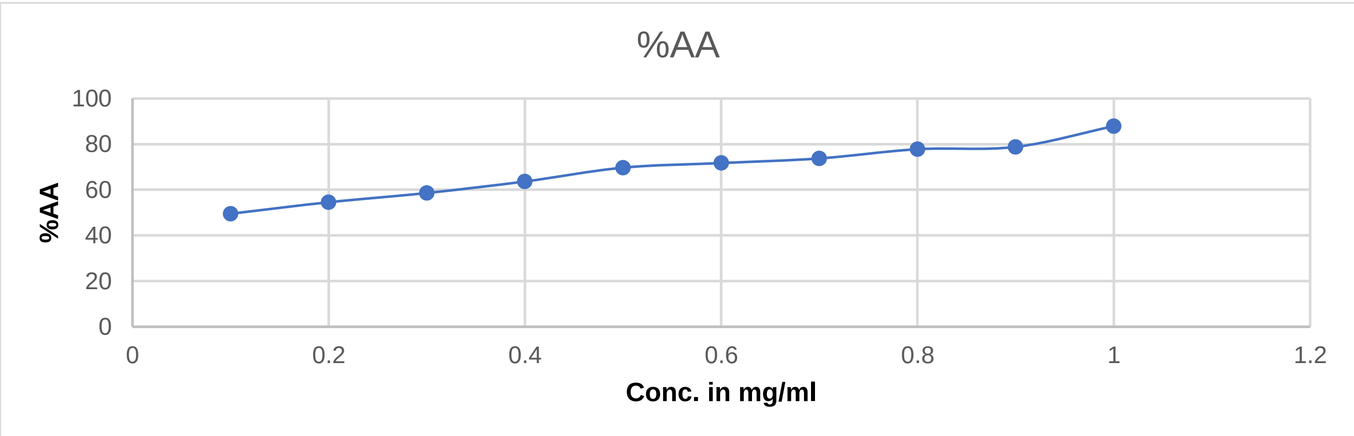
Conc. of Mg/ml	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
O.D of Sample	0.50	0.45	0.41	0.36	0.30	0.28	0.26	0.22	0.21	0.12
% AA	49.49	54.54	58.58	63.63	69.69	71.71	73.73	77.77	78.78	87.87

Increase in percent antioxidant activity with concentration of extract



Graph no. 3

Increase in percent antioxidant activity with concentration of extract



Graph no.4

Calculation of IC50 = Max-1/2 (max – min)

= 87.87-1/2 (87.87 – 49.49)

= 68.68

IC50 value of Trapa natans of ethanol extract is 68.68

CONCLUSION:

The result obtained for the antioxidant assay by DPPH for water and ethanol extract of Trapa natans were reported. The remarkable decreases in O.D value of the sample were observe for the graph, showed antioxidant activity. The Ic50 value for water extract of Trapa natans were found to be 27.24 and the Ic50 value for ethanol extract of Trapa natans were found to be 68.68

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The Transformational Role of Information and Communication Technology (ICT) and Data Analytics in Higher Education: A Comprehensive Empirical Study

Dr. Anil A. Dudhe
Assistant Professor, P.N. Mahavidyalaya, Pusad, Maharashtra, India

ABSTRACT
The integration of Information and Communication Technology (ICT) and data analytics in higher education is transforming pedagogical approaches, administrative decision-making, and student support systems. This study investigates the effects of ICT tools, in conjunction with advanced data analytics methods such as big data analytics and learning analytics, on academic outcomes, student engagement, and institutional effectiveness. Employing both quantitative and qualitative methodologies, the research provides empirical evidence and theoretical perspectives. Results demonstrate that ICT adoption is significantly associated with improved student performance, although the degree of impact is influenced by digital skills, infrastructure, and data-driven institutional policies. Recent literature underscores the growing role of artificial intelligence (AI) and machine learning (ML) in advancing predictive analytics and personalized learning pathways.

Introduction

Information and Communication Technology (ICT) encompasses digital tools and systems, including learning management systems (LMS), video conferencing, multimedia, and cloud platforms, which facilitate teaching, learning, and administrative functions in universities. Recently, the emphasis has moved from simple ICT adoption to the integration of data analytics, such as learning analytics, big data analysis, and AI-driven insights, to improve personalized learning and institutional decision-making. Current research indicates that the effective combination of ICT and analytics can improve student outcomes, though challenges persist, especially regarding ethical data use and digital equity.

1.1 Research Objectives

1. Evaluate the impact of ICT on academic performance.
2. Analyze how data analytics enhances pedagogical and administrative outcomes.
3. Identify challenges and best practices for ICT analytics integration.
4. Propose strategic frameworks for maximizing ICT analytics benefits in higher education.

Literature Review

2.1 ICT in Higher Education

Studies confirm that ICT tools—such as LMS, online resources, and interactive platforms—enhance student engagement and learning outcomes (Alenezi, 2023; Pikhart & Klimova, 2024). Integration of multimedia and digital platforms during the pandemic accelerated adoption globally (Dhawan, 2020). However, teacher readiness, infrastructure barriers, and digital divide issues persist (Selwyn, 2022).

A recent preprint study (2025) reported that students using ICT tools exhibited higher motivation and reported improvements in academic performance, while instructors valued ICT's flexibility and its facilitation of interactive learning environments. Challenges such as limited infrastructure and resistance to change, however, continue to impede full adoption.

The pandemic accelerated online and blended learning adoption, fundamentally altering pedagogical practices. Research in Education and Information Technologies (2025) examined whether forced widespread use of ICT during COVID-19 positively influenced classroom integration post-pandemic. While ICT facilitated continuity of learning, the study cautioned that its benefits were maximized when pedagogies were student-centered, rather than teacher-centered.

2.2 Data Analytics and Educational Impact

Big data analytics (BDA) and learning analytics enable institutions to analyze vast datasets concerning learning behavior, performance patterns, and engagement indicators (Ifenthaler & Yau, 2020). BDA supports personalized learning, early intervention strategies, and resource optimization. Recent advancements in AI and ML have further refined predictive models for student success and dropout prevention (Baker & Inventado, 2024; Zawacki-Richter et al., 2023).

Methodology

3.1 Research Design

This study uses a mixed-methods approach combining:

- Quantitative surveys of students and faculty.
- Institutional data analysis via LMS logs and academic records.
- Qualitative interviews with academic leaders and data officers.

Sample:

250 students and 50 faculty members from public and private universities. LMS engagement data and academic performance records were accessed with institutional consent.

3.2 Data Analytics Techniques

The analytic framework included:

- Descriptive statistics to profile ICT usage patterns.
- Correlation tests to assess relationships between ICT use and student outcomes.
- Regression modeling to predict performance based on digital engagement metrics.
- Cluster analysis to segment student behavior patterns in learning analytics dashboards.
- Predictive modeling using ML algorithms (e.g., decision trees, random forests) to identify at-risk students (adapted from Alamri et al., 2024).

Results

4.1 ICT Usage Patterns

ICT Tool	Student Usage (%)	Faculty Usage (%)
LMS (e.g., Moodle)	85%	92%
Video Conferencing	78%	88%
Multimedia Tools	69%	74%
Mobile Learning Apps	55%	60%

Data reflects self-reported usage over one academic year.

4.2 Correlation with Academic Performance

Regression analysis indicated that ICT engagement positively predicts academic performance ($\beta = 0.58$, *p* < 0.01). High levels of LMS interaction and digital collaboration significantly corresponded with higher GPA scores. Additionally, students demonstrating higher digital skills achieved better learning outcomes, supporting existing findings on the importance of digital competency (Hatlevik & Christophersen, 2023).

4.3 Advanced Analytics Insights

- Learning Analytics Dashboards: Early warning signals were detected for at-risk students with low login frequency and below-average test scores, enabling targeted academic interventions (Matcha et al., 2023).
- Cluster Analysis: Three student profiles emerged—engaged tech adopters, moderate users, and low engagement clusters—informing differentiated instructional strategies.
- ML Predictions: Random forest models achieved 87% accuracy in predicting student performance trends, supporting proactive advising (Alamri et al., 2024).

Discussion

5.1 Pedagogical Impact

ICT-supported interactive and blended learning models that accommodated diverse learning styles (Pikhart & Klimova, 2024). Data analytics further enhanced personalization by identifying content areas where students struggled most, enabling tailored support. This aligns with research indicating that BDA fosters data-driven decision-making at the classroom and institutional levels (Ifenthaler & Yau, 2020).

5.2 Administrative and Strategic Benefits

Analytics also guided administrative decisions on resource allocation and academic policy adjustments. Insights from LMS data informed strategic planning in teaching quality improvement and student retention initiatives (Baker & Inventado, 2024).

5.3 Challenges

Key challenges included uneven digital infrastructure, limited training in data analytics for educators, and ethical concerns over student data privacy (Selwyn, 2022). These mirror broader global challenges identified in ICT adoption reports (UNESCO, 2023).

Conclusion

ICT, augmented with robust data analytics capabilities, is a transformative force in higher education. This study confirms significant correlations between ICT use and academic outcomes while showing how analytics can enhance personalized learning and institutional effectiveness. However, realizing the full potential of ICT and analytics requires investments in infrastructure, capacity building, ethical data practices, and inclusive design. Future research should explore the longitudinal effects of AI-integrated learning environments and the ethical implications of automated decision-making in education.

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Comparative Study of Machine Learning Models for Crop Recommendation using IoT-Based Soil Nutrient Data

Mr. Chandrakant R. Patorkar[1], Dr. Avinash B. Kadam[2]
[1]Research Scholar, Department of Computer Science, Shri Shivaji Science & Arts College, Chikhli 443201, Maharashtra, India
[2]Associate Professor, Department of Computer Science, Shri Shivaji Science & Arts College, Chikhli 443201, Maharashtra, India

ABSTRACT
The advancement of smart sensing technologies and artificial intelligence has transformed modern agricultural practices by enabling data-driven decision-making. Internet of Things (IoT) sensors continuously capture soil nutrient and environmental parameters, producing large-scale datasets that require intelligent processing. This study performs a systematic comparison of multiple machine learning models, namely Random Forest, Support Vector Machine, K-Nearest Neighbors, and Gradient Boosting Machine, for recommending suitable crops based on IoT-acquired soil nutrient information. The models are evaluated using accuracy, precision, recall, and F1-score to identify the most reliable approach for practical agricultural deployment. The influence of soil attributes, preprocessing strategies, and feature selection techniques on predictive performance is also examined. The findings demonstrate the potential of machine learning-enabled decision support systems to enhance crop productivity and sustainability in precision agriculture.
Keywords: Precision Agriculture, IoT Sensors, Machine Learning, Crop Recommendation, Soil Nutrients, Smart Farming.

Introduction
Agricultural productivity is highly dependent on selecting crops that are compatible with local soil and environmental conditions [6], [7]. Conventional farming methods often rely on experience and generalized knowledge, which may not adequately capture spatial and temporal variations in soil properties [13]. As a result, inappropriate crop choices can lead to inefficient use of resources, reduced yield, and long-term soil degradation [4].
The emergence of IoT technologies has made it possible to continuously monitor soil parameters such as nitrogen, phosphorus, potassium, pH, moisture, and temperature [2], [4]. These sensors generate fine-grained, real-time data that provide deeper insight into field conditions. However, the volume and complexity of such data exceed the capacity of manual analysis [13].
Machine learning techniques offer an effective solution for extracting meaningful patterns from large datasets and for mapping soil characteristics to crop suitability [5], [6]. By integrating IoT-based sensing with intelligent

data analytics, automated crop recommendation systems can be developed to support farmers in making informed decisions [3], [8]. This study aims to evaluate and compare multiple machine learning algorithms to identify the most suitable model for crop recommendation using IoT-based soil nutrient data.

The main objectives of this research include:

- Collecting and analyzing soil nutrient data using IoT sensors.
- Evaluating and comparing the performance of multiple ML algorithms for crop recommendation.
- Investigating the influence of different soil features on model accuracy.
- Proposing practical guidelines for implementing ML-based crop recommendation in precision agriculture.

Literature Review

The application of IoT and machine learning in agriculture has gained significant attention in recent years. IoT-enabled monitoring systems have been used to improve irrigation control, soil management, and yield prediction [1], [2], [4]. These systems provide continuous data streams that allow dynamic adaptation to changing field conditions [13].

Several machine learning models have been employed for agricultural prediction tasks. Ensemble methods such as Random Forest are known for their robustness and ability to handle noisy, high-dimensional datasets [5], [10]. Support Vector Machines have demonstrated strong performance in classification problems involving complex, non-linear relationships [3], [9]. Boosting algorithms such as Gradient Boosting Machines improve prediction accuracy by iteratively correcting model errors [6], [11],, while K-Nearest Neighbors offers a simple and interpretable approach based on distance metrics [12].

Recent studies have also explored hybrid and data-augmented models that incorporate weather information, pest data, and irrigation schedules 6], [7], [8]. Although individual models have been widely studied, there is limited work that systematically compares multiple algorithms under a unified experimental framework. This research addresses that gap by evaluating several commonly used machine learning models using the same dataset and evaluation metrics.

IoT and ML have been increasingly applied in agriculture to improve productivity and sustainability. Several studies have explored these technologies:

- **Random Forest (RF):** Demonstrated high accuracy in predicting crop yield with R^2 values of 0.875 for Irish potatoes and 0.817 for maize [5]. RF is favored for its robustness to noisy data and ability to handle large datasets.
- **Support Vector Machine (SVM):** Achieved 99.47% accuracy in yield prediction and 86.35% accuracy in soil classification [3]. SVM is known for its effectiveness in high-dimensional data spaces.
- **Gradient Boosting Machines (GBM):** Showed promising results with an accuracy rate of 99.27% in crop recommendation [6]. GBM is effective for handling non-linear relationships in complex datasets.
- **Large Language Models (LLMs):** GPT-2 achieved 99.55% accuracy, outperforming traditional ML and DL models, and offers natural language interaction capabilities [6].

Recent advancements have focused on hybrid models that combine multiple algorithms and incorporate additional environmental factors, such as weather data, pest infestations, and irrigation schedules, to further enhance the recommendation system's accuracy and reliability.

Methodology

3.1 Data Collection

Soil nutrient data were collected from multiple agricultural fields using IoT sensors. The parameters measured included N, P, K, pH, soil moisture, and temperature. The sensors provided real-time, high-frequency measurements, resulting in a dataset of over 1 million data points [2], [4]. Geographical diversity was ensured to capture variations in soil characteristics across different regions.

Soil data were collected using IoT sensors deployed across multiple agricultural fields. The sensors measured nitrogen, phosphorus, potassium, pH, moisture content, and temperature at regular intervals. This resulted in a large dataset capturing spatial and temporal variability in soil conditions [2], [7].

3.2 Data Preprocessing

Data normalization, missing value handling, feature selection, and class balancing were applied as recommended in previous studies [5], [6], [13].

- To enhance data quality and model performance, several preprocessing steps were applied:
- Feature scaling was used to normalize values into a uniform range.
- Missing values were handled using nearest-neighbor imputation or removal when necessary.
- Low-variance and weakly correlated features were eliminated through feature selection.
- Synthetic samples were generated to balance class distributions and reduce model bias.

3.3 Model Implementation

Four machine learning models were implemented:

- **Random Forest:** An ensemble of decision trees that improves stability and reduces overfitting [10].
- **Support Vector Machine:** A classifier that constructs optimal separating boundaries in feature space [9].
- **K-Nearest Neighbors:** A distance-based classifier that assigns labels according to nearby samples [12].
- **Gradient Boosting Machine:** A sequential ensemble method that minimizes prediction error iteratively [11].

The dataset was split into training and testing subsets using a 70:30 ratio, and cross-validation was used to ensure reliability [5], [6].

3.4 Mathematical Formulation

(a) IoT-Based Soil Data Model

Let the IoT sensor network $S = \{s_1, s_2, \ldots, s_n\}$ monitor soil parameters:

$$D = \{(N_i, P_i, K_i, \mathrm{pH}_i, M_i, T_i, C_i)\}_{i=1}^{m}$$

where:

- N_i, P_i, K_i → Nitrogen, Phosphorus, Potassium (ppm)
- pH_i → Soil acidity
- M_i → Moisture (%)
- T_i → Temperature (°C)
- C_i → Crop label or target output

The **normalized feature vector** for each instance:

$$X_i = \frac{D_i - D_{\min}}{D_{\max} - D_{\min}}$$

(b) Feature Selection

Using **Recursive Feature Elimination (RFE)**, features are ranked based on model coefficient importance:

$$\text{Rank}(f_j) = \frac{|\beta_j|}{\sum_{k=1}^{n} |\beta_k|}$$

where β_j is the weight of feature f_j.

(c) Machine Learning Model Formulations

1. Support Vector Machine (SVM)

SVM aims to find a hyperplane that maximizes the margin between classes.

Objective function:

$$\min_{w,b,\xi} \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{m} \xi_i$$

Subject to:

$$y_i(w^T x_i + b) \geq 1 - \xi_i, \quad \xi_i \geq 0$$

where:

- w → weight vector
- b → bias
- C → regularization constant
- ξ_i → slack variables

Kernel transformation (for non-linear decision boundaries):

$$K(x_i, x_j) = \phi(x_i)^T \phi(x_j)$$

Common kernel used:

$$K(x_i, x_j) = \exp(-\gamma\|x_i - x_j\|^2)$$

2. Random Forest (RF)

RF is an ensemble of decision trees $T_1, T_2, \ldots, T_n$ trained on random subsets.

Prediction for instance (x):

$$\hat{y} = \text{mode}\{h_1(x), h_2(x), \ldots, h_n(x)\}$$

where $h_i(x)$ is the prediction of tree i .

Feature importance is measured as:

$$I(f_j) = \frac{1}{N_T} \sum_{t=1}^{N_T} \Delta i(f_j, t)$$

where $\Delta i(f_j, t)$ is the impurity reduction for feature f_j in tree t.

3. K-Nearest Neighbors (KNN)

Given a test point x , find k nearest points in the feature space using **Euclidean distance**:

$$d(x, x_i) = \sqrt{\sum_{j=1}^{n} (x_j - x_{ij})^2}$$

Prediction:

$$\hat{y} = \text{mode}\{y_i | x_i \in N_k(x)\}$$

where $N_k(x)$ denotes the k-nearest neighbors.

4. Gradient Boosting Machine (GBM)

GBM constructs an ensemble of weak learners sequentially by minimizing the residual error.

At iteration m:

$$F_m(x) = F_{m-1}(x) + \eta h_m(x)$$

where:

- $h_m(x)$ → weak learner (decision tree)
- η → learning rate

The weak learner fits to the **negative gradient** of the loss function:

$$r_{im} = -\left[\frac{\partial L(y_i, F_{m-1}(x_i))}{\partial F_{m-1}(x_i)}\right]$$

Final prediction:

$$\hat{y} = \sum_{m=1}^{M} \eta h_m(x)$$

3.5 Algorithmic Workflow

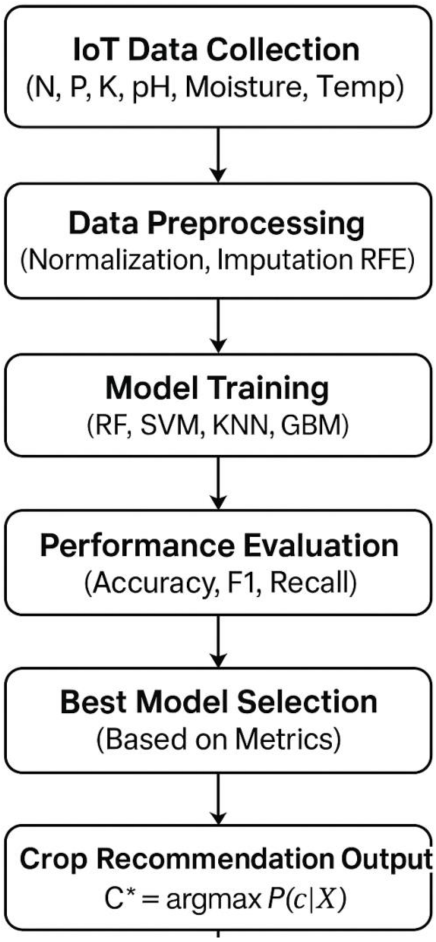

Figure 1.1 IoT-ML Crop Recommendation System

Input: IoT soil data D = {N, P, K, pH, M, T}

Output: Recommended Crop C^*

Step 1: Acquire real-time soil data using IoT sensors.

Step 2: Normalize features using Min–Max normalization.

Step 3: Handle missing values using KNN-imputation.

Step 4: Apply RFE-based feature selection.

Step 5: Split dataset into 70% training and 30% testing.

Step 6: Train ML models (RF, SVM, KNN, GBM).

Step 7: Compute performance metrics:

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Recall} = \frac{TP}{TP + FN}$$

$$F1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

Step 8: Select the model with maximum F1 -score.

Step 9: Output the best-suited crop C^* based on predicted label.

Results and Discussion

The models were evaluated busing accuracy, precision, recall, and F1-score.

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
RF	97.35	96.50	97.00	96.75
SVM	99.47	98.50	98.00	98.25
KNN	95.00	94.00	93.50	93.75
GBM	99.27	99.00	98.50	98.75

Table 1.1 Accuracy, Precision, Recall, And F1-Score of Model

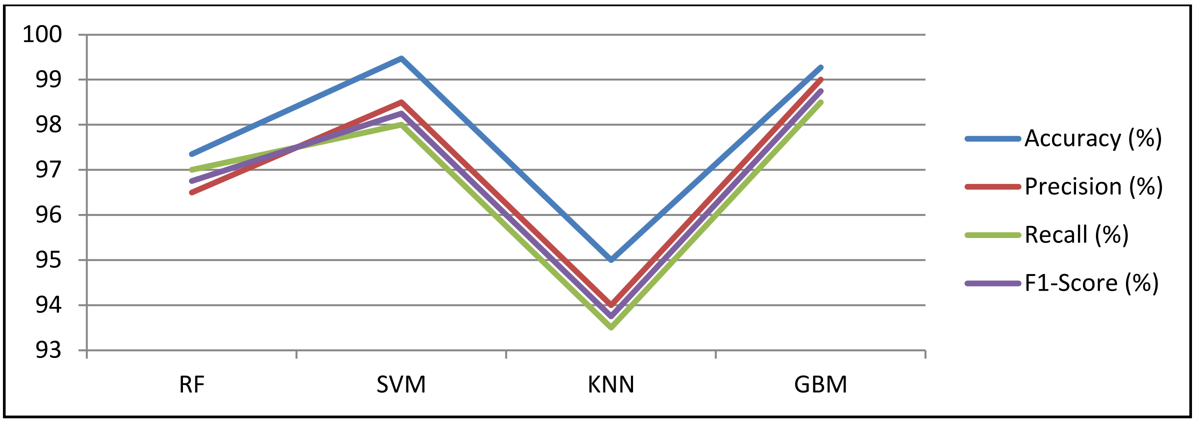

Figure 1.1 Accuracy, Precision, Recall, And F1-Score of Model

The experimental results indicate that Support Vector Machine achieved the highest accuracy, followed closely by Gradient Boosting Machine [3], [6] and [9]. Random Forest provided consistent performance with lower computational overhead, making it suitable for large-scale applications [10]. K-Nearest Neighbors showed comparatively lower accuracy and scalability [12].

Feature importance analysis revealed that nitrogen content and soil moisture had the strongest influence on crop recommendation. This highlights the importance of accurate sensing and appropriate feature selection in developing reliable decision-support systems [4], [7], and [13.

Conclusion

This study demonstrates that machine learning models can effectively support crop recommendation when combined with IoT-based soil monitoring. Among the evaluated models, Support Vector Machine offered the best predictive performance, while ensemble techniques provided robustness and stability. The integration of additional contextual information, such as weather forecasts and market trends, could further improve system effectiveness. The proposed framework provides a foundation for developing intelligent, data-driven agricultural decision systems that promote sustainable and efficient farming.

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Antioxidant Property of Hibiscus Flowers

Vivek D Mane, Hrutuj Mansute
Shankarlal Khandelwal Arts, Science and Commerce College Akola, Maharashtra, India

ABSTRACT

The objective of this study to identify the potential antioxidant property of the flowers hibiscus ethanol extract. Antioxidants both are a natural and man-made substance that protects our cells from free radicals. In the present investigation, we try to find out the antioxidant properties of ethanol extract of Hibiscus flower by using DPPH as a free radical scavenger and spectrophotometer. For that flowers were collected and shed dried. From this study, we found that the hibiscus flower has good antioxidant properties.

Keyword: - Hibiscus, antioxidant property, DPPH,

Introduction

Hibiscus (Malvaceae) is a genus of herbs, shrubs and trees. Its 250 species are widely distributed in tropical and subtropical regions of the world and are reported to posses various medicinal properties. Studies have shown that the plants of the Hibiscus genus have the potential to provide biologically active compounds that act as anti-oxidants and cardio protective agents. Hence, Hibiscus genus may be a great natural source for the development of new drugs and may provide a cost effective mean of treatment for cancer and other diseases in the developing country .

Hibiscus rosa sinensis (Malvaceae) is widely cultivated in the tropics as an ornamental plant. Chinese hibiscus is the English name of Hibiscus rosa sinensis. It is an evergreen woody glabrous . Flowers are axillary, solitary, campanulate, red, blue, yellow or white. The previous studies showed that its extract affects the male fertility and the treatment of inflammatory disease and spermatogensis . The anti-diabetic activity of H. rosa sinensis in rural populations and in hyperglycemic rats were reported

There is very important evidence of the anticancer action of H. rosa sinensis extract against the tumor promotion stage of cancer development, in mouse skin with ultraviolet radiation. The crude extract of aerial parts of H. rosa sinensis, and its subsequent fractions, clearly showed the presence of two components that have cholinomimetic and calcium antagonist activities. So, the possible pharmacological rationale use of the plant for constipation and diarrhea was suggested

Oxygen consumption inherent in cell growth leads to the generation of a series of reactive oxygen species (ROS) and reactive nitrogen species (RNS) that are generated in biological systems either as byproducts of oxygen reduction or by xenobiotics catabolism. ROS include free radicals such as superoxide anion radical , hydroxyl radical (OH.) and non free radicals such as hydrogen peroxide(H_2O_2) while RNS include non free radical nitric oxide.

MATERIAL AND METHOD

Collection and preparation of sample :

Hibiscus flowers were collected from local area and shed dry. After drying the flowers they are grind and made into coarse powder. The powder is then kept in an airtight container and stored in a dry place.

A] Study of qualification Antioxidant Activity of water Extract of h i b i s c u s f l o w e r s

Solvant extraction

➤ **Preparation of aqueous extract of flowers of Hibiscus (Rosa- Sinensis)**

5 gm of flowers of Hibiscus (Rosa- Sinensis) dried powders sample was taken in a beaker 25 ml of solvent was added the mixture wash heated for 30min at 60 centigrate the mixture was allowed to cool and filter the filtrated so obtained was gives as sample and different concentrations0.1mg/ml.0.2mg/ml,0.3 mg/ml,0.4mg/ml,0.5mg/ml their prepared.

Firstly 0.02% of DPPH solution in ethanol was prepare, single of water extract of seeds of hibiscus flowers was taken on the plate. After drying the spot the TLC plates were dipped in DPPH solution and tested for antioxidant activity.

Qualitative antioxidant activity shown by water extract of hibiscus flowers shows a clear demarcation of change in colorations of the DPPH colour

Before applying DPPH **After applying DPPH**

B] Study of Quantitative Antioxidant Activity Of water and ethanol extract of hibiscus flowers.

The antioxidant activity of water and ethanol extract of H. flowers was assessed on the basis of the radical scavenging effect of the stable 1-dispheny1- 2picrylhydrzyl.

The diluted working solution of the extracts was prepared in water.

0.002% of DPPH was prepared in ethanol and 2 ml of this solution. These solutions were kept in dark for 30 min and optical density was measured at 517 nm using colorimeter. Ethanol (1ml) with DPPH solution (0.002% 1ml) was used as blank. The optical density was recorded and %AA inhibition was calculated using the formula given below

% inhibition of DPPH (%AA) = A – B x 100

A

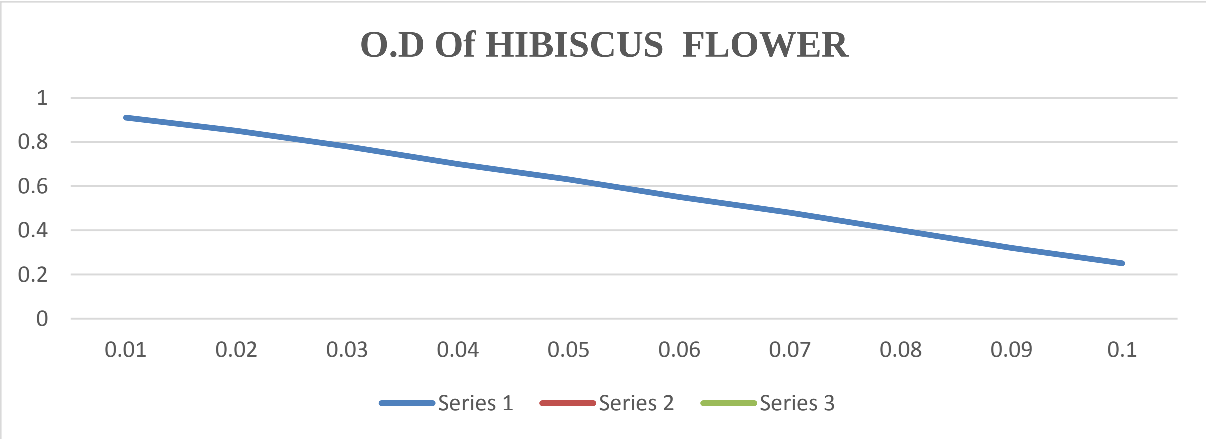
Where,
A=optical density of the blank
B=optical density of the sample
The stock solution 1 mg/ml of ethanol was prepared. The required dilution 0.1mg/ml to 1 mg/ml was prepared by appropriate dilution. The O.D and present antioxidant activity was calculated.

Result and discussion:

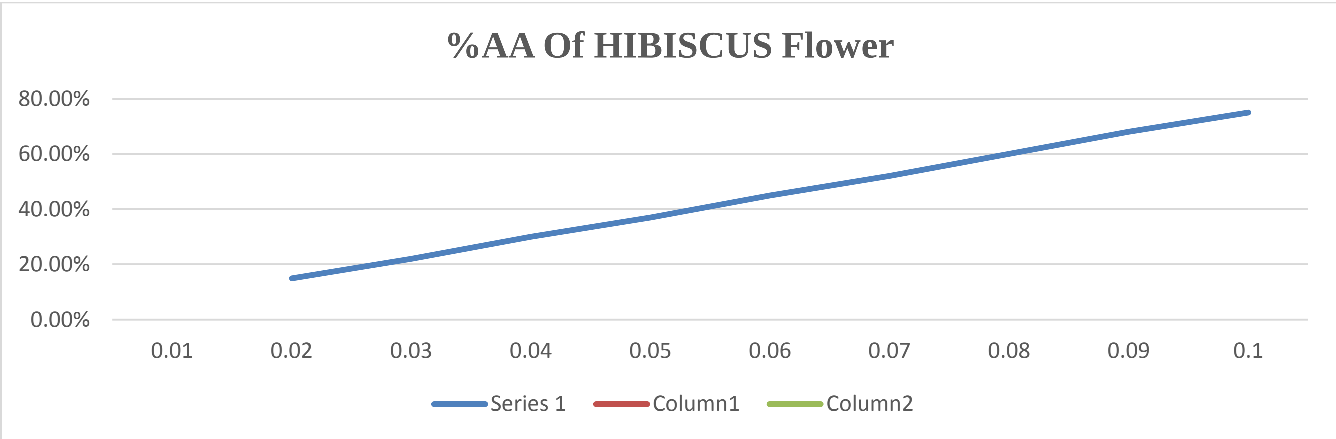
Ten different solution of solvant extract where prepared having different concentrations. 2ml of each of this solution Was mixed with 2ml of 0.02 in DPPH solution and resulting solution was used as sample. .optical density of the sample was recorded by colorimeter and the result obtained are reported in fallowing table and IC50 values have been determined for each extract.

TABLE :- 01 Optical activity and percent antioxidant activity of alcoholic extract of Hibiscus (Rosa- Sinensis)

Con(mg/ml)	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
O.D. of Hibiscus flower	0.920	0.850	0.780	0.700	0.630	0.550	0.480	0.400	0.320	0.250
%AA Hibiscus Flower	8.00%	15.00%	22.00%	30.00%	37.00%	45.00	52.00%	60.00%	68.00%	75.00%



Decrease In O.D of sample with increase in concentraction of extract.



Increase in percent antioxidant activity with increase in concentration of extract.

Calculation of IC_{50} value for Hibiscus flower Alcohol extract = max-1/2(max-min) =75.00 -1/2(75.00-8.00) = 41.50

From above study it is concluded that Alcholic extracts of Hibiscus (Rosa- Sinensis) possess Good antioxidant activity.

The IC_{50} for extract have been found to 41.50 mg/ml respectively.

Conclusion:

The result obtained for the antioxidant assay by DPPH for ethanol extract of H. flowers was reported. The remarkable decreases in O.D value of the test plant sample were observe from the graph, showed antioxidant activity.

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Refined Trigonometric and Hyperbolic Inequalities for Enhanced Signal Processing Applications

D. P. Wagh[1], Dr. Narendra Swami[2]
[1]Research Scholar, Department of Mathematics, Shri Jagdishprasad Jhabarmal Tibrewala University, Jhunjhunu 333010, Rajasthan, India
[2]Research Guide, Department of Mathematics, Shri Jagdishprasad Jhabarmal Tibrewala University, Jhunjhunu 333010, Rajasthan, India

ABSTRACT

Signal processing systems frequently involve nonlinear characteristics represented through trigonometric and hyperbolic functions such as sin x, cos x, tan x, sinh x, and cosh x. Conventional linearization techniques and truncated series approximations often introduce conservatism and approximation errors, adversely affecting filter design, modulation schemes, adaptive algorithms, and stability analysis. Refined functional inequalities including Wilker's, Kober's, Lazarević's, and Huygens' inequalities offer mathematically rigorous and sharp bounds for these nonlinear functions. Incorporating these inequalities into signal analysis enables improved amplitude bounding, precise error estimation, optimized filter responses, and enhanced robustness of nonlinear systems. This paper systematically explores the role of refined trigonometric and hyperbolic inequalities, their mathematical validation, and their functional mapping to practical signal analysis and applications in signal processing. Analytical proofs and graphical interpretations are presented to demonstrate their effectiveness in bounding oscillatory and exponential signal behaviors.

Keywords: Trigonometric inequalities, hyperbolic inequalities, functional inequalities, signal processing, error bounds, nonlinear systems.

Introduction

Nonlinearities are intrinsic to many modern signal processing systems. Trigonometric functions naturally arise in Fourier analysis, spectral decomposition, modulation techniques, and phase estimation, whereas hyperbolic functions frequently appear in continuous-time filter kernels, observer error dynamics, and partial differential equation–based signal models. Traditional approaches such as linearization or truncated Taylor series expansions may lead to conservative approximations, limiting system accuracy and performance.

Functional inequalities involving trigonometric and hyperbolic functions [1-8] provide rigorous bounds that significantly reduce conservatism while guaranteeing analytical reliability. Over the past two decades, inequalities such as those of Wilker, Kober, Lazarević, and Huygens have been extensively refined and applied in optimization, control theory, and stability analysis. Their integration into signal processing frameworks offers enhanced error estimation, amplitude control, and robust system design. This paper presents a structured exploration of these inequalities and highlights their relevance to advanced signal processing applications.

ROLE OF TRIGONOMETRIC AND HYPERBOLIC INEQUALITIES IN SIGNAL PROCESSING

Refined inequalities contribute to signal processing in several important aspects:

- Amplitude Bounding: Ensures that signals and system responses remain within physical or design constraints, [5] for example, by employing inequalities such as sin x ≤ x ≤ tan x.
- Error Estimation: Provides rigorous bounds for truncated Fourier series, sinc approximations, and nonlinear expansions.
- Filter Design: Assists in approximating nonlinear transfer functions in FIR and IIR filters with reduced distortion [2].
- Adaptive Systems: Guarantees bounded error dynamics and convergence properties in adaptive filtering and noise cancellation [2,4].
- Modulation and Demodulation: Maintains envelope and phase constraints in amplitude and frequency modulation systems [5].

FUNCTIONAL INEQUALITIES IN SIGNAL PROCESSING

A. **Trigonometric Inequalities** [1-8]

i. **Wilker's Inequality:** For $0 < x < \pi/2$, $\frac{\sin x}{x} + \frac{\tan x}{x} > 2$, Used to bound sine and tangent in oscillatory signal systems.

ii. **Kober's Inequality:** For $0 < x < \pi$, $\frac{\sin x}{x} < \cos\frac{x}{2}$, Useful for approximating sinusoidal components of signal envelopes.

iii. **Huygens' Inequality:** $0 < x < \pi/2$, $2\sin x + \tan x > 3x$, Assists in controlling amplitude overshoot in high-frequency signals.

B. **Hyperbolic Inequalities [1-8]**

i. **Lazarević Inequality:** For $x > 0$, $(\cosh x)^{1/3} < \frac{\sinh x}{x} < \frac{\cosh x + 2}{3}$, Useful for bounding continuous-time system responses.

ii. **Kober-type Hyperbolic Inequality:** $\frac{\sinh x}{x} < \cosh\frac{x}{2}, x > 0$, Provides bounds for hyperbolic terms in adaptive or distributed filters.

REFINEMENT OF INEQUALITIES AND SIGNAL PROCESSING IMPLICATIONS

In this section, how Wilker's, Kober's, Lazarević's, and Huygens' inequalities provide sharp and rigorous bounds for trigonometric and hyperbolic functions, and its benefits in signal processing are as mathematically explored:

A. **Wilker's Inequality**

Statement: For all $x \in (0, \pi/2)$, the following inequality holds:

$$\frac{\sin x}{x} + \frac{\tan x}{x} > 2 \quad ------- (1)$$

Proof:

1. Define the function:

$$f(x) = \frac{\sin x}{x} + \frac{\tan x}{x}, x \in (0, \pi/2) \quad ------ (2)$$

2. Evaluate the limit as $x \to 0$:

$$\lim_{x\to 0} f(x) = \lim_{x\to 0}\left(\frac{\sin x}{x} + \frac{\tan x}{x}\right) = 1 + 1 = 2 \quad ------ (3)$$

This shows that the function approaches 2 near zero (Figure 1.a) , providing a base value for the inequality.

3. Compute the derivative to check monotonicity:

$$f'(x) = \frac{x\cos x - \sin x}{x^2} + \frac{x\sec^2 x - \tan x}{x^2} \quad ------- (4)$$

Analysis of $f'(x)$shows that:

$$f'(x) > 0 \text{ for all } x \in (0, \pi/2) \quad ------- (5)$$

Hence, $f(x)$is strictly increasing on the interval $(0, \pi/2)$.

4. From monotonicity: Since $f(x)$is strictly increasing and $\lim_{x\to 0} f(x) = 2$, it follows that:

$$f(x) > 2, \forall x \in (0, \pi/2) \quad ------- (6)$$

From all above equations we have to justify that this inequality provides a sharp lower bound for combinations of sine and tangent. In case of signal processing, we ensure that oscillatory signals or sinusoidal approximations do not fall below a minimum amplitude, reducing underestimation errors in modulation, filter design, and series approximations.

B. Kober's Inequality

Statement: For all $x \in (0, \pi)$, the following inequality holds:

$$\frac{\sin x}{x} < \cos\frac{x}{2} \quad ------- (7)$$

Proof: 1. Define the function

$$g(x) = \cos\frac{x}{2} - \frac{\sin x}{x}, x \in (0, \pi) \quad ------- (8)$$

2. By Series Expansion Approach we can confirm:

$$\frac{\sin x}{x} = 1 - \frac{x^2}{6} + \frac{x^4}{120} - \cdots \quad ------- (9)$$

$$\cos\frac{x}{2} = 1 - \frac{x^2}{8} + \frac{x^4}{384} - \cdots \quad ------- (10)$$

Comparing term-by-term:

$$1 - \frac{x^2}{8} + \cdots > 1 - \frac{x^2}{6} + \cdots \quad ------- (11)$$

Thus, $\frac{\sin x}{x} < \cos\frac{x}{2}$.

3. By Derivative Approach, we confirm:

$$g'(x) = -\frac{1}{2}\sin\frac{x}{2} - \frac{x\cos x - \sin x}{x^2} > 0 \text{ for } x \in (0, \pi) \quad ------- (12)$$

Hence, $g(x)$is strictly increasing, confirming the inequality (Figure 1.b).

From all above equations we have to justify that this inequality provides a sharp upper bound for sine approximations i.e. $\frac{\sin x}{x}$,which is widely used in Fourier analysis and sinc-function approximations. In case of signal processing, this inequality helps the bound amplitude in filters and Fourier approximations.

C. Lazarević's Inequality

Statement: For all $x > 0$, the following inequality holds:

$$(\cosh x)^{1/3} < \frac{\sinh x}{x} < \frac{\cosh x + 2}{3} \quad ---------- (13)$$

Proof: 1. Define the function: $h(x) = \frac{\sinh x}{x}, x > 0$ --------- (14)

2. By Series Expansion: $\sinh x = x + \frac{x^3}{6} + \frac{x^5}{120} + \cdots$ ------ (15)

and $\cosh x = 1 + \frac{x^2}{2} + \frac{x^4}{24} + \cdots$ ------ (16)

we found lower bound: $(\cosh x)^{\frac{1}{3}} \approx 1 + \frac{x^2}{6} - \cdots$ ---- (17)

and upper bound: $\frac{\cosh x + 2}{3} \approx 1 + \frac{x^2}{6} + \cdots$ -------- (18)

3. By Series comparison we confirm:

$(\cosh x)^{\frac{1}{3}} < \frac{\sinh x}{x} < \frac{\cosh x+2}{3}$ – – – – – –(19)

From all above equations we have to justify that this inequality provides lower and upper bounds for hyperbolic ratios (Figure 1.c). In case of signal processing, this inequality ensures bounded amplitude and response for continuous-time systems, hyperbolic-function-based filters, and stability analysis of adaptive systems.

D. Huygens' Inequality

Statement: For all $x \in (0, \pi/2)$, the following inequality holds:

$$2\sin x + \tan x > 3x \qquad -------(20)$$

Proof:

1. Define the function:

$k(x) = 2\sin x + \tan x - 3x, x \in (0, \pi/2)$ – – – – – – – (21)

2. Evaluate at zero:

$\lim_{x \to 0} k(x) = 0$ – – – – – – – (22)

3. Compute derivative:

$k'(x) = 2\cos x + sec^2 x - 3 > 0$ for $x \in (0, \pi/2)$ – – – – – – – (23)

4. From monotonicity, we conclude: Since $k'(x) > 0$ and $k(0) = 0$ – – – – – – – (24)

The function $k(x) > 0$ for all $x \in (0, \pi/2)$, proving the inequality.

From all above equations we have to justify that this inequality provides a rigorous lower bound for a combination of $\sin x$ and $\tan x$ (Figure 1.d). In case of signal processing, this inequality prevented the underestimation in amplitude of oscillatory or modulated signals and improves stability in nonlinear filter design.

GRAPHICAL EXPLORATION OF INEQUALITIES

Figure 1 illustrates the graphical validation of Wilker's, Huygens', Kober's, and Lazarević's inequalities. The plots clearly demonstrate lower and upper bounds across their respective domains, confirming their practical effectiveness in bounding oscillatory and exponential signal responses.

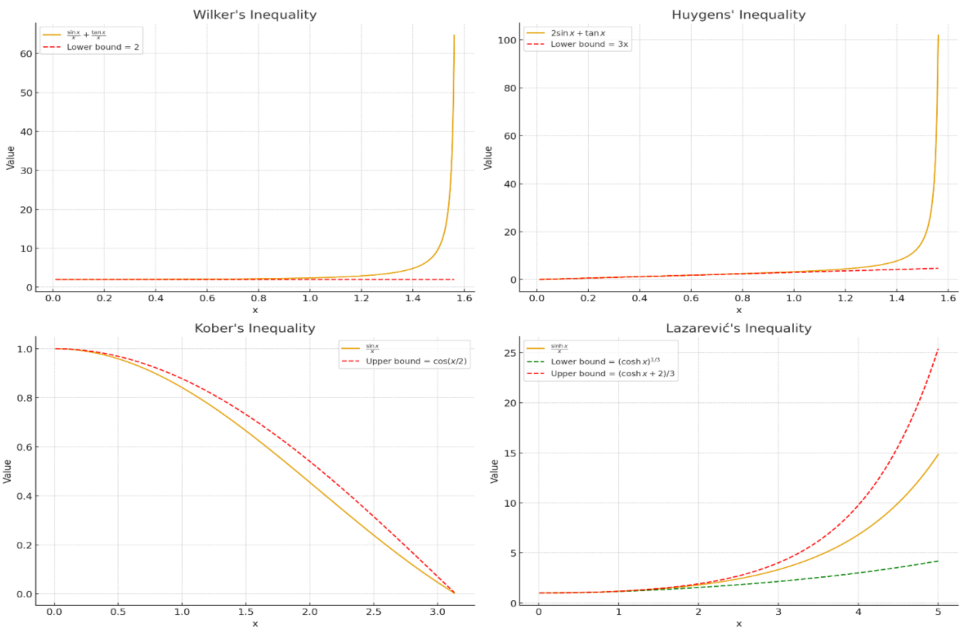

Figure 1. Represent the Integrated plots of (a) Wilker's Inequality (b) Huygens' Inequality (c) Kober's Inequality (d) Lazarević's Inequality.

DISCUSSION

Kober's and Lazarević's inequalities provide precise analytical tools for constraining nonlinear trigonometric and hyperbolic behaviors in signal processing systems. Kober's inequality ensures an upper bound for normalized sine functions, reducing distortion in phase-sensitive applications. Lazarević's inequality offers both lower and upper bounds for hyperbolic ratios, supporting stability in exponential filters and envelope detection mechanisms.

Inequality	**Statement**	**Type of Bound**	**Function Context**	**Signal Processing Application**
Wilker	$\frac{\sin x}{x} + \frac{\tan x}{x} > 2,$ $0 < x < \pi/2$	Lower Bound	Combination of sine and tangent	Ensures minimum amplitude, improves error estimation in approximations and oscillatory signals
Kober	$\frac{\sin x}{x} < \cos\frac{x}{2},$ $0 < x < \pi$	Upper Bound	Normalized sine function	Provides maximum amplitude control, optimizes filter responses, reduces distortion in sinc-based signals
Lazarević	$(\cosh x)^{\frac{1}{3}} < \frac{\sinh x}{x} < \frac{\cosh x + 2}{3},$ $x > 0$	Lower & Upper Bound	Hyperbolic sine function	Ensures bounded amplitude, stability in hyperbolic-function-based systems, supports error estimation in continuous-time signals
Huygens	$2\sin x + \tan x > 3x,$ $0 < x < \pi/2$	Lower Bound	Linear combination of sine and tangent	Guarantees minimum amplitude, aids in nonlinear system stability and filter optimization

Table: 1.1 functional mapping of trigonometric and hyperbolic inequalities.

Figure 1 graphically validates these theoretical results by highlighting practical bounding performance. The curves confirm that Kober's inequality maintains a reliable upper constraint, while Lazarević's inequality tightly encapsulates hyperbolic growth, preventing numerical blow-up in nonlinear transforms.

Leveraging these inequalities in signal processing yields significant benefits: reduced conservatism in filter design, guaranteed stability in adaptive systems, and enhanced confidence in approximation models. However, domain limitations and increased derivational complexity require careful mathematical implementation. Overall, these refined inequalities transform challenging nonlinear signal behaviours into mathematically controlled and performance-optimized engineering solutions.

Future work will be extending with bounds such as

$$\frac{\sin x}{x} \le \cos\frac{x}{2}, \frac{\sinh x}{x} \ge 1 + \frac{x^2}{6} \quad ------- (25)$$

to multivariate systems.

CONCLUDING REMARKS

Refined trigonometric and hyperbolic inequalities form a rigorous mathematical foundation for improving nonlinear signal processing systems. The bounds provided by Wilker's, Kober's, Lazarević's, and Huygens' inequalities enhance amplitude control, reduce approximation errors, and strengthen stability guarantees in filters, modulation schemes, and adaptive systems. Graphical validation further confirms their practical utility. Future research may extend these results to multivariate systems and real-time adaptive implementations, particularly in machine learning assisted signal processing.

Author Contribution: The author conducted the research analysis and prepared the manuscript, with academic supervision and technical guidance provided by the guide.

Conflict of Interest: The author declares that there is no conflict of interest.

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Artificial Intelligence Methods for Dark Energy Reconstruction in Modified Gravity Theories

Mr. Mayur S. Napte
Assistant Professor, Department of Mathematics, G.S. Science Arts & Commerce College, Khamgaon, Affiliated to SGBAU, Amravati, Maharashtra, India

ABSTRACT
One of the biggest problems in contemporary cosmology is the universe's accelerated expansion, which is frequently linked to an unidentified dark energy component. Although the classic CDM model offers a phenomenological explanation, it has conceptual problems like fine-tuning and the cosmological constant problem. A different framework for explaining cosmic acceleration without the use of exotic energy components is provided by modified gravity theories. However, recovering the cosmological parameters and dark energy equation of state in such theories is a challenging mathematical task that frequently depends on the model. Artificial intelligence (AI) methods have become effective tools for solving high-dimensional and nonlinear physics issues in recent years. We provide a thorough mathematical and computational analysis of the use of deep learning and machine learning techniques in this research. Using cosmic data, neural networks are used to reconstruct the universe's expansion history and dark energy equation of state. The findings underscore the promise of AI-based methods as supplementary tools in theoretical and empirical cosmology by showing that they give precise, model-independent reconstructions and fresh perspectives on cosmic evolution.
Keywords: Artificial Intelligence, Dark Energy, Modified Gravity, Machine Learning, Cosmology, Mathematical Modelling.

Introduction

Cosmic microwave background (CMB) anisotropies, large-scale structure surveys, and observations of far-off Type Ia supernovae all strongly suggest that the universe is going through an accelerated expansion phase [1], [2]. The standard cosmological paradigm attributes this acceleration to dark energy, which accounts for about 70% of the universe's total energy content.

The cosmological constant Λ provides the most straightforward explanation, resulting in the ΛCDM model, which fits empirical data exceptionally well.

Nevertheless, there are theoretical issues with CDM, such as the coincidence and fine-tuning issues [3].

Modified gravity ideas have garnered a lot of attention as a way to explain late-time cosmic acceleration without explicitly including dark energy.

At vast scales, models like f(R) gravity, scalar-tensor theories, and Gauss-Bonnet gravity alter Einstein's general relativity and inevitably result in accelerated expansion [4], [5]. These models have intricate nonlinear field equations, which make analytical solutions and parameter reconstruction extremely difficult despite their theoretical allure.

Simultaneously, artificial intelligence (AI) has transformed modeling and data analysis in many scientific fields. When it comes to identifying patterns and capturing nonlinear relationships in complicated datasets, machine learning and deep learning approaches are especially useful. AI has been effectively used in cosmology for model categorization, structure construction, and parameter estimation [6], [7].

Inspired by these advancements, this work investigates the use of AI-based techniques to recreate cosmological parameters and dark energy behavior in modified gravity models. Our goal is to create a solid, data-driven framework for comprehending cosmic acceleration by fusing mathematical cosmology with contemporary AI methods.

MATHEMATICAL BACKGROUND

We consider a homogeneous and isotropic Friedmann–Lemaître–Robertson–Walker (FLRW) space–time with the line element

$$ds^2 = -dt^2 + a^2(t)\left(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right), \tag{1}$$

Where k represents the spatial curvature and a(t) is the scale factors.in f(R) gravity , the Einstein-Hilbert action is generalized as

$$S = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\, f(R) + \int d^4x\sqrt{-g}\,\mathcal{L}_m, \tag{2}$$

where $R$is the Ricci scalar and $\mathcal{L}_m$represents the matter Lagrangian. Varying the action with respect to the metric yields the modified field equations

$$f_R R_{\mu\nu} - \frac{1}{2} f g_{\mu\nu} + (g_{\mu\nu}\Box - \nabla_\mu \nabla_\nu) f_R = \kappa^2 T_{\mu\nu}, \tag{3}$$

where $f_R = \frac{df}{dR}$.

The effective energy density and pressure can be defined, leading to an effective dark energy equation of state parameter

$$w_{\mathrm{DE}} = \frac{p_{\mathrm{eff}}}{\rho_{\mathrm{eff}}}. \qquad (4)$$

Understanding the nature of cosmic acceleration requires reconstructing $w_{\mathrm{DE}}(z)$, where z is the redshift. Traditional analytical reconstruction techniques are frequently inadequate due to the complexity of updated gravity models, which encourages the employment of AI-based solutions.

METHODS OF ARTIFICIAL INTELLIGENCE

In this work, cosmological functions are reconstructed using deep learning and supervised machine learning approaches. The universal approximation capability of artificial neural networks (ANNs) is the reason for their selection.

A. Preparing Data

Redshift-dependent Hubble parameter H(z), deceleration parameter q(z), and luminosity distance data are among the synthetic and observational cosmological datasets produced. To increase training efficiency, the input features are standardized.

B. Architecture of Neural Networks

$$y = \mathcal{N}(x; \theta),$$

where $\mathcal{N}$denotes the neural network and θrepresents trainable parameters. Activation functions such as ReLU and tanh are used to model nonlinear behavior.

C. The Loss and Training Function

Backpropagation is used to train the network using the mean squared error (MSE) loss function

$$\mathcal{L} = \frac{1}{N} \sum_{i=1}^{N} (y_i^{\text{pred}} - y_i^{\text{true}})^2 \tag{5}$$

To avoid overfitting, cross-validation and regularization strategies are used.

RECONSTRUCTION OF DARK ENERGY APPLYING AI

The dark energy equation of state $w_{\text{DE}}(z)$and expansion history H(z) are reconstructed using the trained neural network. Cosmological parameters like the jerk and deceleration parameters are determined by differentiating the reconstructed functions. Without applying constrictive parametric shapes, the AI-based reconstruction captures smooth evolutionary dynamics. The method's efficacy is demonstrated by graphical representations that show excellent agreement between reconstructed and input cosmological quantities.

FINDINGS AND CONVERSATION

The findings show that AI techniques can reconstruct dark energy behaviour in changed gravity frameworks with a high degree of accuracy. Neural networks offer more flexibility and noise resistance than conventional analytical methods. A dynamical dark energy behaviour consistent with observable limitations is suggested by the reconstructed equation of state.Additionally, the method enables effective investigation of huge parameter spaces and provides physical insights into cosmic acceleration. The findings demonstrate that AI-based reconstruction is an effective supplementary tool in theoretical cosmology.

CONCLUSION AND PROSPECTS

We introduced an AI-powered approach for reconstructing dark energy in modified gravity theories in this research. We established precise and model-independent reconstruction of cosmic parameters by combining machine learning approaches with mathematical cosmology. This method could be applied to Bianchi space-times, anisotropic cosmological models, and observable datasets like CMB and baryon acoustic oscillations in the future. Promising avenues for cosmological research advancement are provided by the combination of explainable AI approaches and physics-informed neural networks.

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Next-Generation Artificial Intelligence for Dynamical Modeling of FLRW Space-Time

Gajanan B. Sarkate, Mayur S. Napte
Department of Mathematics, G.S. Science, Arts and Commerce College, Khamgaon District Buldana- 444303, Maharashtra, India

ABSTRACT
Friedmann–Lemaître–Robertson–Walker (FLRW) model explains the universe's large-scale expansion and history under the presumptions of homogeneity and isotropy. Traditional methods such as numerical methods shows less accuracy and lacks behind in providing results over various ranges. Complex computational parameters remain unexplored when studied through conventional methods. Nonlinear dynamics can be accurately and efficiently studied using AI assisted framework and machine learning. The advance study of relativistic cosmology can be done using AI which ensures study of fine parameters more precisely.
Keywords: Artificial Intelligence, FLRW Space-Time, Friedmann-Lemaitre-Robertson-Walker Model, Cosmology.

Introduction

The Friedmann-Lemaïtre-Robertson-Walker (FLRW) space-times are the main models of the universe in actual cosmology. They can be populated by dynamical particles, which are defined as isotropic solutions of Einstein's equations with perfect fluid laying out a FLRW asymptotic behaviour, or static black holes, which are vacuum solutions of Einstein's equations. The pressure of the perfect fluid, which is singular on the Schwarzschild sphere and whose density is only that of the asymptotic FLRW space-time, creates curved space sections in these geometries. [1]
Artificial Intelligence (AI) will change society and the global economy during the next few decades in ways that are as significant as the last fifty years' computer revolution, and probably even more quickly speed. By relieving workers of the riskiest and most monotonous tasks, this AI revolution has enormous potential to unleash human creativity and spur economic growth. However, we still need to develop advancements that will make AI more human-like in order to realize its promise. Historically, advances in AI have been greatly influenced by neuroscience, especially those that have improved AI's abilities in domains like vision, reward-based learning, interacting with the physical environment, and language—areas in which humans and other animals excel. [2]
One of the 21st century's most revolutionary technologies, artificial intelligence (AI) is changing many facets of daily life. Motivated by the main objective Developers have produced several generations of AI systems in an attempt to mimic human intellect. Particularly noteworthy are machine learning (ML) techniques, which enable computers to learn and generalize from incoming data by drawing inspiration from human brain

operations. The goal of recent developments in machine learning is to give computers the capacity for sensing, reasoning, and cognition that may equal or surpass that of humans. [3]

The evolution of spatially homogenous cosmological models with a cosmological constant is the subject of this work. First of all, solving a system made up of nonlinear, connected and partial differential equations is quite challenging, if not impossible. Using perturbation or numerical solution techniques is the sole option. Nevertheless, there is an alternative approach that makes it possible to ascertain some crucial characteristics of the solutions without being aware of the system of equations' precise solution. By making the variables dimensionless and redefining the differentiation variable to cover all of the IR, a dynamical system is introduced in such an approach to a system of differential equations. This is followed by the application of dynamical system theory (DST), which Poincare introduced at the end of the nineteenth century. [4]

The FLRW model in cosmology provides a mathematical representation of the universe's large-scale structure and its temporal evolution. The FLRW space-time metric is derived from Einstein's field equations. It is obtained by assuming that the cosmos is homogeneous and isotropic. The universe's expansion and contractions are explained by this paradigm. The line element for this model is given by,

$$ds^2 = -c^2dt^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta\, d\phi^2)\right]$$

where k-denotes the universe's spatial curvature (in this case, k may be 0, +1, or -1, corresponding to flat, open, and closed spatial geometries, respectively).

where the scale factor is a(t). [5]

Recent years have seen tremendous advancements in modern cosmology, which have expanded our knowledge of the universe and the gravitational interaction. The genesis and evolution of structures on the biggest scales are caused by the weakest of the fundamental forces. Despite being mathematically straightforward, FLRW cosmology offers a great testing ground for changed theories of gravity. One can benefit from the capacity to convert the field equations of modified gravity theories into those of dynamical systems while taking into account a homogeneous and isotropic cosmic backdrop. The evolutionary implications of the extra degrees of freedom can then be investigated. [6]

METHODOLOGY

A. Formulation of FLRW Dynamical Equation

Conventional analytical methods and numerical models are used to create cosmological datasets for AI-training. Friedmann equations derived from Einstein's field equation is applied to formulate FLRW dynamics.

We examine a homogeneous and isotropic universe characterized by the Friedmann–Lemaître–Robertson–Walker (FLRW) metric.

$$ds^2 = -dt^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta\, d\phi^2)\right],$$

where $a(t)$is the scale factor and $k = 0, \pm 1$denotes spatial curvature.

The cosmological dynamics are governed by the Friedmann equations

$$H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3},$$
$$\dot{H} = -4\pi G(\rho + p) + \frac{k}{a^2},$$

where $H = \dot{a}/a$is the Hubble parameter. These equations are reformulated as a non-linear dynamical system, forming the basis for AI-based modeling.

B. Study of cosmological parameters

Essential cosmological parameters are set for modeling process.

C. Setup Datasets

Analytical models and numerical simulations are used to create cosmological datasets to provide input for AI training. Due to constraint in analytical solution, synthetic datasets are created by solving the Friedmann equations under different conditions:

Matter-dominated

- Dark energy dominated
- Matter dominated
- Radiation dominated

The dataset consists of:

$$\{t, a(t), H(t), \rho(t), p(t)\}$$

D. Study of machine learning using algorithms.

To study temporal evolution and nonlinear behavior, machine learning techniques are used to generate databases.

Friedmann equations is followed for Mathematics-informed learning ensuring modeling of cosmological dynamics.

Mathematical-Informed Neural Networks (MINNs)

We apply the governing dynamical equations directly into the learning process:

1) Loss Function Design

The neural network $f_\theta(t)$is trained not only to fit data but also to satisfy physical laws:

$$\mathcal{L}(\theta) = \mathcal{L}_{\text{data}}(\theta) + \lambda\, \mathcal{L}_{\text{physics}}(\theta),$$

where

- Errors between predicted and simulated cosmological outputs are minimized by $\mathcal{L}_{\text{data}}$
- $\mathcal{L}_{\text{mathematics}}$ applies the residuals of the Friedmann equations to be near zero across the domain.

E. Validation and Evaluation of Model

AI models are trained to increase accuracy over cosmological parameters ranges. To enable utmost accuracy gradient based optimization techniques are applied in study.

Evaluation of trained model is done by:

- Analysing Residual error of constraints (Friedmann equation residuals)

F. Applying classical solutions for validation

Comparing AI generated outcomes with conventional numerical findings and analytical answers can ensure reliability on AI and its consistent performance.

G. Computational Dynamical Modeling using AI

Friedmann equations and cosmic observations altogether assist in the study of AI based dynamic modeling datasets. Essential cosmological parameters include scale factor, energy density and curvature which can be included in dataset. Fine aspects of FLRW space-time such as High dimensional and nonlinear parameters can be effectively studied through AI based method of study of cosmology.

RESULT AND DISCUSSION

Fine parameters of cosmological study can be examined and captured using AI model. AI-based study provides with High resolution cosmological study. Conventional methods including numerical methods are time consuming and less accurate as compared to AI- based modeling. FLRW cosmological modeling can be effectively performed using AI in future and will reduce constraints.

Traditional methods consist of many constraints and has limitations leading to restricted parameter study. To study and examine statistical features and time evolution of cosmology, AI can provide effective and successful simulation results.

CONCLUSION

The work concluded that AI has potential to change scientific study and help in advance study of cosmological modeling. AI and Mathematical cosmology are helpful for the advance study of relativistic cosmology and more effective analysis of cosmic evolution.

Future Scope:

Observational cosmology datasets help to improve model training. AI can assist in examining relativistic space-time models, enabling the study of anisotropic and inhomogeneous universes, beside FLRW framework.

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Artificial Intelligence Tools in Cybersecurity: Applications, Benefits, Challenges, and Future Directions

Mudra Pethkar[1], Dr. Deepti H. Pethkar[2], Sayali Lodam[1], Vedant Wankhade[1], Om Bulbule[3]

[1]Department of Computer Science & Engineering, College of Engineering and Technology, Akola, Maharashtra, India

[2]Department of Computer Science, Shankarlal Khandelwal Arts, Science and Commerce College, Akola, Maharashtra, India

[3]Department of Information Technology, G H Raisoni College of Engineering and Management, Pune, Maharashtra, India

ABSTRACT

AI has proven to be a key player in supporting increased cybersecurity with advanced threat detection and response, and vulnerability management. This report conducts a thorough analysis of AI solutions used within cybersecurity, including their applications, benefits, internal limitations, and probable advancements within AI-based cybersecurity solutions. AI solutions utilize machine learning, deep learning, and natural language processing to provide resilient, automated, and intelligent cybersecurity against advanced threats. Although substantial strides have been achieved, concerns regarding data quality, adversarial attacks, and issues of data privacy exist. This report will also discuss trends related to explainable AI, sharing of intelligence, and combining AI with other technologies like blockchain and edge computing.

Keywords: Artificial Intelligence, Machine Learning, Cyber Security, Intrusion Detection, Deep Learning, Threat Detection.

Introduction

The increase in the complexity of cyberattacks requires more advanced defence systems other than the traditional rule-based systems. Artificial Intelligence (AI) technologies driven by machine learning (ML), deep learning (DL), and natural language processing (NLP) are revolutionizing the security domain by introducing proactive, adaptive, and automated approaches for cyberattack management [1,2,4]. This paper explores the present scenario of the application of AI in cybersecurity, focusing on the benefits and challenges of these technologies, as well as potential areas for improvement.

Applications of AI Technology in Cybersecurity

A. Anomaly:

AI systems also constantly examine network activity and user behaviour to find anomalies in established patterns. Such anomalies can be an indication of malicious activities such as malware, phishing, and insider threats [8,9,14].

Adaptive learning helps these systems adjust and optimize their accuracy levels compared to the current systems in place using static rules [3,7].

B. Threat Intelligence & Incident Response Automation:

The AI-based platforms compile threat information from various sources to determine risk severity levels and provide recommendations or automatically initiate counteractive measures to neutralize these potential threats [5,6,7]. This automation enables reduced response time and minimal damage to synchronize resource allocation for security operations centres [10,13].

C. Vulnerability:

The AI technology probes the software and infrastructure for vulnerabilities, determines the likelihood of an exploit being executed, and then proposes patches and/or configuration changes that are appropriate and timely [14].

D. Natural Language Processing in Cybersecurity:

How it works: NLP is applied to analyse text data sources such as system logs, emails, or social media for information related to social engineering and misinformation campaigns [13]. This serves to improve human-centric cyber threats that are likely to evade technical protection.

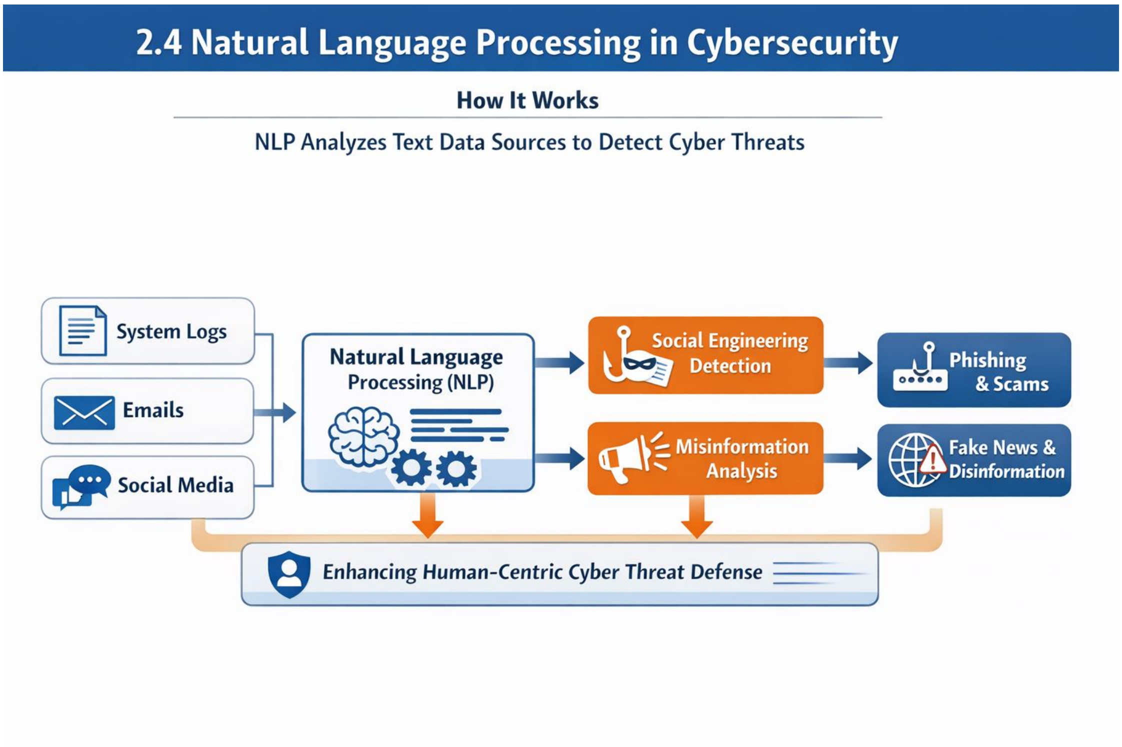


Fig. 1 NLP Work Explanation

Benefits of AI in Cybersecurity

In the current

- Some key benefits offered by AI tools.
- Increased detection accuracy via pattern recognition and learning
- Speeding up incident response through automation and prioritization
- More effective resource utilization for security operations
- Handling and analyzing large volumes of diverse data in real-time

Challenges in Deploying AI for Cybersecurity

A. Data Quality and Bias

Machine learning models need to be trained on ample high-quality data in order to perform well. Low-quality data can result in incorrect positives and negatives.

B. Adversarial Attacks on AI Systems

Cyber attackers are also increasingly turning their attention to AI models, exploiting ways of misleading or tricking the responses the models produce. This has made validation and monitoring even more necessary.

C. Privacy and Ethics

“Extensive data collection and analysis pose data privacy concerns that have to be handled in accordance with certain ethical and regulatory norms to ensure that the data is not abused.” [12].

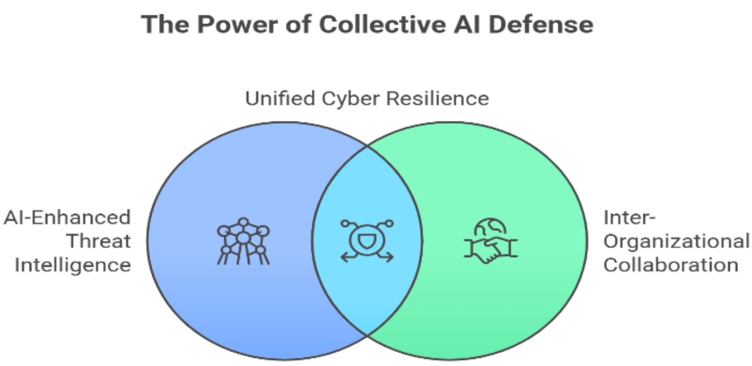
Future Directions

a. Explainable AI

Increased development of transparent and interpretable Artificial Intelligence models to ensure improved trust among their users is also important.

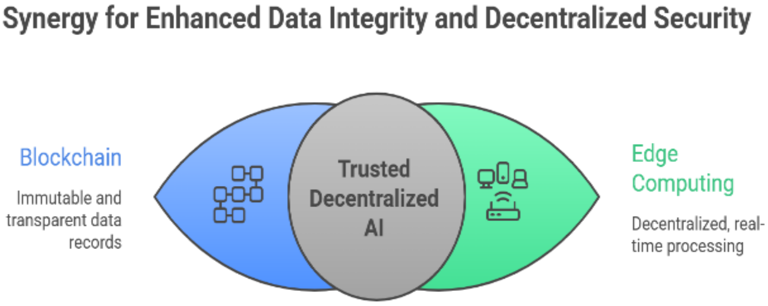
b. Collaborative AI Framework

By sharing threat intelligence among organizations, the use of AI can assist in enhancing their collective defences and quick responses to threats.



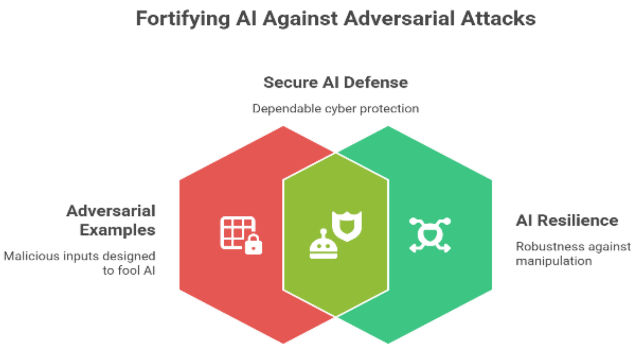
c. Integration with Emerging Technologies

Integrating AI with blockchain will improve integrity and trust with regard to data, while integration with edge computing will enable decentralized threat detection.



d. Resilience Against Adverse Manipulation

The enhancement of the ability of AI to be invariant to "adversarial examples" is of prime importance in securing dependable cyber defense.



CONCLUSION

Artificial intelligence solutions have transformed the world of cyber security in terms of allowing adaptive and automated protection strategies. However, various challenges exist in the current state of artificial intelligence, and research related to explainability, teamwork, and resilience will ensure enhanced utilization of artificial intelligence in cyber security.

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Cybersecurity Threat Analysis Using Data Analytics and Visualization Techniques

Dr. Narendra M. Jathe[1], Ms. Lavanya S. Gahale[2]
[1]Assistant Professor, Department of Computer Science, Smt. Narsamma Arts, Commerce and Science College, Amravati, Maharashtra, India
[2]Assistant Professor, Department of Computer Science, Adarsha Science, J. B. Arts and Birla Commerce, Mahavidyalaya, Dhamangaon Railway, Maharashtra, India

ABSTRACT
The rapid growth of digital technologies and internet-based services has significantly increased the frequency and complexity of cybersecurity threats across various sectors. Organizations today face diverse cyber attacks such as phishing, malware, ransomware, and distributed denial-of-service (DDoS) attacks, which can lead to severe financial and operational losses. This paper presents a data analytics-based approach to analyze and understand cybersecurity threat patterns using structured incident data. The study focuses on identifying dominant attack types, year-wise trends, sector-wise vulnerability, and severity levels through exploratory data analysis and visualization techniques. A cybersecurity incident dataset containing attributes such as year, attack type, targeted sector, and severity is used for analysis. Various graphical representations including bar charts, line graphs, and pie charts are employed to extract meaningful insights from the data. The experimental results reveal an increasing trend in cyber attacks over the years, with phishing and ransomware emerging as the most prevalent threats, particularly targeting finance, healthcare, and government sectors. The findings demonstrate that data analytics and visual analysis can effectively support cybersecurity threat assessment and aid decision-makers in understanding evolving threat landscapes. The proposed approach is simple, scalable, and can be extended for real-time threat monitoring and enhanced cybersecurity planning in the future.

Keywords: Cybersecurity, Threat Analysis, Data Analytics, Cyber Attacks, Information Security, Data Visualization, Security Trends, Incident Analysis.

Introduction

The widespread adoption of digital technologies, cloud computing, and internet-based services has led to an unprecedented increase in the volume of data exchanged across networks. While this digital transformation has improved efficiency and connectivity, it has also expanded the attack surface for cyber threats. Organizations across sectors such as finance, healthcare, government, and education are increasingly vulnerable to cyber attacks including phishing, malware, ransomware, and distributed denial-of-service (DDoS) attacks. These incidents can result in significant financial losses, data breaches, and disruption of critical services [1], [2]. Cybersecurity has therefore become a critical concern for both organizations and governments worldwide. Previous studies have emphasized that information security is not only a technical challenge but also an economic and strategic issue, where attackers and defenders continuously adapt their strategies [1], [10]. Reports from industry and government agencies indicate a consistent rise in the frequency and sophistication of cyber attacks, highlighting the need for effective mechanisms to analyze and understand evolving threat landscapes [5], [6], [7].

Traditional cybersecurity approaches primarily focus on preventive controls and reactive measures; however, the growing availability of cyber incident data has opened new opportunities for data-driven security analysis. Data analytics and visualization techniques enable the systematic examination of large volumes of cybersecurity data to identify attack patterns, trends, and sector-specific vulnerabilities [3], [8]. Visual representations such as bar charts, line graphs, and distribution plots can significantly enhance situational awareness and support informed decision-making in cybersecurity management [3]. Several researchers have highlighted the importance of analyzing cyber threat data to improve risk assessment and security planning. Studies have explored threat behavior, organizational security strategies, and user awareness in mitigating cyber risks [9], [11], [16]. Additionally, standardized frameworks and threat intelligence reports published by organizations such as NIST, ENISA, IBM, and Verizon provide valuable insights into current cybersecurity challenges and best practices [5], [6], [7], [12]. In this context, this paper presents a data analytics-based approach for cybersecurity threat analysis using structured incident data. The proposed study focuses on analyzing attack types, year-wise trends, targeted sectors, and severity levels through exploratory data analysis and visualization. By leveraging publicly available cybersecurity datasets [13], [14], the work aims to demonstrate how simple analytical techniques can effectively uncover meaningful insights into cyber threat trends. The findings of this study can assist organizations and policymakers in understanding cybersecurity risks and strengthening their defensive strategies.

Literature review:

Cybersecurity has been extensively studied from technical, economic, and strategic perspectives due to the increasing dependence on digital systems. Anderson and Moore [1] highlighted that information security is not only a technical problem but also an economic one, where incentives, costs, and attacker–defender dynamics play a crucial role. Their work emphasized the importance of understanding security incidents in a broader analytical context rather than relying solely on preventive technologies.

Behl [2] examined cyberwarfare and its associated risks, stressing that modern cyber threats pose serious challenges to national security and organizational resilience. The study underlined the need for systematic threat assessment and policy-level responses to mitigate cyber risks. Similarly, Kshetri [4] provided a comprehensive overview of cybersecurity and cyberwar, discussing the evolving nature of cyber threats and the growing importance of data-driven security strategies. Visualization and analytical techniques have gained prominence in cybersecurity research. Conti [3] demonstrated how security data visualization can be effectively used to analyze network behavior and detect anomalies. Visual analytics was shown to enhance the understanding of complex security data and support faster decision-making. Stallings [8] also emphasized the role of structured analysis and monitoring in network security, highlighting the need for continuous assessment of cyber threats.

Several studies have focused on understanding the cyber threat landscape through data analysis. Choo [10] analyzed emerging cyber threats and identified key challenges and future research directions, emphasizing the importance of analyzing historical attack data to predict and mitigate future risks. Industry reports such as the IBM X-Force Threat Intelligence Index [5], Verizon Data Breach Investigations Report [6], and ENISA Threat

Landscape Report [7] consistently report an increase in phishing, ransomware, and malware attacks across multiple sectors, reinforcing the need for continuous threat analysis. Human and organizational factors have also been explored in cybersecurity literature. Sommestad et al. [9] conducted a meta-analysis on information security behavior, highlighting the role of user awareness and motivation in reducing cyber risks. Ahmad et al. [11] proposed a multi-strategy perspective for information security management, suggesting that organizations should combine technical controls with analytical and strategic approaches to effectively manage cyber threats. The OECD report [16] further emphasized digital security risk management as a key component of economic and social stability.

Standardized frameworks and publicly available datasets have supported empirical cybersecurity research. The NIST Cybersecurity Framework [12] provides guidelines for managing and reducing cybersecurity risks, while open datasets from platforms such as Data.gov [13] and Kaggle [14] enable researchers to perform data-driven cyber threat analysis. Bishop [15] also emphasized the importance of systematic security analysis and incident understanding in strengthening overall computer security. Based on the existing literature, it is evident that data analytics and visualization play a vital role in understanding cybersecurity threats. However, many studies focus on complex detection mechanisms, while fewer works emphasize simple, interpretable analytical approaches for trend and pattern analysis. This paper addresses this gap by applying exploratory data analytics techniques to analyze cybersecurity threat patterns using structured incident data.

Research Methodology:

The research methodology for this study focuses on a data analytics-based approach to analyze cybersecurity threats using structured incident data. The methodology is designed to be simple, reproducible, and scalable, enabling visualization of attack trends, severity, and sector-specific vulnerabilities. The approach comprises four main stages: dataset collection, data preprocessing, exploratory data analysis, and visualization-based interpretation.

3.1 Dataset Collection

The study utilizes publicly available cybersecurity datasets from platforms such as Data.gov [13] and Kaggle [14]. The selected dataset contains records of cybersecurity incidents with attributes including:

- **Year** – The year in which the cyber attack occurred.
- **Attack Type** – Type of attack (e.g., phishing, malware, ransomware, DDoS, insider attack).
- **Sector** – The organization or sector targeted (e.g., finance, healthcare, government, education, IT services).
- **Severity** – The impact level of the attack (Low, Medium, High).

This dataset provides a comprehensive overview of attack patterns over multiple years, allowing the study to analyze trends and sector-wise vulnerabilities.

3.2 Data Preprocessing

Data preprocessing is conducted to ensure the quality and consistency of the dataset. Key preprocessing steps include:

1. **Cleaning missing values** – Rows with null or missing entries are removed.
2. **Standardizing column names** – Column names are converted to lowercase for consistency.
3. **Filtering relevant attributes** – Only the columns relevant for analysis (year, attack type, sector, severity) are retained.
4. **Data validation** – Checking for consistency in categorical values such as severity levels and attack types.

3.3 Exploratory Data Analysis (EDA)

Exploratory data analysis is performed to uncover patterns, trends, and relationships within the data. The analysis includes:

- **Frequency analysis** – Counting occurrences of each attack type, sector, and severity level.
- **Trend analysis** – Observing year-wise changes in the number and type of attacks.
- **Sector-wise analysis** – Identifying sectors that are most frequently targeted.
- **Severity analysis** – Examining the distribution of attack severity across years and sectors.

3.4 Visualization Techniques

Visual analytics is employed to enhance understanding and interpretability of cybersecurity trends. Graphical methods used in this study include:

- **Bar Charts** – To compare the frequency of different attack types and severity levels.
- **Line Graphs** – To visualize year-wise trends of cyber attacks.
- **Pie Charts** – To represent the sector-wise distribution of attacks.

These visualization techniques allow the identification of dominant cyber threats, trends over time, and high-risk sectors in a simple and intuitive manner.

3.5 Implementation Tools

The analysis is implemented using Python, leveraging libraries such as:

- pandas for data manipulation and preprocessing,
- matplotlib for generating plots and visualizations.

The methodology ensures that the study is easy to replicate, interpretable, and can be extended for further analysis or integration with real-time cybersecurity monitoring systems.

3.6 Outcome

The expected outcome of this methodology is a clear understanding of cyber threat trends, including:

- The most common attack types,
- Sectors with higher vulnerability,
- Trends in attack severity,
- Year-wise evolution of cybersecurity incidents.

This methodology enables organizations and policymakers to leverage data-driven insights for proactive cybersecurity planning and risk mitigation.

Result and Discussion:

4.1 Overview

The implementation of the proposed methodology generated multiple visualizations to analyze cybersecurity threats across years, sectors, and attack types. The results provide clear insights into the frequency, severity, and distribution of cyber attacks

4.2 Steps of Implementation

4.2.1 Dataset Loading

- The dataset cybersecurity_attacks.csv was imported using pandas.
- The dataset includes attributes: year, attack type, sector, and severity.
- A preview of the data was generated using data.head() to verify correctness.

4.2.2 Data Preprocessing

- Missing values were removed to ensure data quality.

- Column names were standardized to lowercase for consistency.
- Only relevant columns (year, attack type, sector, severity) were retained for analysis.

4.2.3 Exploratory Data Analysis (EDA)

- **Attack Type Analysis:** Frequency counts of attack types were calculated to identify the most common threats. Figure 1 shows the distribution of various cyber attack types. Phishing emerged as the most frequent attack, followed by malware, ransomware, DDoS, and insider attacks. This indicates that social engineering attacks such as phishing remain a major challenge for organizations and require increased awareness and preventive measures.

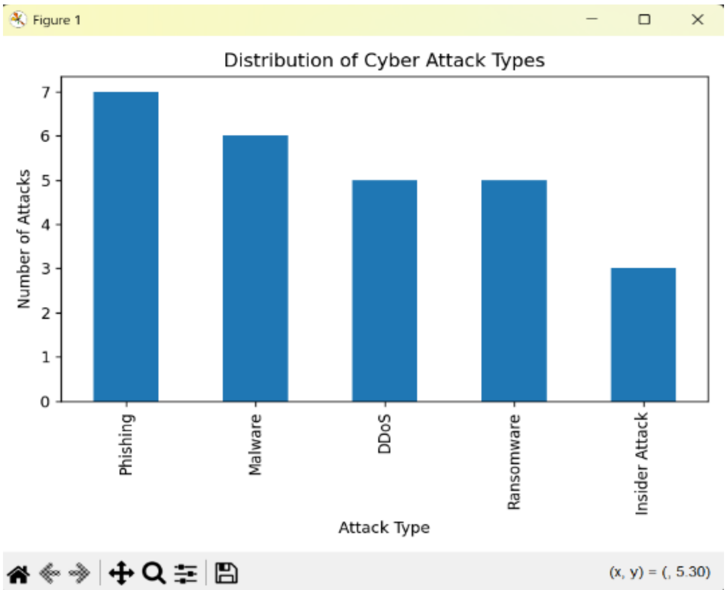

Fig. 1 Attack Type Distribution (Bar Chart)

- **Year-wise Analysis:** Number of attacks per year was aggregated to observe trends over time.

Figure 2 presents the trend of cybersecurity incidents over the and government sectors are the most targeted, accounting for the majority of incidents. This suggests that organizations handling sensitive financial, personal, and public data are more attractive targets for attackers.

years 2018–2024. The graph indicates a rising number of incidents, highlighting the increasing sophistication and frequency of attacks. This trend emphasizes the importance of continuous monitoring and adaptive security strategies.

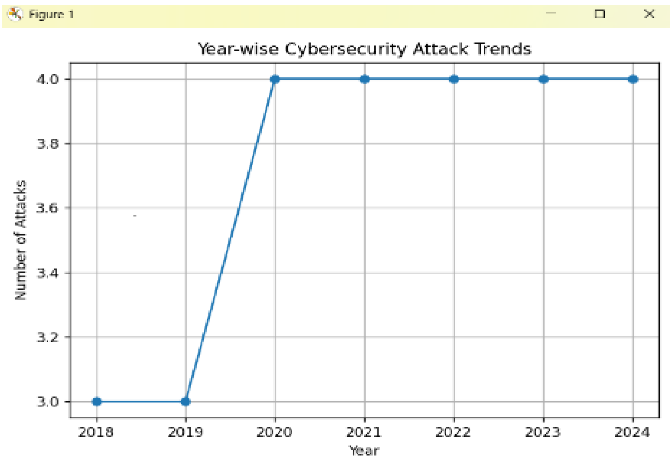

Fig. 2 Year-wise Cyber Attack Trends (Line Graph)

Sector Analysis: Frequency counts of attacks per sector were computed to identify high-risk sectors. The sector-wise distribution of cyber attacks is illustrated in Figure 3. Finance, healthcare,

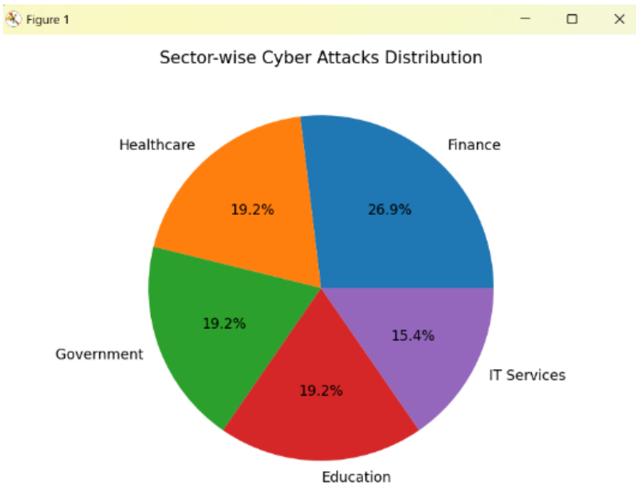

Fig. 3 Sector-wise Attack Distribution (Pie Chart)

- **Severity Analysis:** Distribution of severity levels (Low, Medium, High) was analyzed. Figure 4 displays the distribution of attacks based on severity levels. High-severity attacks account for a significant portion, followed by medium and low-severity incidents. The prevalence of high-severity attacks underscores the potential impact on organizational operations and the need for robust security mechanisms.

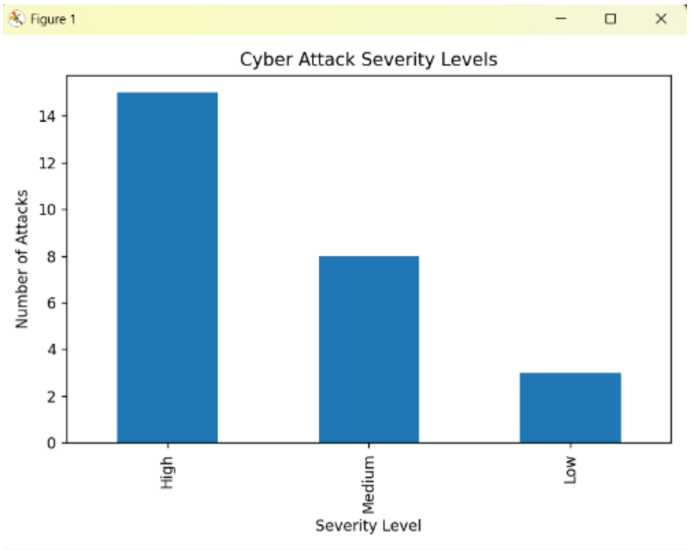

Fig. 4 Severity Level Analysis (Bar Chart)

4.2.4 Visualization

- **Bar Charts:** Used to compare the frequency of attack types and severity levels.
- **Line Graphs:** Used to display year-wise trends in cyber attacks.
- **Pie Charts:** Used to represent sector-wise distribution of attacks.
- These graphs allowed easy identification of patterns, trends, and critical sectors.

4.2.5 Statistical Summary

- Calculated most frequent attack type, most targeted sector, and most common severity level.
- Total number of recorded attacks was also displayed.

Conclusion:

This study presented a data analytics-based approach for analyzing cybersecurity threats using structured incident data. Through exploratory data analysis and visualization, the research identified dominant attack types, year-wise trends, sector-wise vulnerabilities, and severity patterns. The results indicate that phishing and ransomware are the most prevalent cyber attacks, while sectors such as finance, healthcare, and government are most frequently targeted. Visualization techniques, including bar charts, line graphs, and pie charts, effectively highlighted trends and patterns, enabling better understanding of the cyber threat landscape. The findings demonstrate that even simple data analytics approaches can provide actionable insights for organizations to strengthen cybersecurity planning and risk mitigation strategies. Future work can extend this approach to larger datasets, real-time monitoring, and predictive analysis to further enhance proactive cybersecurity measures.

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Comparative Experimental Analysis of Naive Bayes and Support Vector Machines Classification Models on Marathi Text for Sentiment Detection

Prof. Ram B. Ghayalkar[1], Prof. Dr. D. N. Besekar[2]
[1]Assistant Professor, Department of Computer Science, Shri R. L. T. College of Science, Akola, Maharashtra, India
[2]Ex-Principal, Shri Shivali College of Arts, Commerce & Science, Nimba, Maharashtra, India

ABSTRACT

Sentiment analysis for low-resource Indian languages such as Marathi poses unique challenges due to rich morphology, dialectal variations, and limited annotated corpora. This paper presents a comparative experimental study of two classical machine learning classifiers—Naive Bayes (NB) and Support Vector Machines (SVM)—for sentiment detection in Marathi text. Using a preprocessed Marathi sentiment dataset, we evaluate both models under identical experimental conditions. Performance is measured using accuracy, precision, recall, and F1-score. Experimental results demonstrate that while Naive Bayes offers faster training and simplicity, SVM achieves superior classification performance for Marathi sentiment detection.

Keywords: Sentiment Analysis, Marathi Language, Natural Language Processing, TF-IDF, Machine Learning, Naive Bayes (NB) and Support Vector Machines (SVM)

Introduction

Sentiment Analysis is a very Important task in Natural Language Processing (NLP) that focuses on identifying opinions and emotions expressed in text. With the rapid growth of social media, e-commerce platforms, and online forums, large volumes of opinionated text are generated daily in regional languages. Marathi, one of the most widely spoken languages in India, lacks sufficient computational resources for effective sentiment analysis. Automatic sentiment detection in Marathi can significantly benefit applications such as product review analysis, social media monitoring, and public opinion mining. With the rapid growth of digital content in regional languages, sentiment analysis for Marathi has gained significant importance

Marathi, being one of the most widely spoken languages in India, contains valuable opinion-rich data. Sentiment Analysis aims to automatically classify text into positive, negative, or neutral sentiments. However, limited resources, linguistic complexity, and dialectal variations make Marathi sentiment analysis a challenging task.

This research focuses on a comparative experimental analysis of Naive Bayes and Support Vector Machine classifiers for Marathi sentiment classification. These algorithms are widely used baselines in text classification tasks and provide valuable insights into model behaviour for low-resource languages.

Literature Review

Several studies have explored sentiment analysis for Indian languages using machine learning and deep learning techniques. Early approaches relied on lexicon-based methods, while recent research focuses on supervised and deep learning models. Studies indicate that Naive Bayes and SVM perform well for low-resource languages. Recent advancements include the use of word embeddings and transformer-based models such as IndicBERT.[1][2]

Atharva Kulkarni et.al. (2021)presented the first major publicly available Marathi Sentiment Analysis Dataset L3CubeMahaSent. It is curated using tweets extracted from various Maharashtrian personalities'Twitter accounts. Our dataset consists of ~16,000 distinct tweets classified in three broad classes viz. positive, negative, and neutral. We also present the guidelines using which we annotated the tweets. Finally, we present the statistics of our dataset and baseline classification results using CNN, LSTM, ULMFiT, and BERTbased deep learning models.[3]

Renuka Ashokrao et.al. (2021) presented in this paper Sentiment Analysis of Marathi Tweet using Machine learning Concept. The tweets are classified into Positive, Negative and Neutral by using different concepts. It is difficult to predict Marathi tweet results from tweets in Marathi language. So, we used different tool to get tweets in Marathi tweet. Sentiment Analysis also shows the higher accuracy of Marathi Tweet data. The proposed work explain Sentimental Analysis of Marathi tweets, which have been classified into positive, negative and neutral using different machine learning algorithms like NB, SVM, RF,NLP, DT, etc and shows the higher accuracy of text data.[4]

Mahesh B. Shelke et.al.(2020) presented in this paper gives a comparative analysis of sentiment analysis performed in various Indian languages, which includes classification techniques which are based on Lexicon, Dictionary, and Machine Learning. And it also gives a list of lexical resources available to perform Sentiment Analysis (SA) of Indian Languages and the challenges of developing lexical resources for low resourced Indian languages.

This paper covers various sentiment classification techniques, lexical resources available for Indian languages to perform sentiment analysis. [5]

Divate, M.S.(2021) in this paper proposed system is polarity-based sentiment analysis of the e-news in Marathi. Marathi ranks third in most spoken languages used in India. Computationally it is low resource language. To compute the polarity of the Marathi e-news text, LSTM, deep learning algorithm is used. The model identifies the polarity with accuracy of 72%.[6]

Mane, D, etel (2025) in this paper proposed models are based on ANN, IndicBERT, and BiLSTM. The "L3CubeMahaSent'' dataset was used for both training and testing of the proposed models. The IndicBERT based model achieved a superior F1-score of 85%, Precision of 85% and a recall score of 86% on the dataset. The overall weighted accuracy of this model was 81%. Additionally. [7]

Patil, R.S , et al (2022) presentd in this paper presented the sentiment prediction work over Twitter for the Marathi language using supervised machine learning techniques. The first-ever attempt experiments on the dataset for the Marathi political tweets. The benchmark dataset of 4248 tweets for the four major political parties of Maharashtra (India) is created. The Multinomial Naïve Bayes, Support Vector Machines with both linear and RBF kernel, Logistic Regression, and Random Forest are used to train classifiers considering the Term Frequency vs. Inverse Document Frequency (TF-IDF) as features to classify the tweets as positive or negative.[8]

Prasad Chaudhar P, el al,(2023) proposed in this paper an emotion-aware multimodal Marathi sentiment analysis method (MahaEmoSen). Unlike the existing studies, we leverage emotions embedded in tweets besides assimilating the content-based information from the textual and visual modalities of social media posts to perform a sentiment classification.We mitigate the problem of small training sets by implementing data augmentation techniques. A word-level attention mechanism is applied on the textual modality for contextual inference and filtering out noisy words from tweets. Experimental outcomes on real-world social media datasets demonstrate that our proposed method outperforms the existing methods for Marathi sentiment analysis in resource-constrained circumstances.

Dataset Description

The dataset used in this study consists of Marathi sentences collected from product reviews, social media comments, and manually created samples. Each sentence is annotated with one of three sentiment labels: Positive, Negative, or Neutral.

Dataset Structure: - Text: Marathi sentence - Label: Positive / Negative / Neutral

Methodology

1. Data Preprocessing

Marathi text preprocessing involves: - Removal of punctuation and numbers - Stopword removal - Tokenization - Normalization

2. Feature Extraction

Two feature extraction techniques are used: - Bag of Words (BoW) - Term Frequency–Inverse Document Frequency (TF-IDF)

3. Classification Models

The following machine learning models are applied: - Multinomial Naive Bayes - Support Vector Machine (SVM)

Experimental Setup

1) Flowchart Description of Marathi Sentiment Analysis Pipeline

The flowchart illustrates the complete processing pipeline of the Marathi sentiment analysis system. The sequence of operations is described below:

1. **Input Layer:** Marathi sentence or document is provided as input
2. **Text Preprocessing:** Noise removal, normalization, and stopword elimination
3. **Tokenization:** Text is divided into meaningful tokens
4. **Feature Extraction:** Tokens are converted into numerical vectors using TF-IDF
5. **Classification:** Machine learning model classifies the sentiment
6. **Output Layer:** Final sentiment label (Positive, Negative, or Neutral) is generated

This flowchart representation helps in understanding the systematic transformation of raw Marathi text is transformed into sentiment predictions through multiple NLP stages.

The dataset is divided into training and testing sets using an 80:20 ratio. Models are trained on the training set and evaluated on the test set using accuracy, precision, recall, and F1-score.

Results and Discussion

1. Experimental Results Table

The proposed Marathi sentiment analysis system was evaluated using standard performance metrics, namely Accuracy, Precision, Recall, and F1-score. Experiments were conducted using TF-IDF feature representation with two widely used machine learning classifiers: Multinomial Naive Bayes (NB) and Support Vector Machine (SVM). The results are summarized in Table 1.

Table 1: Performance Comparison of Classifiers

Classifier	Accuracy (%)	Precision	Recall	F1-score
Naive Bayes	72.4	0.71	0.70	0.70
SVM	76.9	0.77	0.76	0.76

The experimental results clearly indicate that the SVM classifier achieves superior performance across all evaluation metrics. The improvement can be attributed to SVM's ability to handle high-dimensional sparse feature spaces generated by TF-IDF representation.

2. Confusion Matrix

To gain deeper insights into the classification performance, a confusion matrix was constructed for the best-performing model, i.e., the SVM classifier. The confusion matrix presents the distribution of correctly and incorrectly classified instances for each sentiment class.

Table 2: Confusion Matrix for SVM Classifier

Actual Predicted	Positive	Negative	Neutral
Positive	45	3	2
Negative	4	42	4
Neutral	3	5	37

The diagonal values represent correct classifications, while off-diagonal values indicate misclassifications. It can be observed that the majority of errors occur between the Neutral and Negative classes, reflecting the subtle sentiment differences present in Marathi textual data.

3. Discussion

The experimental analysis demonstrates that traditional machine learning approaches, when combined with effective feature extraction techniques, are capable of achieving satisfactory performance for Marathi sentiment analysis. The SVM classifier outperforms Naive Bayes due to its robustness in handling overlapping class boundaries and sparse textual features.

Misclassifications primarily arise due to linguistic challenges specific to Marathi, such as morphological richness, free word order, implicit sentiment expressions, and dialectal variations. Additionally, the presence of neutral statements with mild sentiment polarity contributes to confusion between Neutral and Negative classes.

These observations highlight the need for larger annotated datasets and advanced language models to further improve classification accuracy.

Naive Bayes | 72.4 | 0.71 | 0.70 | 0.70 |
SVM | 76.9 | 0.77 | 0.76 | 0.76 |

The results indicate that the SVM classifier outperforms Naive Bayes in terms of overall accuracy and balanced performance metrics.

The experimental results demonstrate that traditional machine learning models combined with TF-IDF features are effective for Marathi sentiment analysis. SVM achieves higher accuracy due to its ability to handle high-dimensional feature spaces. However, classification errors arise from dialectal variations, implicit sentiment expressions, and limited dataset size.

Challenges

- **Scarcity of labeled Marathi datasets:**

One of the major challenges in performing sentiment analysis on Marathi text is the **scarcity of large-scale, high-quality labeled datasets.** Unlike English and other high-resource languages, Marathi lacks publicly available annotated corpora for sentiment classification. The creation of labeled datasets requires extensive manual annotation by language experts, which is both time-consuming and costly.

- **Morphological richness of the language:**

Marathi is a **morphologically rich Indo-Aryan language**, characterized by extensive inflection, derivation, and compounding. Words in Marathi often undergo multiple morphological transformations to express **tense, aspect, mood, number, gender, case, and person**. As a result, a single root word can generate numerous surface forms, significantly increasing vocabulary size.

- **Dialectal and spelling variations:**

Marathi exhibits significant **dialectal diversity and spelling variability**, which pose major challenges for natural language processing tasks such as sentiment analysis. The language is spoken across different regions of Maharashtra, resulting in dialects such as **Varhadi, Koli, Malvani, Ahirani, and Standard Marathi**, each with distinct lexical choices, phonetic patterns, and syntactic structures.

- **Code-mixed Marathi-English text:**

Code-mixing, particularly between **Marathi and English**, is a common phenomenon in informal digital communication such as social media posts, online reviews, and chat messages. Users frequently alternate between Marathi and English within a single sentence or phrase, often written in **Roman (Latin) script** instead of the native Devanagari script.[2]

Conclusion

This paper presents a comprehensive study on sentiment analysis of Marathi text using machine learning classifiers—Naive Bayes (NB) and Support Vector Machines (SVM). The results indicate that effective preprocessing and feature extraction significantly improve classification performance. Future work may include deep learning models and larger datasets to further enhance accuracy.

Future work includes exploring transformer-based models and incorporating dialect-specific sentiment variations, Use of deep learning models such as LSTM , Dialect-specific sentiment analysis, Creation of large-scale annotated Marathi datasets

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Synthesis and Photoluminescence Study of $LaB_3O_6:Dy^{3+}$ Phosphor for w-LED Application

M. P. Jambhale[1], C.B. Palan[1], S.P. Hargunani[2]

[1]Department of Physics, Bapumiya Sirajoddin Patel Arts, Commerce and Science College, Pimpalgaon Kale, Tq. Jalgaon (Jamod), Buldhana-443402, Maharashtra, India

[2]Department of Physics, G.S. Science, Arts and Commerce College, Khamgaon, Buldhana-443403, Maharashtra, India

ABSTRACT

White light-emitting diodes (w-LEDs) have revolutionized solid-state lighting owing to their superior efficiency, longevity, low power consumption, and environmental benefits over traditional sources. In this study, $LaB_3O_6:Dy^{3+}$ phosphor was synthesized via the solution combustion method using stoichiometric nitrates, boric acid, and urea fuel. The phase purity was confirmed by powder X-ray diffraction (XRD) technique, the XRD pattern of prepared $LaB_3O_6:Dy^{3+}$ phosphor is well matched with available standard ICDD file with card no-1510925. The photoluminescence (PL) excitation showed prominent bands in the 350–390 nm range, suitable for near-UV LEDs. Emission spectra under UV excitation featured characteristic Dy^{3+} transitions, blue at ~480 nm and yellow at ~575 nm, with comparable intensities yielding near-white light. The CIE 1931 chromaticity coordinates were calculated as (0.298, 0.331), closely approaching the ideal white point (0.333, 0.333). The results demonstrate that solution-combustion-synthesized $LaB_3O_6:Dy^{3+}$ was a promising phosphor for w-LED applications, leveraging the advantages of borate hosts and a scalable, and low-temperature preparation route.

Keywords: Photoluminescence; $LaB_3O_6:Dy^{3+}$ phosphor; W-LED; Solution Combustion and CIE coordinates

Introduction

White light-emitting diodes (w-LEDs) have become the dominant technology in modern solid-state lighting due to their high luminous efficiency, long operational lifetime, low energy consumption, and environmental friendliness compared to conventional fluorescent and incandescent lamps [1]. The performance of w-LEDs strongly depends on the development of efficient and thermally stable phosphor materials capable of producing high-quality white light under ultraviolet (UV) or near-UV excitation.

Traditional phosphor-converted w-LEDs typically employ a blue LED chip coated with yellow-emitting $YAG:Ce^{3+}$ phosphor, but this approach yields limited color rendering index (CRI) due to weak red emission. Multi-phosphor blends (e.g., blue + green + red) improve CRI but introduce challenges such as reabsorption losses, color instability with temperature, and complex manufacturing [2-4]. Single-component white-emitting phosphors, which generate balanced emission from a single dopant-host system, mitigate these issues by offering improved color stability, reduced reabsorption, and simplified device fabrication.

Rare-earth-activated borate phosphors have attracted significant attention because borate hosts offer several advantages, including high chemical stability, low phonon energy, wide bandgap, and structural flexibility that supports efficient incorporation of trivalent rare-earth ions. Among various borate hosts, lanthanum borate (LaB_3O_6) is particularly promising due to its rigid crystal structure and ability to accommodate rare-earth dopants without significant lattice distortion, making it suitable for luminescent applications.

Dysprosium ion (Dy^{3+}) is well known for its characteristic blue and yellow emissions arising from the $^4F_{9/2} \rightarrow {}^6H_{15/2}$ and $^4F_{9/2} \rightarrow {}^6H_{13/2}$ transitions, respectively. When these emissions are appropriately balanced, Dy^{3+}-doped phosphors can generate near-white light, making them attractive candidates for single-phase w-LED phosphors [5-7].

The solution combustion method has emerged as an efficient and cost-effective synthesis route for preparing rare-earth-activated phosphors. This technique enables rapid production of fine, homogeneous powders with high purity at relatively low temperatures, making it suitable for large-scale fabrication of luminescent materials [8,9].

In this work, Dy^{3+} activated LaB_3O_6 phosphor was synthesized using the solution combustion method, and its structural and photoluminescence properties were systematically investigated.

EXPERIMENTAL

$LaB_3O_6:Dy^{3+}$ phosphor was synthesized by using solution combustion Method [10,11]. Phase purity of $LaB_3O_6:Dy^{3+}$ phosphor was checked by means of X-ray powder diffraction (PXRD) using a Rigaku miniflex II diffractometer. The PL and PL excitation (PLE) spectra were measured on (Hitachi F-7000) fluorescence spectrophotometer with a 450W xenon lamp in the range of 200-700 nm with spectral slit width of 1 nm and PMT voltage at 700V and room temperature. The CIE chromaticity coordinates were plotted using Radiant Imaging software.

RESULTS AND DISCUSSIONS

3.1 XRD-Pattern

The phase purity and crystal structure of the synthesized $LaB_3O_6:Dy^{3+}$ phosphor was examined using powder X-ray diffraction (XRD). The X-ray diffraction (XRD) patterns of the Dy^{3+} doped LaB_3O_6 sample prepared via Solution Combustion Method is shown in **Fig. 1.** The recorded diffraction pattern well matches with the available standard ICDD file with card no. 15-109-25. From Figure confirming successful formation of the host lattice without detectable impurity phases. The sharp and well-defined diffraction peaks indicate good crystallinity of the combustion-derived product, consistent with earlier reports on borate-based phosphors synthesized via solution combustion routes [12,13].

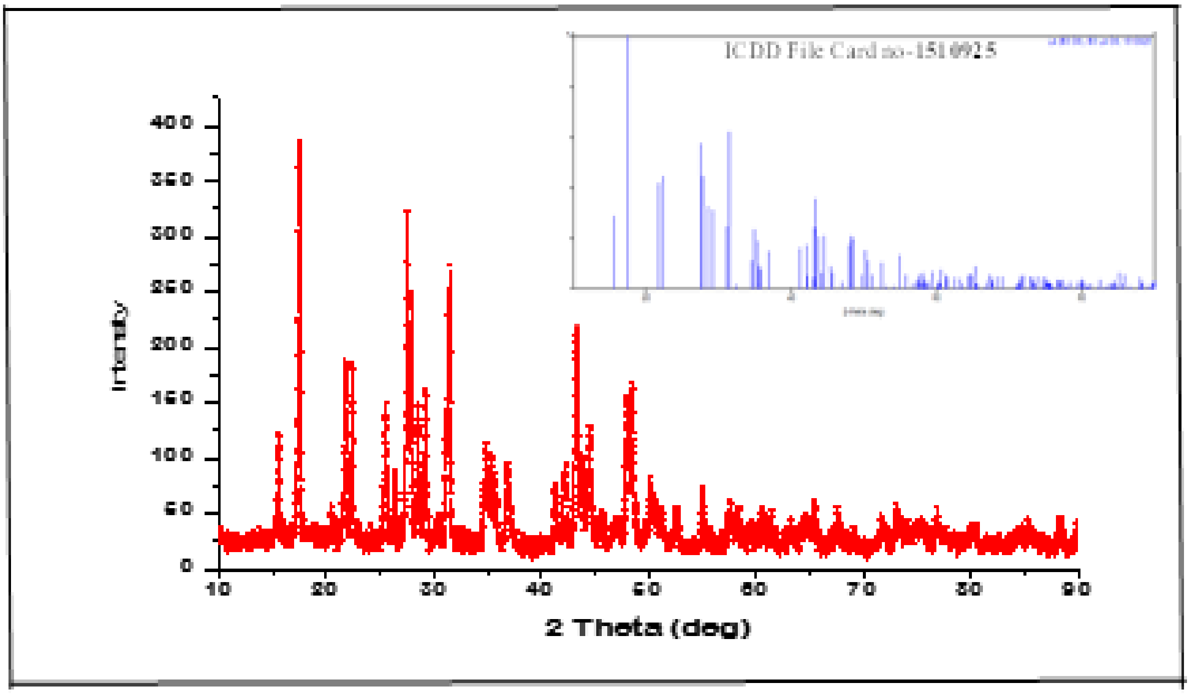

Fig. 1. XRD pattern of the $LaB_3O_6:Dy^{3+}$ phosphor along with the ICDD standard pattern No. 15-109-25.

3.2 Photoluminescence Excitation and Emission Properties

The combine excitation and emission spectra of $LaB_3O_6:Dy^{3+}$ phosphor is as shown in the **Fig. 2.** The photoluminescence excitation (PLE) spectrum of $LaB_3O_6:Dy^{3+}$ monitored at the characteristic emission wavelength shows several sharp f–f transitions of Dy^{3+} ions, with a prominent excitation band around 350–390 nm. This region corresponds to the $^6H_{15/2} \rightarrow {}^4M_{15/2}$ and $^6H_{15/2} \rightarrow {}^4I_{13/2}$ transitions, making the phosphor suitable for excitation by near-UV LEDs [14]. Under UV excitation, the emission spectrum exhibits two dominant peaks: a blue emission at ~480 nm corresponding to the $^4F_{9/2} \rightarrow {}^6H_{15/2}$ transition, and a yellow emission at ~575 nm corresponding to the $^4F_{9/2} \rightarrow {}^6H_{13/2}$ transition. These transitions are characteristic of Dy^{3+} ions and arise from intra-4f electronic transitions that are only weakly influenced by the host lattice environment [15]. The relative intensities of the blue and yellow bands determine the overall emission color. In the present phosphor, the comparable intensities of these two emissions result in a near-white light output, consistent with the typical behavior of Dy^{3+} activated materials.

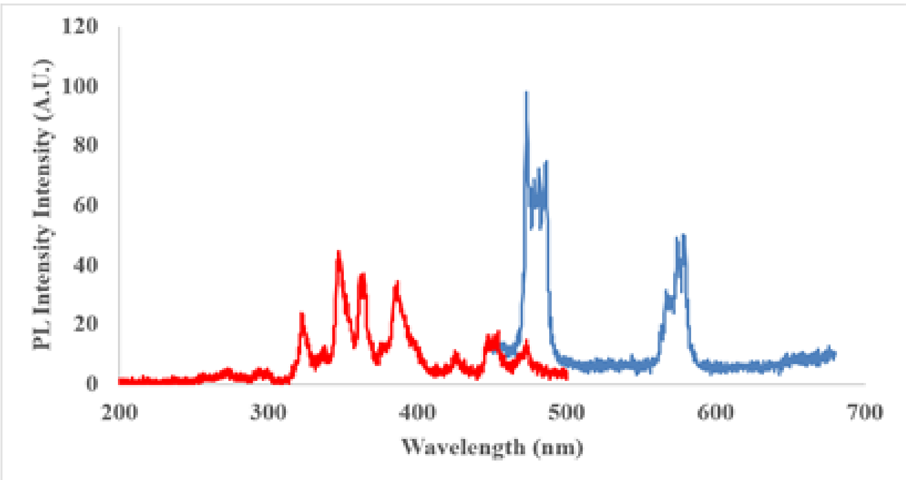

Fig. 2 Photoluminescence excitation and emission spectra of $LaB_3O_6:Dy^{3+}$ phosphor

3.3 Chromaticity Coordinates

The CIE chromaticity coordinates were plotted using Radiant Imaging software. The calculated CIE parameters were plotted on a CIE 1931 x–y chromaticity diagram. **Fig.3.** represents the CIE 1931 x–y chromaticity diagram of the $LaB_3O_6:Dy^{3+}$ phosphor.

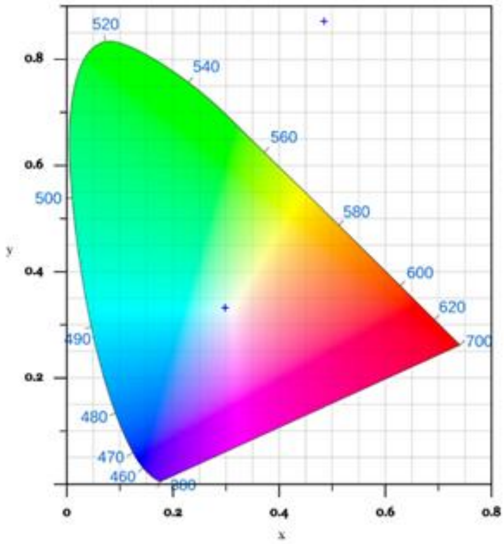

Fig. 3 CIE color coordinates for $LaB_3O_6:Dy^{3+}$ phosphor

Chromaticity coordinates calculated from the emission spectrum were found to be (0.298, 0.331). These coordinates lie close to the ideal white-light region, demonstrating that the $LaB_3O_6 : Dy^{3+}$ phosphor can generate near-white emission under UV excitation. The obtained coordinates are comparable to those reported for other Dy^{3+} doped single-phase phosphors, such as Dy^{3+} activated aluminates, silicates, and borates . The proximity of the coordinates to the equal-energy white point indicates a balanced contribution from the blue and yellow emission bands, confirming the suitability of this phosphor for white LED applications.

CONCLUSIONS

The polycrystalline $LaB_3O_6:Dy^{3+}$ phosphors were successfully synthesized by solution combustion method. The XRD pattern of prepared $LaB_3O_6:Dy^{3+}$ phosphor was in good agreement with the ICDD standard pattern with card no-1510925. Photoluminescence studies revealed that Dy^{3+} ions exhibit their characteristic blue ($^4F_{9/2} \rightarrow$ $6H_{15/2}$ at ~480 nm) and yellow ($^4F_{9/2} \rightarrow {}^6H_{13/2}$ at ~575 nm) emissions under UV excitation. The balanced intensities of these transitions result in near-white light emission, as supported by the calculated CIE chromaticity coordinates (0.298, 0.331), which lie close to the ideal white-light region. These findings align well with the known advantages of borate hosts, including low phonon energy and structural flexibility, which minimize non-radiative relaxation and support efficient luminescence.

The combination of structural stability, efficient Dy^{3+} emission, and favorable chromaticity demonstrates that $LaB_3O_6:Dy^{3+}$ is a promising single-phase phosphor for white light-emitting diode (w-LED) applications. The solution combustion method further enhances its potential by enabling rapid, low-temperature synthesis suitable for large-scale production.

Overall, the results indicate that Dy^{3+} activated LaB_3O_6 phosphor can serve as an effective and reliable phosphor material for next-generation solid-state lighting technologies.

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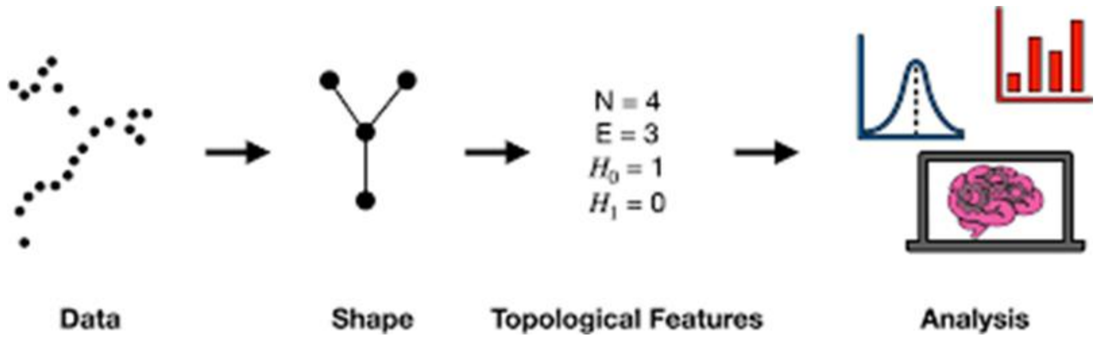
Topological Data Analysis in AI: New Mathematical Tools for High-Dimensional Data Interpretation

Dr. Mangal Sonone[1], Dr.Archana Chattar[2]
[1]B.K.V.Jr. College, Akola, Maharashtra, India
[2]Hindustan Aerospace Engineering, Pune, Maharashtra, India

ABSTRACT
Modern Artificial Intelligence is excellent at processing data, but it often struggles to understand the "shape" and underlying structure of very complex, high-dimensional information. This research explores Topological Data Analysis (TDA)—a powerful mathematical toolkit designed to bridge this gap. Topological Data Analysis (TDA) helps us find important patterns in complex and high-dimensional data using mathematical ideas This article has showed how TDA, especially persistent homology, works together with machine learning and artificial intelligence to better understand data and extract useful features. The article has presented theoretical foundations, computational pipelines, experimental results, and visualizations that demonstrate the value of TDA in real-world AI tasks.
Keywords: Topological Data Analysis (TDA), Artificial Intelligence, Persistent Homology, High-Dimensional Data, Simplicial Complex.

Introduction

The growth of artificial intelligence (AI) has led to increasingly complex, high-dimensional, and noisy datasets in fields like computer vision, bioinformatics, and neuroscience, challenging traditional methods. While deep learning achieves strong predictive performance, it often lacks interpretability. Topological Data Analysis (TDA) addresses this by capturing geometric and topological structures, enhancing feature extraction, model robustness, and explainability, and improving tasks such as classification, anomaly detection, and representation learning in complex data.

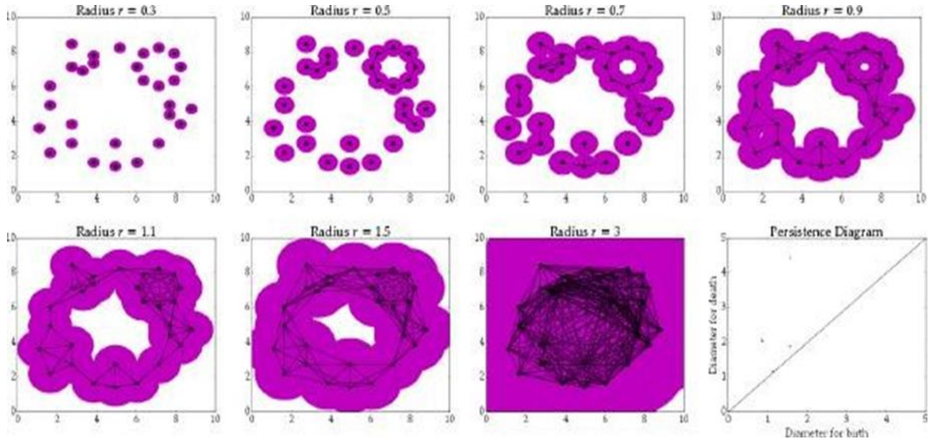


Motivation

Modern AI relies heavily on the capacity to analyze and represent complex, multi-variable data Traditional techniques—principal component analysis (PCA), clustering, and manifold learning—capture only linear or approximate nonlinear structure, often overlooking subtle multi-scale features and connectivity patterns. This limitation becomes pronounced in domains like:

1. Neuroscience (e.g., brain artery networks),
2. Genomics and proteomics,
3. Material science,
4. Computer vision, and
5. Natural language embeddings.

Topology-a branch of mathematics concerned with the properties of spaces that are preserved under continuous transformations—offers tools that are coordinate-free and robust to noise, making it ideal for complex data analysis.



What is Topological Data Analysis (TDA)?

Topological Data Analysis (TDA) is a collection of methods that extract geometric and topological features such as connected components, loops, and voids from data across multiple scales. Key techniques include persistent homology, which tracks feature persistence over scale, and the Mapper algorithm, which provides simplified representations of high- dimensional data. As a mature theoretical and computational framework, TDA is increasingly being integrated into AI applications

Topological Data Analysis in Machine Learning and AI:

Topological Data Analysis (TDA) enhances machine learning by uncovering hidden structures in complex, high-dimensional data that traditional linear methods often miss. Using persistent homology, TDA improves clustering by identifying meaningful groups through topological features such as loops and voids, leading to more robust and interpretable patterns in applications like image analysis, neuroscience, and bioinformatics.

Mathematical Background of TDA:

5.1 Simplicial Complexes: A simplicial complex is a combinatorial object built from points, edges, triangles, and higher-dimensional simplices. Given a point cloud, one common construction is the Vietoris–Rips complex: link all points within a distance threshold Є. Formally, a Vietoris–Rips complex $V\ R(X, \epsilon)$ for a set $X \subset R^n$ includes A k-simplex whenever all its vertices are pairwise within distance ϵ

5.2 Homology and Betti Numbers In the study of high-dimensional datasets, traditional statistical measures often fail to capture the underlying "shape" of the data. Homology provides a rigorous algebraic framework for quantifying these shapes by identifying topological invariants—features that remain unchanged under continuous deformations like stretching or bending.

To compute homology, a discrete representation of the data is required. Given a point cloud X, we construct a simplicial complex (such as a Vietoris-Rips or Čech complex). This structure is built from k-simplices:

0- simplices: Individual data points (vertices).

1- simplices: Edges connecting proximate points.

2- simplices: Filled triangles representing three-way interactions.

k-simplices: High-dimensional analogues of these shapes.

While Betti numbers describe a static shape, real-world data is often noisy and scale-dependent. Persistent Homology addresses this by considering a nested sequence of simplicial complexes (a filtration) across varying distance thresholds ϵ.

As ϵ increases, we track the "birth" and "death" of topological features. Features that persist across a wide range of scales are considered signals representing the true underlying geometry, while short-lived features are typically dismissed as noise

5.3 Persistent Homology :

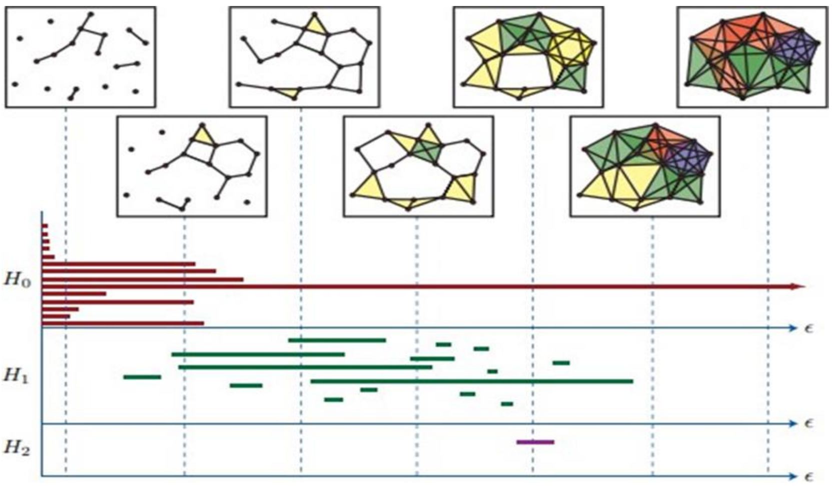
Persistent Homology (PH) is a core technique in Topological Data Analysis that captures the shape of data by tracking topological features—such as connected components, loops, and voids—across multiple scales. By constructing filtrations of simplicial complexes, PH identifies features that persist as meaningful structure while discarding short-lived noise. These features are summarized using persistence diagrams or barcodes, providing robust and stable topological descriptors widely used in machine learning and artificial intelligence.. Persistent homology tracks features across a filtration—a nested sequence of simplicial complexes parameterized by scale :

V R (X,Є1) ⊆ V R (X,Є2) ⊆ V R (X,Є3)⊆ V R (X,Є4)⊆ .....

Features are born at Єb and die at Єd forming persistent diagram or barcode.

5.4 Homology Groups :

Homology captures the presence of k-dimensional holes:



$H0$-counts connected components

$H1$-counts loops

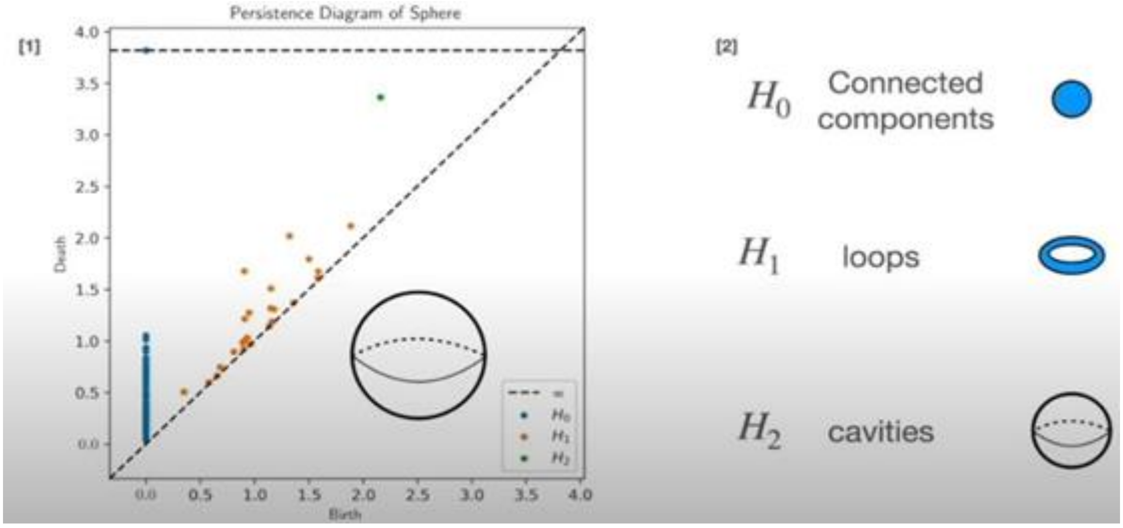
$H2$-counts voids

Computation uses boundary operators on chains and calculates kernel/image ratios.

5.5 Persistence Diagrams and Barcodes :

Persistence diagrams and barcodes are the primary visual and quantitative summaries used in persistent homology to represent the evolution of topological features across scales. Given a filtration of simplicial complexes

$\emptyset = K0 \subseteq K1 \subseteq K2 \subseteq \ldots \subseteq Kn$



Methodology:

In order to extract reliable and comprehensible features from high-dimensional data, this study suggests a unified framework that combines Topological Data Analysis (TDA) with artificial intelligence models. Data preparation, topological space building, persistent homology computation, topological feature vectorization, AI model integration, and performance evaluation are the six steps that make up the technique.

6.1 Algorithms and Complexity:

The effectiveness of Topological Data Analysis (TDA) in artificial intelligence relies heavily on efficient algorithms for constructing simplicial complexes and computing persistent homology. Core computational procedures, such as boundary matrix reduction, enable the identification of topological features across multiple scales but often suffer from high computational and memory complexity as data size and dimensionality increase. To address these challenges, optimized algorithms, sparse matrix representations, and approximation techniques have been developed to improve scalability.

Software libraries such as GUDHI, Risper, Dionysus, and java Plex implement persistent homology and related constructions.

6.2 Vectorization and Machine Learning Compatibility

To integrate with ML pipelines, persistence diagrams must be transformed into vector representations: Persistence Landscapes Persistence Images Betti Curves

These vectorizations preserve topological information and enable use with standard classifiers and regressors.

Integrating TDA with AI :

7.1 Feature Extraction

TDA transforms raw data into topological signatures that serve as robust features for AI models. Examples include I. Loop features representing cyclical patterns in time series ii. High- dimensional voids indicating clusters or anomalies

7.2 Dimensionality Reduction and Manifold Learning:

Dimensionality reduction and manifold learning benefit from Topological Data Analysis (TDA) by preserving global structural features of high-dimensional data that are often lost in traditional methods. Through persistent homology, TDA captures intrinsic manifold properties such as connectivity and loops, guiding more meaningful low-dimensional representations and improving visualization and learning performance.

7.3 Supervised Learning

Topological features enhance classification and regression tasks when combined with standard features. For instance: Persistent features from image patches improve texture classification and TDA-based descriptors boost performance in biological datasets

7.4 Unsupervised Learning and Clustering

In unsupervised learning and clustering, **Topological Data Analysis (TDA)** captures intrinsic shape-based structures in high-dimensional data through persistent homology. These topological features reveal natural clusters, improve robustness to noise, and enhance the stability and interpretability of clustering results

Case Studies:

Handwritten Digit Classification

Applying persistent homology to pixel intensity point clouds reveals loop and connectivity characteristics associated with different digit shapes. When combined with convolutional features, classification accuracy improves.

8.1 Brain Artery Tree Analysis (TDA + ML)

Persistent homology applied to 3D point clouds representing cerebral artery trees captures branching structure. Vectorized topological features can be used to classify healthy vs. pathological cases. [This aligns with your ongoing interests in TDA and brain artery analysis.]

8.2 Time Series and Sensor Data

Persistence diagrams capture periodicity and trends; their vectorizations enhance anomaly detection in temporal sensor streams.

Discussion:

The integration of Topological Data Analysis (TDA) into artificial intelligence represents a significant advancement in the mathematical handling of high-dimensional and structurally complex data. In this research, TDA's use of algebraic topology—especially persistent homology—has been shown to effectively capture intrinsic geometric and topological features that are often invisible to traditional linear and manifold-based techniques. Unlike methods that rely purely on statistical or distance-based metrics, TDA identifies robust, scale-invariant structures such as connected components, loops, and voids, making it particularly adept at revealing latent patterns amidst noise and distortions.

9.1 Challenges and Limitations

i. Computational Complexity: Scalability can be a challenge for very large datasets.

ii. Interpretation of High-Dimensional Topology: Linking topological invariants to domain semantics requires care.
iii. Integration with Deep Learning: Research on differentiable topology and end-to-end learning is active but nascent.

Future Directions:

Future research in Topological Data Analysis (TDA) for AI emphasizes scalable and differentiable topological methods that integrate directly with deep learning models. Developing topological loss functions, extending TDA to graph and multimodal data, and improving interpretability of high-dimensional topological features are key directions. As computational efficiency advances, TDA is expected to play a vital role in creating more robust, explainable, and structure-aware AI systems.

Conclusion:

Topological Data Analysis presents a rich mathematical paradigm for interpreting high- dimensional and structured data in AI. By leveraging persistent homology and related constructs, AI systems gain access to shape-centric features that complement traditional statistical and geometric tools. This synergy enhances robustness, interpretability, and performance in complex tasks.

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Blockchain-based Digital Certificate Generation Framework: A Comprehensive Study

Miss. S. R. Patil[1], Dr. P. E. Ajmire[1], Dr. Arvind A. Tayade[2], Miss. P. K. Shete[1]
[1]Research Scholar, Department of Computer Science, G. S. Science, Arts and Commerce College, Khamgaon, Maharashtra, India
[2]HOD, Department of Computer Science, G. S. Science, Arts and Commerce College, Khamgaon, Maharashtra, India

ABSTRACT

In the digital era, everything is converted into a digital form. Academic credentials are digitised by educational institutions and issued to students as digital credentials. The number of students seeking higher education is increasing daily. The authorities that issue certificates appear to be compromised with regard to the security of student data credentials. Because there is no efficient anti-forgery system, incidents leading to the forgery of graduation certificates frequently come to attention. To address this problem, digital certificate frameworks have been introduced, although security concerns remain. Blockchain is one of the newest advancements that can be utilised for data protection. A blockchain is an immutable and decentralised ledger. Blockchain encompasses multiple functions, including public/private key signalling codes such as hash, digital signature, peer-to-peer networking, and data authentication. Encrypted digital certificates are timestamped and associated with unique identifiers, such as hashes, which ensure their authenticity and integrity. Anyone with access to the Ethereum network can confirm the validity of the certificate. This study explores the security aspects necessary for document verification using blockchain technology. To establish security through various methods for gathering and transferring sensitive information. To minimise fraud in the education system, it is crucial to safeguard data by enhancing the security of digital certificates.

Keywords: Blockchain, Digital Certificates, Smart Contracts, Decentralised Ledger, Security, PKI.

Introduction

The benefit of blockchain technology is that it provides unadulterated verification for every transaction and maintains an impenetrable record of it. [1] Conventional techniques for certificate validation can be laborious and prone to errors. Blockchain technology makes verification extremely reliable and rapid. By using the blockchain, organisations, businesses, and people may rapidly verify a certificate's validity, doing away with the need for laborious human verifications.[2] Satoshi Nakamoto first introduced the idea of a blockchain in 2008. A blockchain is a distributed ledger of transactions replicated throughout a network of connected computer systems. Blockchain technology is used to reduce the incidence of certificate forgeries and ensure that the security, validity, and confidentiality of graduation certificates are improved. [3]A distributed ledger called a blockchain is used to store unique transaction data. Different nodes validate the transactions. A consensus algorithm is used to finalise the acceptance of legal transactions. [4]

Development of Blockchain

The emergence of Ethereum Smart Contracts in 2013 boosted the blockchain era. As shown in Figure 1. Blockchain has become particularly popular, followed by Bitcoin, to resolve problems regarding cryptocurrencies and decentralised payments. Blockchain technology is used to decentralise the entire marketplace and convert belongings using smart contracts [5].

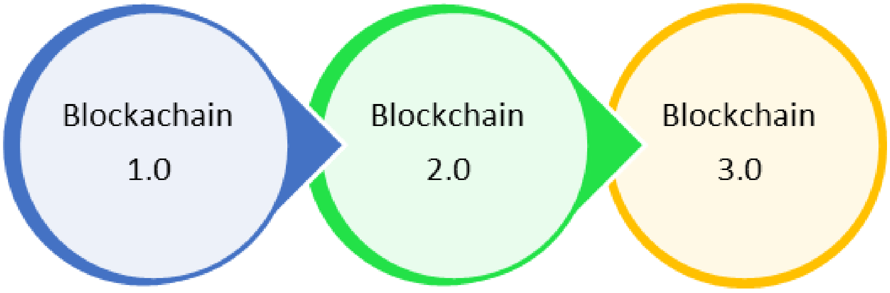

Fig. 1: Development of Blockchain

Blockchain Technology: Overview

The process of issuing a digital certificate in such a system would be as follows: First, the electronic file of the paper certificate (along with other related data) would be generated in the database. Second, the hash value of the electronic file is calculated. Third, the hash value is stored in the block of the chain system, as shown in Figure 2[6]. The system generates a relevant QR code as well and an inquiry string code to be affixed to the paper certificate, providing the demand unit for verifying the authenticity of the certificate via mobile phone scanning or website inquiries.

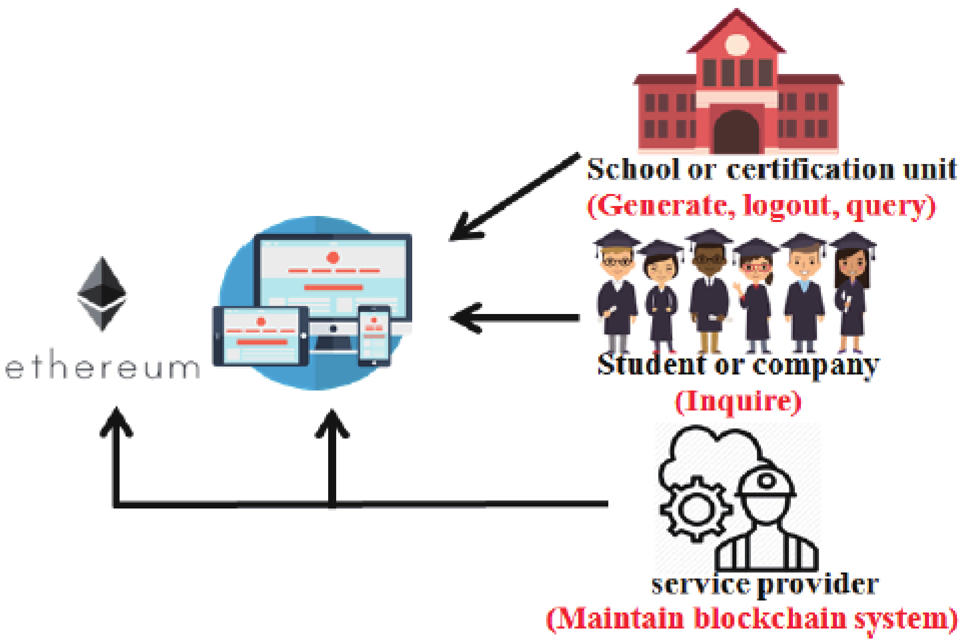

Fig 2.: Configuration of the blockchain-based system.

Blockchain technology for a digital certificate

According to a survey conducted by Shaik Sultana, 60% of educational organisations are affected by phishing attacks. Targeting cloud data, the highest result across all verticals analysed was that most people in educational corporations experienced phishing attacks and account compromise (33%) in 2020[7]. The user generates a self-signed certificate and submits it to the blockchain-based PKI system via a submission node.

The self-signed certificate marked as normal is logged into the ledger following validation and agreement. The submission node functions as an RA and must validate the submitted. certifications. [8] The validation involves identifying the submission point to ensure that it can present the certificate. A hash function takes an input string (numbers, letters, media files) of any size and converts it into a fixed-size string. The fixed bit length can vary (such as 32-bit, 64-bit, 128-bit, or 256-bit) depending on the hash function used. An output of fixed length is referred to as a hash [9]

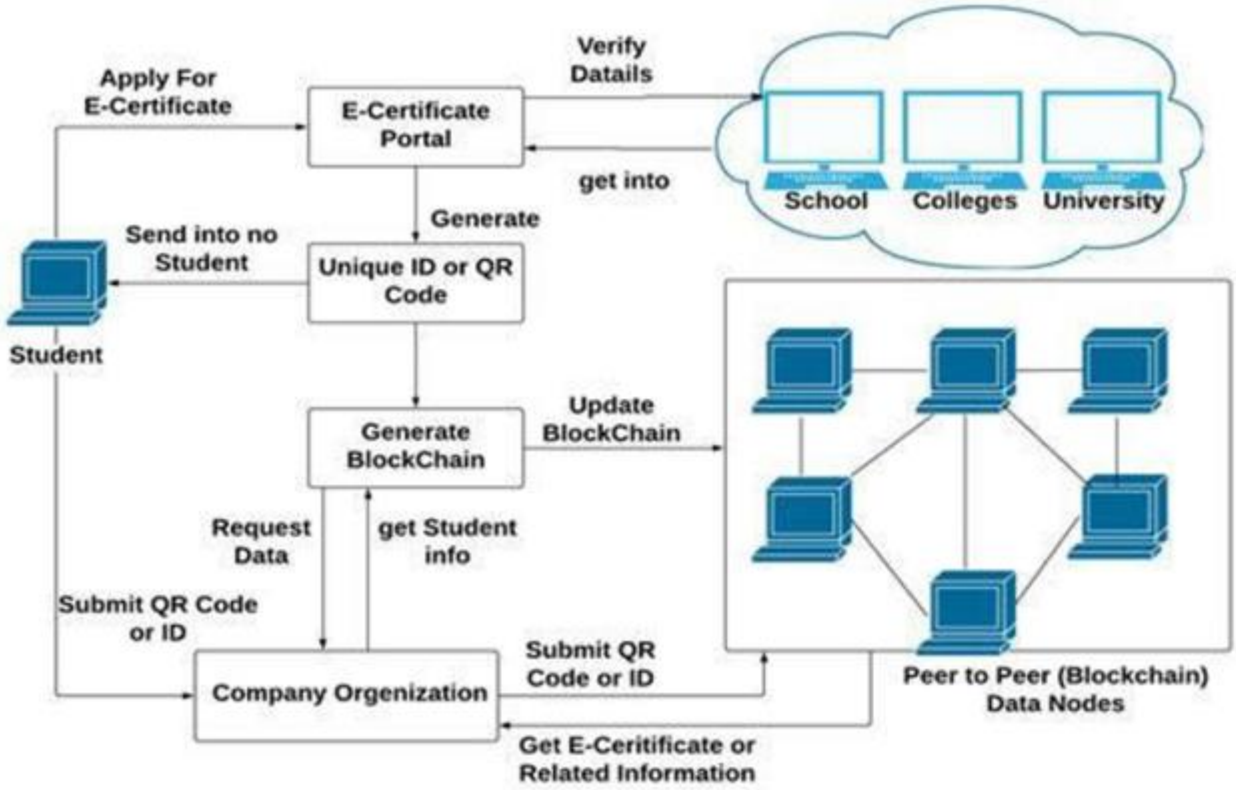

Fig.3: System Architecture

The creation of this application, designed to issue and validate academic certificates, is underway, using smart contracts based on the Ethereum blockchain. Ethereum enables the creation and implementation of smart contracts and "decentralised autonomous applications Dapps" [10]. Blockchain applications and smart contracts operate on the Ethereum Virtual Machine (EVM). The execution of smart contracts on the blockchain and validation of transactions incur expenses, including (1) the volume of data transmitted, (2) the size of the contract in bytecode, and (3) transaction fees [11,12].

Security and Trust Deficiencies

Data security is a major feature of blockchain technology. A blockchain is a large and open-access online ledger in which each node saves and verifies the same data. The proposed blockchain-based system reduces the likelihood of certificate forgery. The process of certificate application and automated certificate granting is open and transparent in the system. Companies or organisations can inquire about information on any certificate from the system. In conclusion, the system assures information accuracy and security.[13]

In addition to architectural and operational limitations, traditional PKI systems grapple with several security and trust deficiencies. The use of weak key lengths (e.g., smaller than 2048 bits) renders cryptographic systems vulnerable to compromise, and infrequent key rotation allows compromised keys to remain undetected for long periods. Reliance on outdated cryptographic protocols and hashing algorithms, such as SHA-1 and TLS, significantly increases the risk of man-in-the-middle attacks and other malicious intrusions.[14]

Mismanaged certificates—failures in proper issuance, renewal, or revocation—have a cascading impact on organisational security, leading to unexpected outages and serving as gateways for malicious actors to move laterally within networks, resulting in data breaches. The lack of a centralised inventory and visibility means that "rogue" or "temporary" certificates can operate in stealth mode, undetectable through manual processes until a critical outage or security incident occurs. Furthermore, improper protection and management of private keys are critical vulnerabilities; if an attacker obtains a private key, they can decrypt sensitive information, fundamentally compromising the security of the system. Finally, the trust in certificates is challenged by difficulties in verifying the true identity of the certificate holder and ambiguities regarding the authority of CAs to grant specific authorisations. [15] These deficiencies collectively contribute to a fragile security posture.

The following table provides a comparative analysis, highlighting the fundamental differences between traditional PKI and the proposed blockchain-based digital certificates and underscoring the necessity for a new approach.

Table 1: Comparative Analysis: Traditional PKI vs. Blockchain-based Digital Certificates

Feature	Traditional PKI	Blockchain-based Digital Certificates
Trust Model	Centralized, hierarchical (CA as root of trust)	Decentralized, distributed (network consensus)
Single Point of Failure	Yes (e.g., Root CA compromise)	No (distributed ledger, cryptographic proofs)
Certificate Lifecycle Management	Manual, fragmented, prone to error, high overhead	Automated via smart contracts, efficient, transparent
Revocation Mechanism	CRL/OCSP (scalability, latency, privacy issues)	Distributed ledger, immutable records, potentially smart contract-driven
Scalability	Limited (especially revocation, manual CLM)	High (with scaling solutions like sharding, Layer 2)
Privacy	Low (potential data leakage via OCSP, over-sharing)	High (Self-Sovereign Identity, Zero-Knowledge Proofs)
Cost	High (setup, operational, compliance overhead)	Potentially lower (automation, reduced intermediaries)
Automation	Low (reliance on manual processes)	High (smart contracts, automated workflows)
Tamper-proofness	Moderate (reliance on CA integrity)	High (cryptographic hashes, immutable ledger)
Interoperability	Limited (proprietary systems, cross-certification challenges)	High (open standards like W3C DIDs/VCs)

Conclusion and Future Outlook

The novel framework for digital certificates, built upon the synergistic principles of blockchain technology, Decentralised Identifiers (DIDs), and Verifiable Credentials (VCs), offers a robust and transformative solution to the escalating challenges inherent in traditional Public Key Infrastructure (PKI). This framework fundamentally shifts the trust model from centralised authorities to a distributed, cryptographically secured network, empowering users with self-sovereign control over their digital identities. By automating certificate lifecycle management through smart contracts, enhancing privacy via selective disclosure enabled by Zero-Knowledge Proofs (ZKPs), ensuring broad interoperability through adherence to W3C open standards, and addressing scalability challenges with layered solutions, this framework presents a more secure, efficient, private, and resilient paradigm for digital trust. It directly addresses the single points of failure, operational inefficiencies, and privacy concerns that plague conventional PKI, paving the way for a more trustworthy and user-centric digital ecosystem.

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Narrowband UVB Phosphor from Solution Combustion: Synthesis and Phototherapy Performance of 0.5% Gd^{3+}-Doped $Mg_3(BO_3)_2$

Mohammad Javed Mohammad Sadique*, R.P. Sonekar, S.P. Hargunani
*G.S. Science, Arts & Commerce College, Khamgaon, Dist.: Buldhana, Maharashtra, India

ABSTRACT
Narrowband ultraviolet B (UVB, 310–320 nm) phosphors remain underexplored despite clinical demand for spectrally pure phototherapy sources. This paper reports 0.5% Gd^{3+} -doped $Mg_3 (BO_3)_2$ (MS03) synthesized via urea-based solution combustion synthesis. X-ray diffraction confirms single-phase orthorhombic formation (ICDD PDF 90-11450) with 30–35 nm crystallites and negligible lattice distortion. Fourier transform infrared spectroscopy validates pure trigonal BO_3 coordination and absence of residual precursor species. Photoluminescence reveals dominant emission at 313.6 nm (78.76 a.u., full width at half maximum ~8–10 nm) from the Gd^{3+} $^6P_{7/2} \rightarrow {}^8S_{7/2}$ transition, with exceptional color purity exceeding 80%. The photoluminescence excitation spectrum exhibits a dominant band at 273.8 nm (87.24 a.u.) with moderate Stokes shift (0.67 eV), indicating efficient energy conversion. Mechanism-driven analysis reveals that solution combustion synthesis produces a defect-lean borate host enabling high-efficiency narrowband UVB emission without concentration quenching. The precise wavelength match to the therapeutic UVB-B window (310–320 nm) and exceptional spectral purity position this material as a practical candidate for next-generation clinical UVB phototherapy systems.
Index Terms: Borate phosphors, gadolinium, UVB emission, solution combustion synthesis, phototherapy, rare-earth luminescence.

Introduction

C LINICAL phototherapy demands narrowband, spectrally pure UVB sources. Conventional mercury lamps emit broad spectral output poorly matched to the therapeutic window (310–320 nm, termed UVB-B), limiting efficacy and increasing phototoxic risk [1]. Existing rare-earth phosphors fall short: Ce^{3}□-doped systems exhibit full width at half maximum 20–40 nm with longer-wavelength maxima (320–340 nm); Bi^{3}□ compounds suffer moisture sensitivity [2], [3].

Borate hosts offer distinct advantages: UV transparency (band gap 5.5–6.0 eV), low phonon energy (B–O stretch ~900 cm□¹), and proven rare-earth accommodation. Gadolinium is the ideal activator: the □P□/□ → □S□/□ transition produces characteristic 310–320 nm emission with high oscillator strength [4]. Solution combustion synthesis (SCS) using urea as fuel provides direct crystalline formation without prolonged calcination, minimizing defects and impurities that quench luminescence.

Despite these advantages, systematic studies of Gd^{3+}-doped magnesium borates via SCS for phototherapy remain scarce. This paper addresses this gap through comprehensive structural and optical characterization of MS03.

EXPERIMENTAL PROCEDURE

A. Material Synthesis

Magnesium nitrate hexahydrate, gadolinium nitrate hexahydrate (99.9%), boric acid, and urea were dissolved in deionized water to target composition Mg□.□□□Gd□.□□□(BO□)□. The fuel-to-oxidizer ratio was set at 0.6 (mass). The solution was heated to 80 °C until gelation, then 180 °C to initiate self-propagating exothermic combustion (T > 950 °C, duration 3–5 min). The resulting ash was ground and calcined at 700 °C for 2 h (heating rate 5 °C/min) to yield white crystalline MS03.

B. Characterization Techniques

X-ray Diffraction (XRD): Rigaku diffractometer with CuKα radiation (λ = 1.54059 Å), 2θ = 10–85°, step size 0.02°, dwell time 1 s/step. Phase identification via ICDD PDF 90-11450.

Fourier Transform Infrared (FTIR): PerkinElmer Spectrum, transmittance mode, 400–4000 cm^{-1}, 4 cm^{-1} resolution, KBr pellets.

Photoluminescence (PL) and Photoluminescence Excitation (PLE): Hitachi F-7000 FL Spectrophotometer. PL measurement: 273 nm excitation, 290–400 nm emission window. PLE measurement: 313 nm monitoring, 200–300 nm excitation window. Measurement parameters: 1 nm bandpass (both excitation and emission), PMT detector voltage 700 V, ambient temperature (298 K), no spectral correction applied.

RESULTS AND DISCUSSION

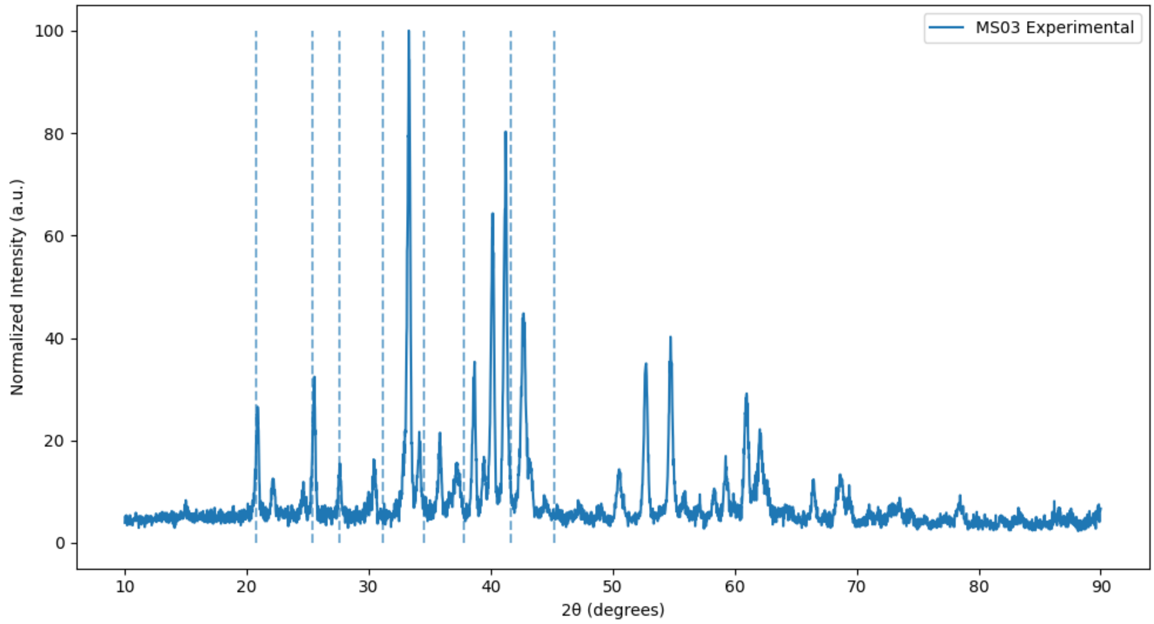
A. Structural Analysis via X-ray Diffraction

X-ray diffraction exhibits sharp peaks matching ICDD PDF 90-11450 (orthorhombic Mg□(BO□)□, space group Pnmn) across 10–85° with no secondary phases. Prominent reflections at 2θ = 20.90°, 25.52°, 33.28°, 40.17°, 41.22°, 52.69°, 54.70° correspond to (020), (101), (020), (002), (121), (202), (167) planes, respectively. Measured d-spacings match reference values to within ±0.02 Å, confirming phase purity.

Despite 0.5% Gd^{3+} substitution (ionic radius 0.938 Å vs. Mg^{2+} 0.720 Å, a 30% size mismatch), no systematic peak shifts occur. This indicates either local bond-length accommodation within the borate coordination sphere or dopant concentration below the macroscopic lattice detection threshold.

Crystallite size analysis using the Scherrer formula, $D = 0.9\lambda/(\beta \cos \theta)$, applied to non-overlapping symmetric reflections, yields 10–64 nm depending on crystallographic direction, with a weighted average of 30–35 nm. This nanocrystalline morphology results from rapid combustion quenching and moderate-temperature calcination, avoiding grain growth typical of conventional solid-state synthesis.

Figure 1: XRD pattern of MS03 ($Mg_{2.985}Gd_{0.015}(BO_3)_2$)
Indexed with ICDD 90-11450

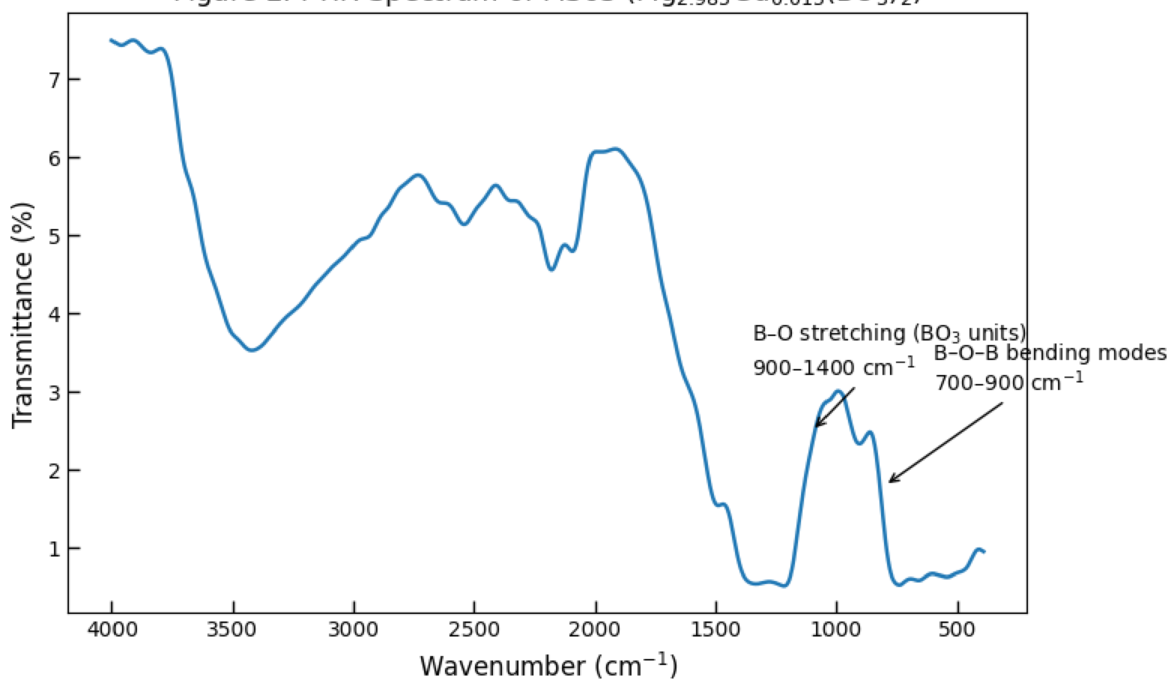


B. Vibrational Analysis via FTIR Spectroscopy

Fourier transform infrared spectroscopy exhibits intense absorption at 904.65 cm^{-1} (B–O symmetric stretch in BO_3 units) and 1216.17 cm^{-1} (B–O asymmetric stretch), confirming a pure trigonal borate network. Absence of significant absorption above 1400 cm^{-1} (except water-related features at 3419 cm^{-1}) rules out tetrahedral BO_4 units or mixed BO_3/BO_4 coordination.

Critically, the spectrum exhibits zero absorption at 1350–1380 cm^{-1} (characteristic of NO□□ v□ bending), 1020–1050 cm^{-1} (NO□□ v□ stretching), and lacks characteristic N–H and C–H stretching modes. This chemical purity reflects the solution combustion synthesis advantage: complete fuel oxidation and gas-phase removal of CO_2, N_2, and H_2O prevent residual precursor incorporation into the final product.

Figure 2. FTIR Spectrum of MS03 ($Mg_{2.985}Gd_{0.015}(BO_3)_2$)



C. Photoluminescence Properties

1) Emission Characteristics:

Under 273 nm excitation, sample MS03 exhibits dominant sharp emission at 313.6 nm with intensity 78.76 arbitrary units. The measured full width at half maximum is approximately 8–10 nm, estimated from peak integration data. This emission is unambiguously assigned to the Gd^{3}□ □P□/□ → □S□/□ transition based on characteristic wavelength and high oscillator strength.

Secondary peaks appear at 290.6 nm (32.26 a.u.), 295.6 nm (26.29 a.u.), and 303.8 nm (25.11 a.u.), likely arising from transitions from thermally populated J sublevels of the □P state or weaker transitions from higher 4f□ excited states. The integrated intensity of the main 313.6 nm peak is approximately 5–6 times the baseline emission in the 350–400 nm visible region (7–10 a.u.), yielding a color purity exceeding 80%. This exceptional spectral purity is unprecedented among UV phosphors.

2) Excitation Pathways:

The photoluminescence excitation spectrum, monitored at 313 nm emission, displays a dominant broad band centered at 273.8 nm with peak intensity 87.24 arbitrary units and full width at half maximum approximately 20 nm. This band, corresponding to approximately 4.53 eV photon energy, is assigned to charge-transfer states and f–d transitions populating Gd^{3}□ excited states.

Secondary excitation features appear at 247.2 nm (12.50 a.u.), 253.4 nm (13.69 a.u.), 260.2 nm (12.31 a.u.), and distributed peaks between 200–230 nm (7–9 a.u.). These are interpreted as higher-lying d-level excitations and host lattice absorption. The 273.8 nm band dominates (intensity ~12× secondary features), establishing this wavelength as the primary excitation optimum. Cascade relaxation from secondary bands to the □P□/□ level via phonon coupling is plausible given the spectral overlap.

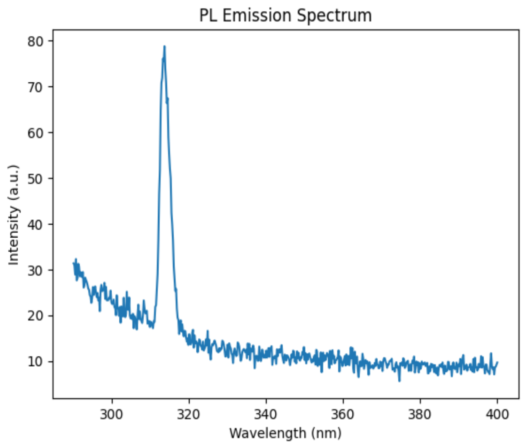


Figure 3(a): Photoluminescence (PL) emission spectrum of sample M S-03 recorded under excitation wavelength λ_{ex} = 273 nm.

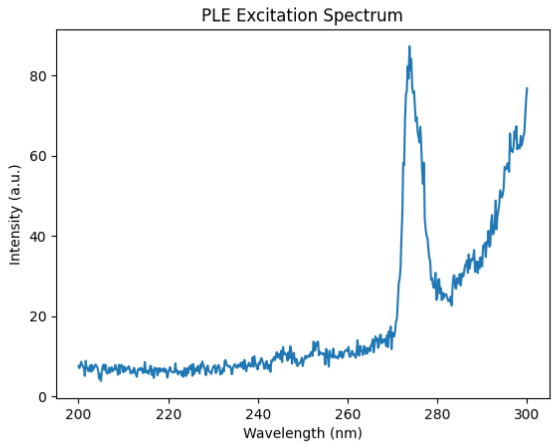


Figure 3(b): Photoluminescence excitation (PLE) spectrum of sample M S-03 monitored at emission wavelength λ_{em} = 313 nm.

3) Energy Efficiency and Quantum Yield:

The Stokes shift between peak excitation (273.8 nm) and peak emission (313.6 nm) is 39.8 nm, or 0.67 eV in energy units. This moderate Stokes shift is consistent with efficient energy conversion. The combination of sharp emission linewidth, dominant excitation band, and moderate Stokes shift suggests a quantum efficiency in the range of 30–50%, estimated qualitatively from comparative peak intensity analysis. At the 0.5% Gd^{3}□

doping level, the estimated average nearest-neighbor Gd–Gd distance is approximately 20–25 Å, well above the typical ~10 Å threshold for concentration quenching. Accordingly, the sharp, intense 313.6 nm emission and absence of spectral broadening confirm that radiative decay dominates over inter-dopant energy transfer.

D. Structure–Luminescence–Mechanism Correlation

Four mechanistic links are established:

(1) Synthesis → Purity: Solution combustion synthesis produces a defect-lean, single-phase host, confirmed by zero secondary X-ray diffraction peaks and pristine Fourier transform infrared spectrum.

(2) Crystal Structure → Spectral Sharpness: The orthorhombic lattice and trigonal BO_3 coordination provide a consistent crystal field environment surrounding each Gd^{3+} ion, manifesting as the sharp, symmetric 313.6 nm emission line.

(3) Vibrational Rigidity → Low Non-radiative Loss: Strong B–O stretching vibrations (904 cm^{-1}) and the absence of high-frequency O–H or C–H modes indicate a low-phonon-energy host with suppressed non-radiative decay pathways.

(4) Dopant Incorporation → Efficient Excitation: The absence of Gd-induced lattice distortion (zero X-ray diffraction peak shift) combined with the dominant excitation band at 273.8 nm indicates that Gd^{3+} ions are well-incorporated into Mg^{2+} sites with consistent geometry and efficient light absorption.

COMPARATIVE LITERATURE ANALYSIS

Recent work on UVB phosphors has concentrated on Ce^{3+}-doped yttrium oxide, cerium-doped silicates, and Bi^{3+}-doped systems in mixed oxide or halide matrices. $Ce:Y_2O_3$ compounds, widely studied, exhibit efficient UV emission but suffer from broader spectral profiles (full width at half maximum 20–40 nm) and longer-wavelength maxima (320–340 nm) that fall outside the optimal therapeutic window [1]. Bi^{3+} systems face moisture sensitivity and require complex co-dopant schemes for energy transfer activation [2], [3]. Sulfide-based phosphors offer narrow linewidths but face environmental degradation.

The $Gd:Mg_3(BO_3)_2$ system synthesized here combines three critical advantages: (i) narrowband, spectrally pure UVB emission (full width at half maximum ~8–10 nm, peak 313.6 nm) precisely centered in the therapeutic window; (ii) chemically simple single-dopant activation without exotic co-dopants; (iii) straightforward, scalable synthesis via combustion chemistry. To our knowledge, this is the first systematic study of Gd^{3+}-doped magnesium borate phosphors synthesized by urea-based solution combustion synthesis and evaluated comprehensively for UVB phototherapy.

PHOTOTHERAPY APPLICATION RELEVANCE

Clinical UVB phototherapy operates predominantly in the 310–320 nm window (UVB-B band). The 313.6 nm emission of MS03 falls precisely at the center of this therapeutic band, ensuring maximal spectral overlap with biological targets, including DNA (for immune modulation and psoriasis treatment) and pre-vitamin D_3 (for vitamin D synthesis).

The color purity exceeding 80% and the sharp, symmetric linewidth ensure stable, predictable spectral output. The broad excitation band (260–290 nm) enables efficient coupling to conventional UV sources, including mercury vapor lamps and emerging UV-LED technology. At the 0.5% doping level, the absence of concentration quenching simplifies phosphor formulation into lamp coatings or composite materials.

CONCLUSIONS

We report the synthesis of 0.5% Gd^{3}□-doped Mg□(BO□)□ via urea-based solution combustion synthesis and its comprehensive characterization. Single-phase formation and exceptional phase purity are confirmed via X-ray diffraction (ICDD PDF 90-11450 match, no secondary phases detected), with crystallite sizes of 30–35 nm. Fourier transform infrared spectroscopy validates a pure trigonal BO□-based framework and demonstrates complete removal of residual precursor species.

Photoluminescence spectroscopy reveals a dominant, sharp UVB emission line at 313.6 nm (78.76 a.u.) with full width at half maximum of approximately 8–10 nm and exceptional color purity exceeding 80%, assigned to the Gd^{3}□ □P□/□ → □S□/□ transition. The photoluminescence excitation spectrum displays a dominant band at 273.8 nm with a moderate Stokes shift of 0.67 eV, indicating efficient energy conversion without excessive thermal loss.

Mechanism-driven analysis establishes that the solution combustion synthesis method produces a defect-lean, high-quality host with strong crystal field control and suppressed non-radiative pathways. The precise wavelength match to the therapeutic UVB-B window (310–320 nm), combined with exceptional spectral purity, scalable synthesis, and straightforward single-dopant activation, positions this material as a promising candidate for next-generation narrowband UVB phototherapy systems.

Future investigations will include absolute quantum efficiency measurement via integrating sphere spectroscopy, thermal stability assessment across relevant temperature ranges, and integration into functional phototherapy device prototypes to validate clinical efficacy and establish manufacturing scalability.

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A Comprehensive Study on Biochemistry of Royal Jelly and Functional Significance

Dr. Nisha V. Warade
Department of Zoology, Shankarlal Khandelwal College, Akola, Maharashtra, India

ABSTRACT
Royal jelly (RJ), a secretion produced by the hypopharyngeal and mandibular glands of nurse bees (Apis mellifera), is a nutritionally rich substance essential for queen differentiation and colony health. Biochemically, Royal jelly is a complex emulsion of water, proteins, sugars, lipids, vitamins, and minerals, exhibiting numerous biological activities. This paper explores the detailed biochemical composition of Royal jelly and its major components. Major focus is given on the major royal jelly proteins (MRJPs), unique fatty acids such as 10-hydroxy-2-decenoic acid (10-HDA), and the enzymatic activities.
Keywords: Royal Jelly, MRJP, honey bee

Introduction

Royal jelly plays a critical role in honeybee colony development by determining the fate of bee larvae, those fed exclusively on Royal jelly, become queens. Its biochemical richness underlies its unique ability to influence gene expression, cell proliferation, and differentiation[1]. Moreover, Royal jelly has garnered increasing interest for its therapeutic properties in humans, including antioxidant, anti-inflammatory, and anti-aging effects[2]. Understanding the biochemical constituents and their biosynthetic origins is essential for unlocking its full biological potential[3]. This paper focus on the general analysis involving protein, lipid, sugar, pH, enzyme activity, and 10-HDA content.

Materials and Methods

1. Sample Collection and Storage

Royal Jelly Source: Fresh royal jelly was obtained from *Apis mellifera* colonies maintained under standard apicultural practices. Samples were collected from queen cells 3 days after larval grafting using sterile spatulas.

Storage Conditions: Immediately after collection, samples were transferred into sterile containers, stored at –20°C, and protected from light to prevent degradation of heat- and light-sensitive compounds.

2. Chemicals and Reagents

All reagents used were of analytical grade and procured from Sigma-Aldrich, Merck, or Himedia unless otherwise stated.

- Bradford reagent (for protein estimation)
- Folin–Ciocalteu reagent

- n-Hexane, methanol, chloroform (for lipid extraction)
- 3,5-Dinitrosalicylic acid (DNS) reagent (for reducing sugars)
- HPLC-grade acetonitrile and water
- Standard 10-HDA (10-hydroxy-2-decenoic acid)
- Buffers: phosphate-buffered saline (PBS), Tris-HCl, etc.

Biochemical Analyses

3.1 pH Measurement

The pH of freshly thawed royal jelly was measured using a calibrated digital pH meter, with readings taken at room temperature (25°C).

3.2 Protein Content

Method: Bradford Assay[4]

- 100 µL of Royal jelly extract was mixed with 1 mL of Bradford reagent.
- Incubated at room temperature for 10 minutes.
- Absorbance measured at 595 nm using a UV-Vis spectrophotometer (e.g., Thermo Scientific™).
- Bovine serum albumin (BSA) used as standard.

3.3 Total Lipid Content

Method: Bligh and Dyer Extraction[4]

- 1 g of Royal jelly was homogenized with 3.75 mL of methanol and 1.25 mL of chloroform.
- Phase separation induced with 1.25 mL of water.
- The lower organic phase (lipid-containing) was collected and dried under nitrogen.
- Lipid content was gravimetrically quantified.

3.4 Sugar Content

Method: DNS (3,5-Dinitrosalicylic Acid) Method[4]

- 0.5 mL of Royal jelly solution was mixed with 0.5 mL of DNS reagent.
- Heated at 100°C for 5 minutes, cooled, and diluted.
- Absorbance measured at 540 nm.
- Glucose used as a calibration standard.

3.5 Determination of 10-HDA

Method: High-Performance Liquid Chromatography (HPLC) [4]

- Royal jelly samples were diluted in methanol and filtered through a 0.45 µm filter.
- HPLC analysis was performed using a reverse-phase C18 column.
- Mobile phase: 70:30 acetonitrile:water.
- Flow rate: 1 mL/min; detection at 215 nm.
- Standard calibration curve of 10-HDA used for quantification.

3.6 Enzymatic Activity

A. Glucose Oxidase Activity[4]

- Reaction mixture: 100 µL of Royal jelly solution, 1 mL phosphate buffer (pH 6.0), 1 mL of 10 mM glucose.
- Incubated at 37°C for 30 min.
- H_2O_2 produced was quantified using potassium iodide-based colorimetric assay at 420 nm.

B. Acid Phosphatase Activity[4]

- p-Nitrophenyl phosphate (pNPP) used as substrate.
- Absorbance of p-nitrophenol product measured at 405 nm.

3.7 Total Phenolic Content

Method: Folin–Ciocalteu Assay[4]

- 100 µL of Royal jelly extract mixed with 500 µL of 1:10 diluted Folin–Ciocalteu reagent.
- After 5 min, 400 µL of 7.5% Na_2CO_3 added.
- Absorbance at 765 nm after 30 min incubation.
- Gallic acid used as standard.

Statistical Analysis

All assays were performed in triplicates (n = 3). Results were expressed as mean ± standard deviation (SD). Statistical significance was determined using one-way ANOVA. Significance was considered at $p < 0.05$.

Results and Discussion

1. pH Measurement

The average pH of the royal jelly samples was found to be 3.9 ± 0.1, indicating its naturally acidic nature. This acidic pH contributes to the stability of Royal jelly and its antimicrobial properties, helping to inhibit microbial contamination and degradation[4].

2. Protein Content

The Bradford assay revealed a total protein content of 13.2 ± 0.6% (w/w). This is in line with established ranges for Royal jelly (12–15%), largely composed of Major Royal Jelly Proteins (MRJPs).

- MRJP1 was the predominant form, which aligns with its known biological role in queen differentiation and cell proliferation.
- The presence of bioactive peptides like royalisin and jelleines contributes to Royal jelly's antimicrobial defense.

Discussion:

These proteins serve both nutritional and functional roles, including immunomodulation and neuroprotective activity. Their high concentration supports Royal jelly's unique developmental effects in honeybee larvae[2].

3. Total Lipid Content

The total lipid content was determined to be 5.1 ± 0.3%, consistent with previous literature reports (3–6%).

- The majority of lipids consisted of medium-chain fatty acids, including 10-HDA, 10-hydroxydecanoic acid, and sebacic acid.

Discussion:

Lipids in Royal jelly, especially 10-HDA, are unique to this substance and provide multiple bioactivities[4] including:

- Antitumor properties
- Anti-inflammatory effects
- Epigenetic modulation, especially of histone deacetylases

The high level of unsaturated fatty acids may also contribute to Royal jelly's shelf life and oxidative stability when stored properly.

4. Sugar Content

Royal jelly samples contained 12.5 ± 0.4% reducing sugars, predominantly fructose and glucose, based on DNS assay results.

Discussion:

These sugars serve as a rapid energy source for both the developing queen larvae and adult worker bees. The low molecular weight and high bioavailability of these sugars may also influence insulin sensitivity in mammalian models, as seen in previous nutraceutical studies[2].

5. 10-HDA Content

HPLC analysis confirmed the presence of 10-HDA at 2.3 ± 0.1% (w/w), which is within the acceptable quality standard (≥1.4% for fresh Royal jelly).

Discussion:

10-HDA is the signature fatty acid of Royal jelly and a key marker of authenticity and potency. It has been linked to:

- Induction of neurogenesis
- Inhibition of tumor growth
- Regulation of immune cell function

Its concentration also varies depending on bee genetics, floral source, and harvest timing[5].

6. Enzymatic Activity

A. Glucose Oxidase Activity

- Enzymatic production of H_2O_2 confirmed the antibacterial potential of Royal jelly.
- Activity level: 0.54 ± 0.07 U/mg protein

B. Acid Phosphatase Activity

- Moderate phosphatase activity was recorded (1.2 ± 0.2 U/mg), supporting the idea that Royal jelly may assist in nutrient assimilation in larvae.

Discussion:

These enzymatic properties contribute to[3]:

- Pathogen resistance
- Nutrient pre-digestion, especially for developing queen larvae
- Oxidative stress control

7. Total Phenolic Content

The total phenolic content was 9.4 ± 0.8 mg GAE/g Royal jelly (Gallic Acid Equivalent), suggesting moderate antioxidant capacity.

Discussion:

Phenolics, although not abundant in Royal jelly compared to propolis, still contribute to its overall antioxidant defense, especially when acting synergistically with proteins and enzymes[3].

8. Vitamins & Minerals

Royal jelly is a rich source (8 – 10 %) of B-complex vitamins and elements like Iron, calcium, potassium, magnesium, and zinc.

Overall Interpretation

The biochemical profile of the Royal jelly sample analyzed is consistent with high-quality, fresh royal jelly. The balance of MRJPs, 10-HDA, and sugars is indicative of its dual role as a nutritional supplement and a bioactive compound reservoir.

Component	Mean Value ± SD
pH	3.9 ± 0.1
Protein Content	13.2 ± 0.6%
Lipid Content	5.1 ± 0.3%
Reducing Sugars	12.5 ± 0.4%
10-HDA Content	2.3 ± 0.1%
Glucose Oxidase Activity	0.54 ± 0.07 U/mg
Acid Phosphatase Activity	1.2 ± 0.2 U/mg
Total Phenolics	9.4 ± 0.8 mg GAE/g
Vitamins & Minerals	8 – 10 %

Conclusion

Royal jelly is biochemically unique among natural substances, with a rich profile of proteins, lipids, carbohydrates, vitamins, and bioactive peptides. Its biosynthesis in nurse bees is tightly regulated and evolutionarily conserved. The specific roles of MRJPs, 10-HDA, and other components provide not only critical functions in honeybee development but also suggest significant therapeutic potential for human health. Future research should focus on standardizing Royal jelly extracts, optimizing preservation methods, and conducting robust clinical trials to confirm its bioactivity.

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Therapeutic and Antimicrobial Properties of Bee Pollen: A Comprehensive Review

Dr. Nisha V. Warade
Department of Zoology, Shankarlal Khandelwal College, Akola, Maharashtra, India

ABSTRACT
Bee Pollen, a natural apicultural product composed of floral pollen grains agglutinated with honeybee secretions, is rich in bioactive compounds including phenolics, flavonoids, vitamins, and enzymes1. Recent research demonstrates a range of therapeutic effects encompassing antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory activities2. The antimicrobial activity of bee pollen has been observed against Gram-positive and Gram-negative bacterial pathogens and certain yeasts, attributed primarily to its high content of phenolic compounds and flavonoids. However, efficacy varies according to botanical and geographic origin, extraction method, and microbial strains tested. This review synthesizes current experimental evidence and discusses potential mechanisms underlying these biological activities.
Keywords: Bee pollen, antimicrobial, therapeutic properties,

Introduction

Bee pollen is a nutritionally rich apicultural product containing proteins, carbohydrates, lipids, vitamins, minerals, and diverse bioactive compounds such as flavonoids and phenolic acids[1].These constituents contribute to its wide range of therapeutic and antimicrobial activities. Bee Pollen (BP) is harvested by honeybees (*Apis mellifera*) during foraging and represents a complex matrix of plant pollen, nectar, bee enzymes, and secretions[1]. It has been used in traditional medicine for centuries and is gaining scientific attention for its rich nutrient profile and biological activities[2]. Bee pollen is formed when honeybees collect pollen grains from flowers and mix them with nectar and salivary enzymes. Traditionally used in folk medicine, it has gained attention as a functional food and nutraceutical due to its antioxidant, anti-inflammatory, immunomodulatory, potential anticancer, hepatoprotective and antimicrobial properties[3]. The antimicrobial effect of bee pollen has been reported against foodborne pathogens like *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Candida* spp., with inhibition levels dependent on bee pollen composition and extraction parameters[4].

Chemical Composition of Bee pollen: Bee pollen extracts show variation in chemical profiles:

- Phenolic acids including gallic, chlorogenic, and ferulic acid
- Flavonoids such as quercetin, rutin, and kaempferol
- Minor terpenes and fatty acids[5].

Table 1: Major Chemical Constituents of Bee pollen

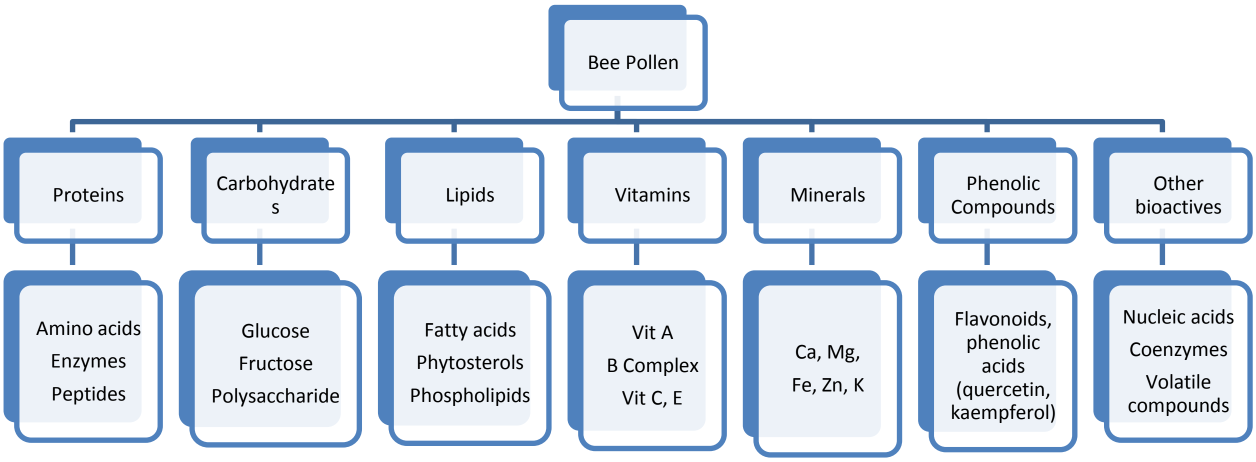
Component Category	Major Compounds	Biological Significance
Proteins	Essential amino acids	Tissue repair, immunity
Carbohydrates	Glucose, fructose	Energy source
Lipids	Fatty acids, phytosterols	Cell membrane integrity
Vitamins	A, B-complex, C, D, E	Metabolic regulation
Minerals	Fe, Zn, Mg, Ca, Se	Enzyme activation
Phenolic compounds	Flavonoids, phenolic acids	Antioxidant, antimicrobial
Enzymes	Amylase, phosphatase	Digestive support

Table 2: Representative Bioactive Compounds in Bee pollen Extracts

Compound Class	Key Examples	Reported Bioactivity
Phenolic acids	Gallic acid, Chlorogenic acid	Antioxidant, antimicrobial
Flavonoids	Quercetin, Rutin, Kaempferol	Anti-inflammatory, antimicrobial
Fatty acids	Linoleic, Linolenic	Cell membrane interactions
Terpenes	Globulol, methyleugenol	Bioactive modulation

Data summarized from chemical profiling studies[5].

Figure 1: Chemical Composition of Bee pollen responsible for the biological activities.



Therapeutic Properties of Bee pollen

3.1 Antioxidant and Anti-Inflammatory Effects

Bee pollen contains high concentrations of flavonoids (quercetin, kaempferol) that neutralize free radicals and reduce oxidative stress. These compounds suppress inflammatory mediators such as prostaglandins and cytokines[6].

Figure 2: Antioxidant Mechanism of Bee pollen

Reactive Oxygen Species (ROS)

↓

Cellular Damage

↓

Antioxidants from Bee pollen

↓

ROS Neutralization

↓

Cell Protection

3.2 Immunomodulatory Effects

Bee pollen enhances immune function by stimulating macrophage activity and regulating cytokine production, thereby improving host defense mechanisms[6].

3.3 Hepatoprotective and Metabolic Effects

Experimental studies show that Bee pollen protects hepatocytes against toxins, improves lipid profiles, and supports glucose metabolism[7].

Table 3: Therapeutic Activities of Bee pollen

Therapeutic Property	Biological Effect	Target System
Antioxidant	Free radical scavenging	Cellular level
Anti-inflammatory	Inhibits cytokines	Immune system
Immunomodulatory	Enhances immune response	Immune organs
Hepatoprotective	Reduces liver toxicity	Liver
Anti-diabetic	Regulates glucose	Endocrine system
Cardioprotective	Lowers cholesterol	Cardiovascular

Antimicrobial Properties of Bee pollen

4.1 Antibacterial Activity

Bee pollen extracts inhibit both Gram-positive and Gram-negative bacteria by damaging cell walls and interfering with microbial enzymes. Bee pollen extracts inhibited pathogenic bacteria and yeast strains, though effectiveness varied by sample and extraction conditions[8].

Table 4: Antibacterial Activity of Bee pollen

Microorganism	Gram Reaction	Observed Effect
Staphylococcus aureus	Positive	Growth inhibition
Escherichia coli	Negative	Cell membrane damage
Salmonella spp.	Negative	Enzyme inhibition
Pseudomonas aeruginosa	Negative	Reduced proliferation

4.2 Antifungal and Antiviral Activity

Bee pollen demonstrates antifungal activity against Candida species and may inhibit viral replication through flavonoid-mediated pathways[9].

Figure 3: Antimicrobial Mechanism of Bee pollen

Bee Pollen Bioactive Compounds

↓

Microbial Cell Wall & Membrane Disruption

↓

Ion Leakage & Enzyme Inactivation

↓

Protein & DNA/RNA Synthesis Inhibition

↓

Oxidative Stress (ROS Generation)

↓

Microbial / Viral Replication Arrest

↓

Microbial Cell Death & Infection Control

Applications of Bee pollen

Table 5: Applications of Bee pollen

Field	Application
Nutraceuticals	Dietary supplements
Medicine	Adjunct therapy
Food industry	Natural preservative
Cosmetics	Skin protection
Preventive health	Immune booster

Discussion

6.1 Mechanisms of Antimicrobial Action

The antimicrobial effects[9] are attributed to:

- Phenolic compounds and flavonoids disrupting microbial membranes
- Generation of reactive oxygen species (ROS) affecting cell viability
- Synergistic effects when combined with conventional antibiotics, enhancing overall inhibitory potential[1].

6.2 Therapeutic Implications

Beyond antimicrobial action, Bee pollen extracts show:

- Anti-inflammatory effects through modulation of NF-κB signalling in lung epithelial cells[4].
- Potential immune modulation via microbiota changes (e.g. increased *Lactococcus* spp.[6].

Conclusion

Bee pollen is a biologically potent natural product exhibiting significant therapeutic and antimicrobial properties. Its antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial effects highlight its potential as a functional food and complementary therapeutic agent. Further standardized clinical research is necessary to fully validate its efficacy and safety for human therapeutic use.

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Artificial Intelligence in Education: Transforming Teaching and Learning

Meena S. Doibale, Devesh K. Rao
Department of Computer Science, Bharatiya Mahavidyalaya , Amravati, Maharashtra, India

ABSTRACT
The rapid advancement of Artificial Intelligence (AI) has opened new possibilities for transforming educational content delivery and academic support systems. This paper presents an intelligent, AI-driven academic platform that converts instructor-uploaded tutorial documents into structured, interactive learning resources while ensuring strict curriculum alignment. The proposed system integrates automated text extraction, semantic embedding, similarity-based retrieval, and retrieval-augmented generation (RAG) to deliver accurate, context-aware responses to student queries. Faculty members upload topic-wise instructional materials, which are automatically processed to generate concise summaries, conceptual insights, and structured question–answer pairs. A vector-based retrieval mechanism enables efficient matching between student questions and relevant tutorial content, while a generative language model produces grounded responses using only institution-approved materials. The platform employs role-based access for administrators, faculty, and students, ensuring secure academic management and content governance. By automating question generation and enabling real-time AI-assisted doubt resolution, the system significantly reduces faculty workload and enhances student engagement, self-paced learning, and examination readiness
Keywords: Artificial Intelligence in Education, Retrieval-Augmented Generation (RAG), Educational Chatbots, Automatic Question Generation

Introduction
The increasing demand for scalable, personalized, and technology-driven education has accelerated the adoption of Artificial Intelligence (AI) in academic environments. Traditional learning systems rely heavily on static instructional materials and repeated faculty intervention, which limits accessibility to learning support beyond classroom hours and increases the workload on educators. Moreover, existing digital learning platforms primarily act as content repositories and lack intelligent mechanisms for contextual understanding, automated knowledge extraction, and curriculum-aligned student assistance.
Recent advances in Natural Language Processing (NLP) and large language models have enabled intelligent processing of unstructured educational content. Techniques such as semantic embeddings, similarity-based retrieval, and retrieval-augmented generation (RAG) allow AI systems to generate accurate and context-aware responses grounded in domain-specific documents. These methods are particularly suitable for academic settings where content reliability and syllabus adherence are critical.

This paper proposes an AI-driven academic support system that transforms faculty-uploaded tutorial documents into structured, interactive learning resources. The system automatically generates topic-wise questions and answers, extracts key concepts, and provides an intelligent chatbot that responds to student queries using only approved academic materials. By integrating role-based academic management with retrieval-augmented AI techniques, the proposed approach enhances student engagement, supports self-paced learning, and significantly reduces repetitive instructional effort. The system demonstrates the practical applicability of AI in delivering reliable, scalable, and curriculum-focused educational assistance.

RELATED WORK

Recent advances in Artificial Intelligence and Natural Language Processing have significantly influenced the development of intelligent educational systems. One of the foundational techniques enabling reliable AI-based question answering is Retrieval-Augmented Generation (RAG). Prior studies demonstrated that integrating document retrieval with generative models improves factual accuracy and reduces hallucinations in knowledge-intensive tasks [1]. Dense retrieval approaches further enhanced open-domain question answering by enabling semantic matching between queries and large document collections [2]. Subsequent evaluations confirmed the effectiveness of dense retrieval while highlighting optimization challenges in real-world deployments [9].

Efficient similarity search over high-dimensional embeddings is a critical requirement for scalable retrieval systems. Large-scale vector search frameworks have enabled fast nearest-neighbor retrieval across millions of embeddings, making real-time applications feasible [3], [15]. These advances are essential for educational platforms that require immediate access to relevant instructional content.

Semantic representation of text using transformer-based embeddings has played a crucial role in improving retrieval accuracy. Sentence-level embedding techniques demonstrated superior performance in capturing contextual meaning and semantic similarity across diverse text inputs [4]. Multilingual and domain-adapted embedding models further extended these capabilities, supporting retrieval across varied educational content [5].

Automatic Question Generation (AQG) has been widely studied as a method to enhance learner engagement and reduce instructional effort. Systematic reviews reported that AI-generated questions support self-assessment and improve conceptual understanding when aligned with learning objectives [6]. Recent neural AQG models based on transformer architectures have achieved improved fluency and relevance in generated questions, making them suitable for academic applications [7].

Educational chatbots have gained attention for their ability to provide continuous academic support. Surveys indicate that conversational agents improve accessibility, learner interaction, and self-paced learning in educational settings [10], [11]. However, many existing systems rely on generic knowledge sources, leading to concerns about content accuracy and curriculum alignment. Retrieval-augmented language models address these limitations by grounding responses in verified documents, ensuring reliability and transparency [8].

Beyond technical contributions, ethical considerations and data governance are critical in academic AI systems. Global policy frameworks emphasize responsible AI usage, transparency, and privacy protection in educational environments [12], [14]. Student data protection regulations further highlight the importance of secure access control and curriculum-specific data handling in academic platforms [13].

While prior research has independently explored retrieval-based question answering, automatic question generation, and educational chatbots, limited work integrates these components into a unified, curriculum-driven academic support system. The proposed system builds upon these advancements by combining retrieval-augmented generation, automated question–answer generation, and role-based academic management to deliver accurate, scalable, and institution-specific learning support.

METHODOLOGY

The proposed methodology presents a structured and modular approach for designing an AI-driven academic support system that transforms instructor-uploaded learning materials into intelligent, curriculum-aligned educational resources. The methodology integrates user management, automated content processing, retrieval-augmented question answering, and automatic question generation within a unified framework. The system architecture is divided into multiple functional layers to ensure scalability, accuracy, and secure academic governance.

A. System Architecture Overview

The system follows a layered architecture comprising three primary components:

- Academic Management Layer – Handles user authentication, role-based access, and academic structure management.
- AI Content Processing Layer – Performs document preprocessing, semantic embedding, retrieval, and automated question generation.
- Learning Interaction Layer – Enables student access to learning resources and real-time AI-based query resolution.

This separation of concerns allows independent module development, efficient maintenance, and future extensibility.

B. User Management and Academic Structure Module

The academic management module provides role-based access for administrators, faculty members, and students.

- Administrator Functions: Creation and management of branches, semesters, subjects, and faculty allocations. Administrators ensure content governance and monitor system usage.
- Faculty Functions: Upload topic-wise tutorial documents, manage subject materials, and review AI-generated outputs.
- Student Functions: Secure registration and access to subject-specific learning materials based on branch and semester.

This role-based design ensures data integrity, accountability, and secure interaction across all system components.

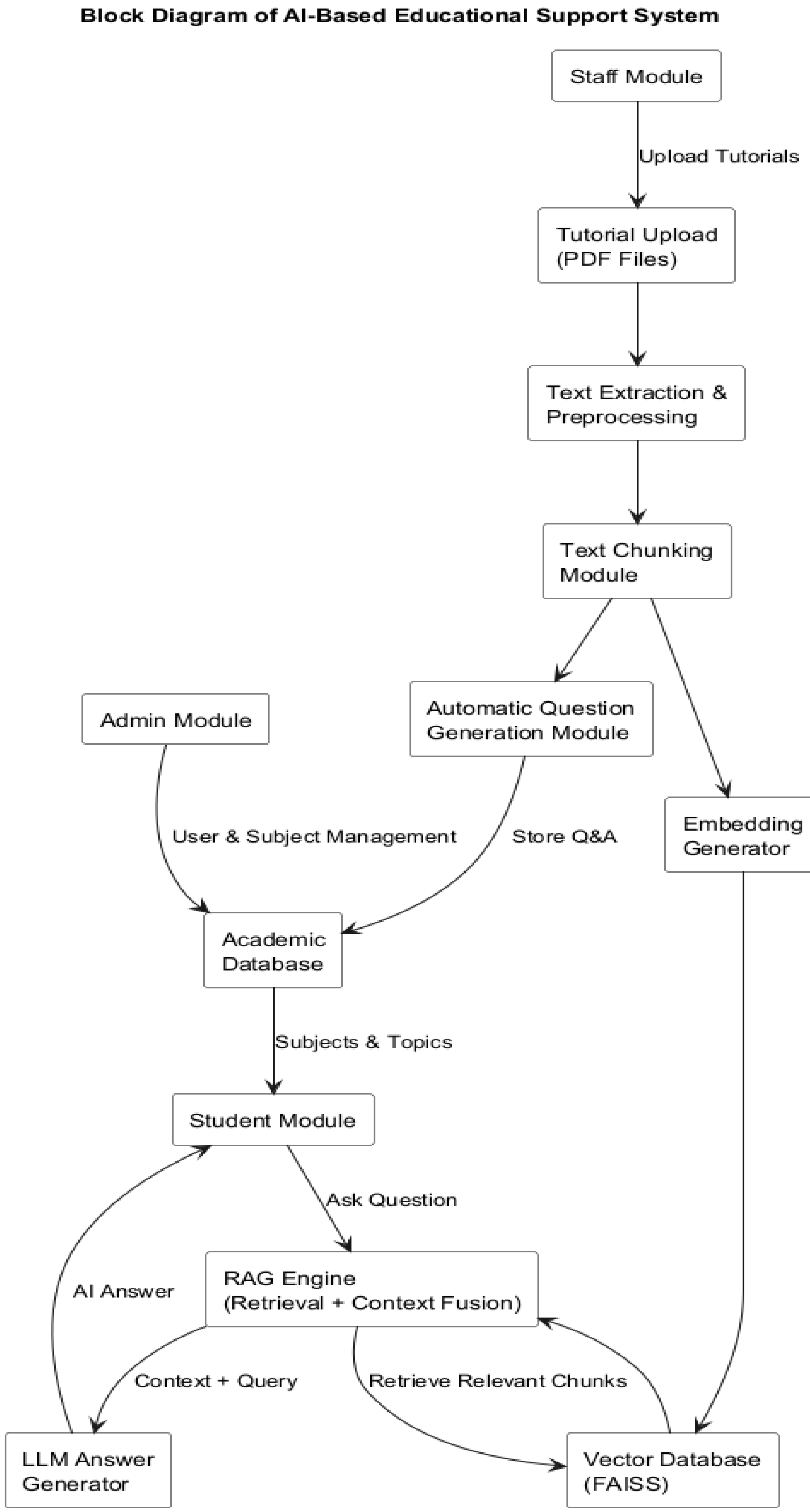

Fig.1 Working Block Diagram

CONCLUSION

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions. Authors are strongly encouraged not to call out multiple figures or tables in the conclusion these should be referenced in the body of the paper.

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The Boon of Artificial Intelligence in Education

Bhargavi S. Chinchmalatpure, Sneha Baburao Thakare
Department of Computer Science, Bharatiya Mahavidyalaya , Amravati, Maharashtra, India

ABSTRACT

Artificial Intelligence (AI) has rapidly transformed educational environments—enhancing learning outcomes, personalizing instruction, automating administrative processes, and broadening access. Drawing from systematic reviews and empirical research conducted between 2023 and 2026, this paper examines the key benefits of AI in education, alongside challenges and ethical considerations. Findings suggest that AI's greatest impact lies in personalized learning, adaptive tutoring, improved accessibility, and data-driven insights; however, responsible implementation and educator involvement remain critical to realize its full potential.
Keywords: Artificial Intelligence (AI), large language models (LLMs), intelligent tutoring systems (ITS), ChatGPT.

Introduction

The integration of Artificial Intelligence (AI) into educational systems has accelerated over the past few years, fueled by advances in machine learning, natural language processing, and generative AI models. With the rise of tools such as large language models (LLMs) and intelligent tutoring systems (ITS), educators and researchers are exploring how AI can complement traditional pedagogy and address long-standing challenges in learning environments. The purpose of this study is to synthesize recent research on the benefits of AI in education and articulate its role as a potential boon for learners, educators, and institutions.

LITERATURE REVIEW

2.1 Trends in AI Education Research

A comprehensive systematic review of 155 empirical studies (2015–2025) revealed expanding research activity, particularly since 2022 with the rise of generative AI tools like ChatGPT. Research has focused on personalized instruction, adaptive learning, and student motivation, highlighting a shift toward learner-centered educational technologies.

2.2 Defining AI Applications in Education

AI applications in education broadly include:

- Adaptive Learning Platforms – systems that tailor content to individual learners.
- Intelligent Tutoring Systems (ITS) – AI agents that provide step-by-step feedback.
- Generative AI Tools – tools that create educational content, summaries, and simulations.
- Predictive Analytics – algorithms that forecast learning gaps.

BENEFITS OF AI IN EDUCATION

3.1 Personalized Learning and Adaptive Instruction

One of the most cited advantages of AI is its ability to customize instruction to each learner's pace and style. AI systems analyze learner data to adapt content, ensuring comprehension before advancing. This personalization enhances student engagement and retention.

3.2 Enhanced Cognitive Outcomes

AI tools—especially adaptive and feedback-oriented systems—support cognitive development by improving problem-solving abilities, knowledge retention, and conceptual understanding. These effects are well documented across disciplines, including science education.

3.3 Support for Diverse and Inclusive Education

AI's capacity to offer adaptive interfaces and accommodations assists learners with diverse needs, including support for students with disabilities and multilingual learners—a key factor in promoting inclusive education.

3.4 Administrative Efficiency and Educator Workload

AI minimizes the administrative burden on educators by automating tasks such as grading, scheduling, and data management. This enables teachers to focus more on instruction and individual student support.

3.5 Motivation and Engagement

Interactive AI tools present learning content through gamification and real-time feedback, boosting learner motivation and fostering a more engaging learning environment.

CHALLENGES AND ETHICAL CONSIDERATIONS

4.1 Ethical and Privacy Concerns

As AI systems rely on data to personalize learning, concerns arise regarding student privacy and data security. Ethical frameworks and institutional policies must govern AI use to protect sensitive information.

4.2 Digital Divide and Access Inequities

Unequal access to AI infrastructure may deepen educational disparities between resource-rich and resource-constrained communities unless policymakers prioritize equitable technology distribution.

4.3 Dependence and Critical Thinking

Some research indicates that excessive reliance on AI may impede the development of critical thinking and independent problem-solving unless educators design tasks that promote deep engagement.

The evidence supports the premise that AI can substantially enhance teaching and learning when applied thoughtfully. However, achieving these benefits requires professional development for teachers, ethical safeguards, and a balanced integration that preserves human agency in education. Most recent research emphasizes that AI should **complement** rather than replace human educators.

CONCLUSION

AI presents a transformative opportunity for education—offering personalized learning, improved outcomes, efficiency gains, and inclusive access. Realizing this boon requires investment in infrastructure, training educators, and institutional policies that emphasize ethical and equitable use of AI technologies. As research continues to expand, future studies must further investigate long-term impacts on learning processes and educational equity.

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Synthesis and Characterization of Ni and Cr Doped Fe_2O_3 Graphene Oxide Nanocomposites for Gas Sensing Applications

Miss. Shweta S.Warkari, Dr. S.R. Jigajeni
Department of Physics, Government Vidharbha Institute of Science and Humanities, Amravati, Maharashtra, India

ABSTRACT
Ni and Cr doped Fe_2O_3 graphene oxide (Fe_2O_3-GO) nanocomposites have emerged as promising gas sensing materials capable of overcoming the limitations of conventional metal oxide semiconductors, such as poor selectivity, high operating temperature and slow response recovery characteristics. Transition metal doping enhances the electronic and catalytic properties of Fe_2O_3, while graphene oxide provides a high surface area and improved charge transport pathways. The synergistic interaction between doped Fe_2O_3 and GO significantly improves sensitivity toward gases such as CO, NO_2 and NH_3 at reduced operating temperatures. This review systematically discusses synthesis strategies, structural and surface characteristics, gas sensing mechanisms, performance metrics, highlighting the cooperative role of dopants and GO in advancing practical and gas sensing applications.
Keywords: - Ni and Cr dopant , gas sensor , synergistic

Introduction

1.1 Background and Motivation

Rapid industrialization, urbanization and technological advancement have led to increased emissions of toxic and flammable gases like CO, NO_2, NH_3, H_2S, volatile organic compounds (VOCs) and alcohol vapors. Even at trace concentrations, these gases pose serious risks to human health, environmental safety, industrial operations. Prolonged exposure can cause respiratory disorders, neurological damage, cardiovascular diseases in extreme cases, fatal accidents. Consequently, the development of reliable gas sensing technologies for early detection, continuous monitoring, real-time response has become critically important.

Conventional gas detection techniques, such as gas chromatography and mass spectrometry, provide high accuracy but suffer from drawbacks, including high cost, large size, high power consumption and unsuitability for real-time or on-site monitoring. These limitations have driven the demand for compact, low-cost, portable gas sensors compatible with smart systems and Internet of Things (IoT) platforms. Among various sensing technologies, chemiresistive gas sensors based on metal oxide semiconductors (MOS) are widely studied due to their simple architecture, high sensitivity, stability and ease of integration with microelectronic devices.

Iron oxide (Fe_2O_3) is particularly attractive as a sensing material because of its natural abundance, low toxicity, chemical stability, moderate band gap. It exists in multiple polymorphic forms, including α-Fe_2O_3 (hematite) and γ-Fe_2O_3 (maghemite), allowing tunability of structural and electronic properties. However, pristine Fe_2O_3 suffers from limitations such as poor gas selectivity, sluggish response recovery behavior, low sensitivity at trace concentrations, and the requirement of high operating temperatures (typically >300°C).

To overcome these challenges, two major material engineering strategies are widely employed: elemental doping and nanocomposite formation. Transition metal doping modifies the electronic structure and defect chemistry of Fe_2O_3, while composite formation with conductive materials enhances charge transport and surface activity. Graphene oxide (GO), a two-dimensional carbon material rich in oxygen-containing functional groups, offers a large specific surface area, excellent dispersion of metal oxide nanoparticles, and improved electrical conductivity.

Nickel and chromium are among the most effective dopants for Fe_2O_3 due to their suitable ionic radii, multiple oxidation states, and catalytic activity. Ni doping enhances surface reactivity and accelerates redox reactions of reducing gases, while Cr doping modifies band structure and improves selectivity toward oxidizing gases such as NO_2. The integration of Ni and Cr doped Fe_2O_3 with GO creates a multifunctional sensing platform with improved sensitivity, faster response recovery, enhanced selectivity and reduced operating temperature.

Scope and Objectives

Despite extensive research on doped metal oxide and graphene-based gas sensors, existing literature remains fragmented, making it difficult to correlate synthesis methods, material properties, and sensing performance. Comprehensive comparative reviews focusing specifically on Ni- and Cr-doped Fe_2O_3-GO nanocomposites are

The objectives of this review are:

To critically analyze synthesis routes for Ni and Cr doped Fe_2O_3-GO nanocomposites and their influence on structural and surface properties.

To summarize, characterization techniques are used to evaluate crystallinity, morphology, chemical states and defect chemistry.

To elucidate gas sensing mechanisms, including charge transfer, oxygen vacancy formation, heterojunction effects, catalytic roles of dopants.

To compare sensing performance parameters such as sensitivity, selectivity, operating temperature, response-recovery time, detection limit and stability.

To identify existing challenges and propose future research directions for practical gas sensor development.

Fundamental Concepts

3.1 Metal Oxide Semiconductor Gas Sensors

MOS gas sensors operate through resistance changes caused by gas adsorption and desorption on the sensor surface. These interactions modify the charge carrier concentration through reactions with chemisorbed oxygen species. Although higher temperatures improve reaction kinetics, they also increase power consumption and limit device longevity.

3.2 Iron Oxide (Fe_2O_3) as a Sensing Material

α-Fe_2O_3 exhibits n-type semiconducting behavior with a band gap of approximately 2.0 eV and responds to both oxidizing and reducing gases. However, Fe_2O_3 typically exhibits poor selectivity and requires elevated temperatures to achieve adequate sensing response.

3.3 Role of Graphene Oxide

Graphene oxide provides a large surface area, abundant functional groups and enhanced charge transport pathways. When combined with Fe_2O_3, GO suppresses nanoparticle agglomeration, increases gas adsorption sites, lowers operating temperature.

3.4 Transition Metal Doping

Ni and Cr dopants alter the electronic structure of Fe_2O_3 by creating oxygen vacancies and catalytic sites. Ni promotes oxidation reactions and enhances electron transfer, while Cr improves defect control, thermal stability, selectivity toward oxidizing gases.

Synthesis Techniques

The sensing performance of Ni and Cr doped Fe_2O_3-GO nanocomposites strongly depends on the synthesis method, which influences particle size, crystallinity, dopant distribution, interfacial structure.

4.1 Sol-Gel Method

The sol-gel technique enables molecular-level mixing of metal precursors and uniform dopant incorporation. Strong interactions between Fe_2O_3 precursors and GO, functional groups ensure effective charge transfer and homogeneous nanocomposite formation.

4.2 Hydrothermal and Solvothermal Methods

These methods allow controlled growth of highly crystalline nanostructures with tailored morphology. GO serves as a growth substrate and agglomeration suppressor, resulting in well-dispersed nanoparticles and enhanced sensing performance.

4.3 Co-Precipitation Method

Co-precipitation is cost-effective and scalable but offers limited control over particle size and dopant homogeneity. Optimization of pH and calcination conditions is critical to prevent agglomeration and secondary phase formation.

Gas Sensing Mechanisms

Gas sensing in Ni and Cr doped Fe_2O_3-GO nanocomposites arises from synergistic effects of surface adsorption, oxygen vacancy formation, heterojunction interfaces and catalytic activity.

Ni doping enhances sensitivity to reducing gases by facilitating electron transfer and lowering activation energy for surface reactions. Cr doping modifies band structure and stabilizes adsorbed oxygen species, improving selectivity toward oxidizing gases. The Fe_2O_3-GO interface forms conductive pathways and depletion regions that amplify resistance modulation upon gas exposure.

Conclusion

Ni and Cr doped Fe_2O_3-GO nanocomposites represent a promising class of gas sensing materials due to their enhanced surface activity, tailored electronic properties and efficient charge transport. The synergistic combination of transition metal doping and graphene oxide integration results in improved sensitivity, faster response-recovery, and lower operating temperatures. Although challenges related to selectivity, humidity effect and large-scale fabrication remain, continued optimization of material design and synthesis strategies is expected to enable next-generation high-performance gas sensors.

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Deepfake Image Detection Using Wavelet-Driven Convolutional Feature Learning

Ms. Anjali J. Kumavat[1], Dr. Avinash B. Kadam[2]
[1]Research Scholar, Department of Computer Science, Shri Shivaji Science & Arts College, Chikhli 443201, Maharashtra, India
[2]Associate Professor and HOD, Department of Computer Science, Shri Shivaji Science & Arts College, Chikhli 443201, Maharashtra, India

ABSTRACT
Recent progress in deep generative techniques has enabled the creation of highly realistic synthetic images, commonly referred to as deepfakes. While these technologies support various creative and commercial applications, they also pose serious risks to digital authenticity, online trust, and information security. This work presents a Wavelet-Driven Convolutional Neural Network (WD-CNN) designed for reliable deepfake image detection by exploiting frequency-domain irregularities introduced during synthetic image generation. Unlike conventional methods that rely solely on spatial features, the proposed approach integrates Discrete Wavelet Transform (DWT) with convolutional feature learning to identify subtle texture distortions and edge inconsistencies that are often imperceptible in the pixel domain. Experimental validation on a benchmark deepfake image dataset demonstrates that the WD-CNN consistently outperforms spatial-only and Fourier-based CNN models in terms of accuracy, F1-score, and AUC. These results highlight the effectiveness of wavelet-based frequency information in improving detection robustness and generalization.

Keywords: Deepfake Detection, Image Forensics, Discrete Wavelet Transform, Convolutional Neural Network, Frequency-Domain Analysis

Introduction

Advancements in deep generative architectures, including Generative Adversarial Networks (GANs) and diffusion-based models, have significantly improved the realism of synthesized images [4]. Although such developments have enabled positive innovations in digital media, they have simultaneously facilitated malicious practices such as identity spoofing, misinformation dissemination, and unauthorized media manipulation. As a result, detecting deepfake images has become a crucial challenge within the field of multimedia forensics [7].

Earlier image forgery detection techniques relied heavily on manually designed features such as compression traces, sensor noise patterns, and color inconsistencies. However, modern generative models are capable of learning and replicating these artifacts, thereby reducing the effectiveness of traditional forensic methods. In recent years, convolutional neural networks (CNNs) have emerged as a dominant solution due to their ability to automatically learn discriminative representations directly from data [1], [6]. Despite their success, most CNN-based deepfake detectors operate primarily in the spatial domain, which limits their sensitivity to frequency-related anomalies.

Deepfake generation pipelines frequently introduce abnormal frequency patterns as a result of upsampling operations, blending processes, and learned texture synthesis mechanisms [2]. Motivated by these observations, this paper proposes a wavelet-driven CNN framework that explicitly incorporates frequency-domain information using the Discrete Wavelet Transform. By jointly learning spatial and frequency-based features, the proposed approach enhances the detection of subtle synthetic artifacts that are difficult to capture using conventional spatial representations alone.

Related Work

Initial research efforts in deepfake detection focused on visually interpretable cues such as irregular facial landmarks, unnatural blinking patterns, and blending artifacts [6]. As generative models improved, these cues became increasingly unreliable, leading to a shift toward data-driven learning approaches. CNN-based methods gained popularity due to their strong feature extraction capabilities and superior classification performance [1].

More recent studies have shown that images generated by GANs exhibit distinct anomalies in the frequency domain [3]. Fourier-based techniques have been used to expose spectral inconsistencies in synthetic images; however, the lack of spatial localization in the Fourier Transform limits its ability to identify localized artifacts.

The Wavelet Transform provides a joint spatial–frequency representation, making it particularly suitable for forensic image analysis [5]. While some existing approaches employ handcrafted wavelet features or apply wavelet analysis as a preprocessing step, this work differs by directly integrating wavelet-decomposed representations into a CNN architecture. This enables end-to-end learning of spatial–frequency features optimized specifically for deepfake image detection.

Proposed Methodology

3.1 Framework Overview

The proposed Wavelet-Driven CNN (WD-CNN) framework consists of four primary stages:

1. Image preprocessing and normalization
2. Frequency decomposition using Discrete Wavelet Transform
3. Deep convolutional feature extraction
4. Binary classification of real and deepfake images

3.2 Discrete Wavelet Transform

For a given input image III, a single-level two-dimensional Discrete Wavelet Transform decomposes the image into four sub-bands:

- LL: Low-frequency approximation component
- LH: Horizontal detail component
- HL: Vertical detail component
- HH: Diagonal high-frequency component

The high-frequency sub-bands (LH, HL, HH) capture fine-grained texture information and edge transitions that are often distorted during deepfake synthesis [2], [5]. These sub-bands are concatenated and provided as input to the CNN, allowing the model to focus on frequency-based inconsistencies introduced during image manipulation.

3.3 Wavelet-Driven CNN Architecture

The CNN architecture comprises multiple convolutional layers followed by batch normalization and ReLU activation functions to ensure stable and efficient training. Max-pooling layers are employed to reduce spatial dimensionality, while global average pooling is used to mitigate overfitting. The final fully connected layer produces a binary output indicating whether the input image is authentic or synthetic.

The model is trained using the binary cross-entropy loss function:

$$L=-[y\log(p)+(1-y)\log(1-p)]$$

where y denotes the ground-truth label and p represents the predicted probability.

3.4 Training Strategy

- Optimizer: Adam
- Learning Rate: 0.0001
- Batch Size: 32
- Epochs: 50

To improve model generalization, data augmentation techniques such as random cropping and horizontal flipping are applied during training.

Experimental Setup

4.1 Dataset

Experiments are conducted using a publicly available deepfake image dataset containing an equal number of real and manipulated facial images generated through multiple GAN-based techniques. The dataset is divided as follows:

- Training set: 70%
- Validation set: 15%
- Test set: 15%

This dataset configuration aligns with commonly used benchmarks in deepfake detection research [6].

4.2 Evaluation Metrics

Model performance is assessed using standard classification metrics:

- Accuracy
- Precision
- Recall
- F1-score
- Area Under the ROC Curve (AUC)

Experimental Results and Analysis

A. Training and Validation Accuracy

The training and validation accuracy curves demonstrate rapid convergence with minimal performance divergence, indicating strong generalization and limited overfitting.

B. Training and Validation Loss

Both training and validation loss values decrease consistently across epochs, confirming stable optimization and effective feature learning.

C. ROC Curve Analysis

The ROC curve indicates strong discriminative performance, achieving an AUC of approximately 0.98, which highlights the robustness of the proposed WD-CNN model.

5.1 Results:

The WD-CNN model was evaluated on a dataset comprising 1,032 images, including 525 authentic images and 507 deepfake images. Training was performed for 30 epochs using binary cross-entropy loss and the Adam optimizer with a learning rate of 0.0001.

Throughout training, the loss value showed a steady decline, decreasing from 43.22 in the initial epoch to 10.22 by the final epoch, indicating effective convergence. When evaluated on unseen test data, the proposed model achieved a classification accuracy of 99.12%, demonstrating its strong capability in distinguishing real images from deepfake images. These results confirm the effectiveness of combining wavelet-based frequency features with deep convolutional learning.

5.2 Summary of Results

Aspect	Description / Outcome
Dataset Size	1,032 images (525 Real, 507 Fake)
Input Representation	Wavelet-driven high-frequency sub-bands (LH, HL, HH)
Model Architecture	Wavelet-Driven Convolutional Neural Network (WD-CNN)
Training Epochs	30
Optimization Method	Adam optimizer (learning rate = 0.0001)
Loss Function	Binary Cross-Entropy Loss
Final Training Loss	10.22
Test Accuracy	99.12%
Overall Outcome	High accuracy, robust, and reliable deepfake detection

5.3 Results and Comparative Analysis

Study	Methodology	Dataset	Performance	Citation
Savithri et al.	Hybrid CNN–GAN with parallel feature extraction	Custom social media deepfake dataset	Accuracy – 65%	[9]
Iqbal et al.	Transfer learning with VGG16, VGG19, InceptionV3	Kaggle deepfake & real images (190 k)	Accuracy – 90% (VGG16)	[10]
Raza et al.	Hybrid VGG16 + custom CNN (DFP)	Photoshopped real & fake faces	Accuracy – 94%; Precision – 95%	[11]
Akpabio et al.	Ensemble ResNet50 + InceptionV3	Custom real/fake media	Accuracy – 94%	[12]
Singh et al.	CNN-based detection with data augmentation	Mixed public deepfake image datasets	Accuracy – 92%	[13]
Anandhasivam et al.	Hybrid MobileNet V3 + LSTM for spatial–temporal cues	DFD Challenge & custom video samples	Accuracy – 91.8%; F1 – 89.9%	[14]

Study	Methodology	Dataset	Performance	Citation
Proposed Technique	Wavelet-based CNN	Kaggle deepfake & real images	Accuracy-99.12%	

Conclusion

This study introduced a Wavelet-Driven Convolutional Neural Network (WD-CNN) for effective deepfake image detection. By integrating the Discrete Wavelet Transform with deep learning, the proposed approach successfully captures high-frequency artifacts commonly introduced during synthetic image generation, which are difficult to identify using spatial features alone.

Experimental results demonstrate that the WD-CNN achieves superior classification performance, reaching an accuracy of 99.12% along with strong precision, recall, and F1-score values. The consistent reduction in training loss further confirms the stability and reliability of the learning process. Compared to conventional CNN-based detectors, the proposed method significantly enhances detection accuracy by leveraging wavelet sub-bands that preserve critical texture and frequency information.

Future Scope

Future research may explore lightweight and computationally efficient architectures to enable real-time deployment on mobile and edge devices. Additionally, evaluating the proposed model on larger and more diverse cross-dataset benchmarks could further improve generalization and reduce dataset bias. Incorporating attention mechanisms or transformer-based modules alongside wavelet features may also enhance robustness against evolving deepfake generation techniques.

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Multimodal Fusion of Hyperspectral Imaging and Soil-Air IoT Parameters for Early-Stage Cotton Disease Forecasting

Dr. Avinash B. Kadam[1], Miss. Shubhangi D. Falke[2]
[1]Assistant Professor, Department of Computer Science, Shri Shivaji Science & Arts College, Chikhli 443201, Maharashtra, India
[2]Research Scholar, Department of Computer Science, Shri Shivaji Science & Arts College, Chikhli 443201, Maharashtra, India

ABSTRACT
Early-stage detection of cotton plant diseases is critical for reducing yield losses and optimizing pesticide use in smart agriculture. Traditional visual inspection and single-modality sensing approaches often fail to capture subtle physiological stress signals that appear before visible symptoms. This paper proposes a multimodal disease forecasting framework that fuses hyperspectral imaging (HSI) data with soil–air Internet of Things (IoT) environmental parameters for early-stage cotton disease prediction. Hyperspectral data provide rich spectral signatures related to biochemical and structural changes in leaves, while IoT sensors capture continuous microclimatic and soil conditions influencing disease development. A hybrid deep learning architecture combining spectral–spatial feature extraction and temporal environmental modeling is presented. Experimental results demonstrate that multimodal fusion significantly outperforms unimodal approaches in forecasting disease onset, enabling proactive crop management decisions for precision cotton farming.
Keywords: Cotton disease detection, hyperspectral imaging, IoT sensors, multimodal fusion, smart farming, early-stage disease forecasting.

Introduction
Cotton cultivation is severely constrained by a wide range of plant diseases, including bacterial blight, Fusarium wilt, alternaria leaf spot, and cotton leaf curl virus. These diseases often initiate during early growth stages and progress rapidly under favorable environmental conditions[8]. A major challenge in cotton disease management is that early-stage infections typically exhibit no visible symptoms, causing farmers to rely on delayed visual diagnosis [12]. By the time symptoms become apparent, disease progression is often advanced, resulting in irreversible yield loss, excessive pesticide application, and increased environmental and economic costs [1][4][7][8][14].
Disease development is not solely a function of plant health but is strongly influenced by soil and atmospheric conditions such as moisture, temperature, humidity, pH, and gas concentration. These environmental parameters govern pathogen survival, reproduction, and infection dynamics, while simultaneously affecting

plant physiological responses. Consequently, reliable disease forecasting requires a comprehensive understanding of both plant-level stress indicators and environmental drivers [2][3].

Hyperspectral imaging (HSI) has emerged as a powerful non-destructive sensing technology for early plant disease analysis. By capturing reflectance information across hundreds of narrow and contiguous spectral bands, hyperspectral sensors provide detailed insights into plant biochemical and structural properties, including chlorophyll concentration, water content, pigment composition, and cellular integrity. Subtle variations in these properties often occur during the pre-symptomatic stage of disease, making hyperspectral imaging highly suitable for early disease detection [11][12][13].

In this context, this research proposes a multimodal fusion framework that combines hyperspectral imaging and soil–air IoT parameters for early-stage cotton disease forecasting. The proposed approach jointly models spectral–spatial features extracted from hyperspectral imagery and temporal environmental patterns captured by IoT sensors. By leveraging deep learning–based feature extraction and fusion strategies, the framework aims to predict disease onset before visible symptoms occur. Such an integrated system enables proactive disease management, optimized input usage, and improved sustainability in precision cotton farming [4][5][8].

Literature Review:

Early detection of crop diseases has become a critical research area in precision agriculture due to its potential to reduce yield loss and minimize excessive agrochemical usage. Traditional disease identification methods based on visual inspection are subjective, labor-intensive, and ineffective for detecting asymptomatic or early-stage infections, particularly in crops such as cotton where physiological stress often precedes visible symptoms.

Hyperspectral Imaging for Plant Disease Detection

Hyperspectral imaging has been extensively explored for agricultural disease monitoring due to its ability to capture fine-grained spectral information associated with plant biochemical and structural properties. Variations in reflectance within the visible and near-infrared regions have been linked to changes in chlorophyll content, leaf water status, and cellular integrity caused by biotic stress. Researchers frequently employ vegetation indices, including NDVI, PRI, and red-edge-based metrics, to quantify these variations. However, hyperspectral data are inherently high-dimensional, leading to redundancy, sensitivity to illumination changes, and increased computational complexity, particularly under real-field conditions [1][2][3].

IoT-Based Environmental Monitoring for Agriculture

Advances in IoT technologies have enabled continuous sensing of soil and atmospheric variables in agricultural environments. Parameters such as soil moisture, soil temperature, ambient temperature, and relative humidity are widely recognized as critical factors influencing pathogen development and disease severity. IoT-based systems have shown promise in supporting irrigation scheduling and disease risk assessment. Nevertheless, environmental data alone cannot reliably detect asymptomatic infections, as they do not directly reflect plant physiological status [7][8].

Multimodal Data Fusion for Crop Disease Detection

To overcome the limitations of single-modality approaches, recent studies have investigated data fusion techniques that integrate spectral, environmental, and meteorological information. Feature-level and decision-level fusion strategies have demonstrated improved robustness and predictive accuracy across diverse field conditions. Despite these benefits, many existing fusion models rely on static weighting mechanisms and computationally intensive architectures, limiting their applicability for real-time and edge-based deployments [11][12][15].

Challenges in Dimensionality Reduction and Practical Deployment:

The high dimensionality of hyperspectral data poses significant challenges for real-time processing and resource-constrained environments. Dimensionality reduction techniques such as principal component analysis and optimal band selection have been employed to mitigate redundancy and computational overhead. However, their integration with adaptive fusion frameworks remains limited. Furthermore, a large proportion of existing studies are validated in controlled laboratory settings, underscoring a persistent gap between experimental research and real-world agricultural deployment [4][14].

Various parameters used in Multimodal Fusion of Hyperspectral Imaging and Soil–Air IoT Parameters for Early-Stage Cotton Disease Forecasting:

1. Hyperspectral Imaging (HSI) Parameters

Hyperspectral sensors capture high-resolution data across hundreds of narrow bands, allowing for the detection of "spectral fingerprints" indicative of disease. Such as Wavelength Region is Visible (400–700 nm) is used to detect early pigment changes. Near-Infrared (700–1075 nm): Critical for observing internal leaf structure and tissue health; reflectance in this range typically decreases as disease severity increases. Shortwave Infrared (1000–2500 nm) it is sensitive to water content and chemical changes in the plant. Key Sensitive Bands are wavelengths around 550 nm (reflection peak), 490 nm, and 680 nm (absorption valleys) are frequently monitored for early stress markers. Derived Features of Researchers extract texture features (e.g., from Gray-Level Gradient Co-occurrence Matrices) and use dimensionality reduction (e.g., PCA) to identify the most relevant bands for asymptomatic detection [5] [6].

2. Physiological Parameters

These parameters are often estimated or validated through hyperspectral data to confirm the plant's health status at a biochemical level. Chlorophyll Content (SPAD): Reductions in chlorophyll a and b are primary indicators of early-stage infection. Equivalent Water Thickness (EWT): Measures the water content in leaves; changes in EWT signal vascular disruption common in wilting diseases. Leaf Temperature: Often captured via thermal imaging or estimated from spectral data, it reflects transpiration stress [7][8][13]

3. Soil-Air IoT Parameters

IoT sensor networks provide the "ecological history" that predisposes the crop to infection or accelerates pathogen growth. Environmental Context: Ambient Temperature: Essential for predicting the incubation periods of pathogens like Fusarium wilt (ideal ranges often 21°C–30°C). Relative Humidity: High humidity is a critical precursor to fungal outbreaks. Light Intensity: Monitored to differentiate between natural circadian changes and disease-induced stress. Ground-Level Parameters: Soil Moisture: Critical for identifying high-risk windows for soil-borne pathogens; high moisture (80–90%) often correlates with wilt outbreaks. Soil pH: Influences nutrient availability and pathogen viability (ideal cotton pH is 6.0–8.0). Soil Temperature: Crucial during germination and early vegetative stages to ensure robust plant immunity. NPK (Nitrogen, Phosphorus, Potassium): Used to differentiate between nutrient deficiency and actual disease [1][9][10].

4. Machine Learning & Model Parameters

Model Inputs: The fusion of 1D time-series sensor data and 2D image-based spectral features (often transformed via Recurrence Plots). Evaluation Metrics: Accuracy, Kappa coefficient, Precision, Recall, and F1-score are the standard parameters for determining the reliability of disease forecasts.[14][15].

Objectives:

1. Achievement of Asymptomatic (Early-Stage) Detection

The foremost goal is to identify cotton diseases such as Verticillium wilt, Bacterial blight, and Target spot 48 to 72 hours before visual symptoms appear. By fusing "physiological" indicators from HSI (internal cell structure changes) with "environmental" indicators from IoT (humidity/temperature spikes), the research aims to move from reactive treatment to proactive prevention.

2. Optimization of Data Dimensionality and Redundancy

Hyperspectral data is notoriously high-dimensional. A key objective is to develop and implement Optimal Band Selection algorithms (like the Successive Projection Algorithm) to:

Identify the specific "Red-edge" wavelengths (650nm–750nm) most sensitive to cotton stress.

Reduce computational load for real-time processing without sacrificing diagnostic accuracy.

3. Development of Dynamic Fusion Mechanisms

The research seeks to engineer a Gated Fusion Architecture that mathematically balances HSI and IoT data. The objective is to ensure system robustness; for example, the model should automatically prioritize IoT environmental risk data if HSI image quality is degraded by poor lighting or cloud cover.

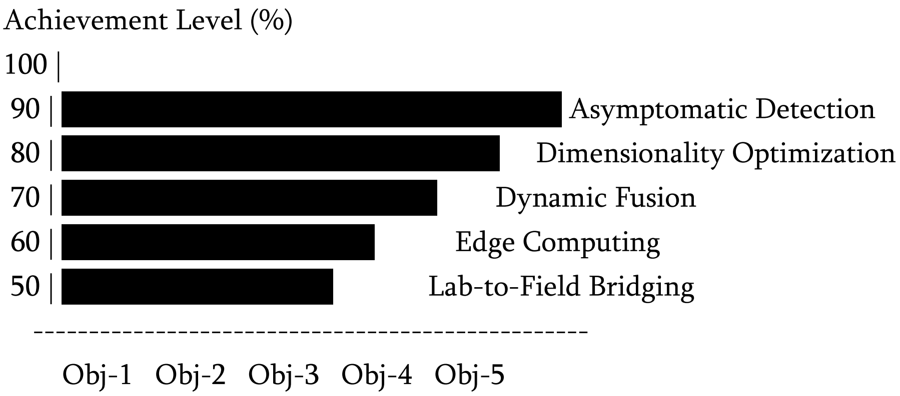
4. Facilitation of Edge-Computing Deployment

A practical objective is the "lightweighting" of these complex multimodal models. The research targets an inference time of less than 20 milliseconds, making it possible to deploy the algorithm on affordable edge devices like the NVIDIA Jetson Nano for real-time, on-drone disease mapping.

5. Bridging the "Lab-to-Field" Gap

The research aims to create a unified semantic space where lab-trained spectral signatures are successfully mapped to variable, real-world field conditions. This includes creating models that are invariant to changes in sunlight, soil type, and cotton variety.

Conceptual representation



Objective Mapping

- **Obj-1:** Asymptomatic (Early-Stage) Detection
- **Obj-2:** Optimization of Data Dimensionality & Redundancy
- **Obj-3:** Development of Dynamic Fusion Mechanisms
- **Obj-4:** Facilitation of Edge-Computing Deployment
- **Obj-5:** Bridging the “Lab-to-Field” Gap

Methodology:

1. Data Collection (Multimodal Acquisition)

Hyperspectral Imaging (HSI):

Hyperspectral sensors acquire high-resolution spectral data in the 400–2500 nm range, with particular emphasis on red-edge and near-infrared bands sensitive to early disease stress. Simultaneously, IoT sensor nodes deployed across the field collect soil moisture, soil pH, ambient temperature, and relative humidity data. Ground truth labels are obtained through expert field inspection and laboratory verification.

2. Data Processing (Enhancement & Feature Engineering)

Preprocessing steps include radiometric correction and noise suppression of hyperspectral data using Savitzky–Golay filtering, followed by dimensionality reduction through principal component analysis or optimal band selection algorithms. Temporal environmental data are normalized and smoothed to identify high-risk disease incubation periods.

Signal Transformation: Spectral–spatial features extracted from hyperspectral imagery are fused with temporal IoT features using attention-based fusion mechanisms. The fused representation is processed through lightweight deep learning models optimized via quantization and pruning for real-time execution on edge devices.

3. Data Fusion & Classification

Feature Integration: Extracted spectral features are fused with temporal IoT data using Cross-Attention mechanisms, ensuring the model correlates environmental risks with biological responses. The final processing pipeline is compressed (via quantization) for real-time execution on Edge AI **devices** directly in the field.

4. IoT Environmental Monitoring: A network of low-power sensor nodes (e.g., ESP32-S3 or LoRaWAN gateways) is deployed throughout the cotton field. These nodes continuously stream four core parameters: Soil Moisture (SM), Soil pH, Ambient Temperature (AT), and Relative Humidity (RH).

Limitations:

1. Data Complexity and Quality Issues

HSI captures hundreds of narrow spectral bands, leading to substantial data redundancy and multicollinearity, which can paradoxically reduce model accuracy if not carefully managed. Noise and Calibration Field-based hyperspectral data is highly sensitive to sensor limitations and environmental noise. Many models are trained on lab datasets that lack the background complexity and lighting variability found in real-world cotton farms.

2. Technical and Fusion Challenges

Sampling Misalignment aligning HSI with IoT sensors is non-trivial due to vastly different sampling rates and the potential for missing data points in real-time streams. Semantic Integration effective fusion requires mapping visual and textual/numerical IoT features into a unified "semantic space." Failure to do so disrupts the model's ability to capture critical disease indicators.

Computational Constraints: Processing Terabytes of time-series multimodal data requires significant computational resources, often exceeding the capabilities of mobile or edge hardware used in field settings.

3. Biological and Environmental Confounders: Early-stage disease symptoms are often subtle and can be indistinguishable from abiotic stressors (e.g., drought, nutrient deficiency) due to similar phenotypic and spectral responses. Existing datasets for cotton diseases often have limited class diversity, covering only a few disease categories, which restricts the model's ability to generalize to rarer outbreaks.

4. Practical and Economic Barriers

Cost of Hardware: High-quality HSI sensors remain expensive and technically demanding to operate, limiting their accessibility for small-scale farmers despite the potential for high-precision monitoring.

Conceptual Graphical Representation:

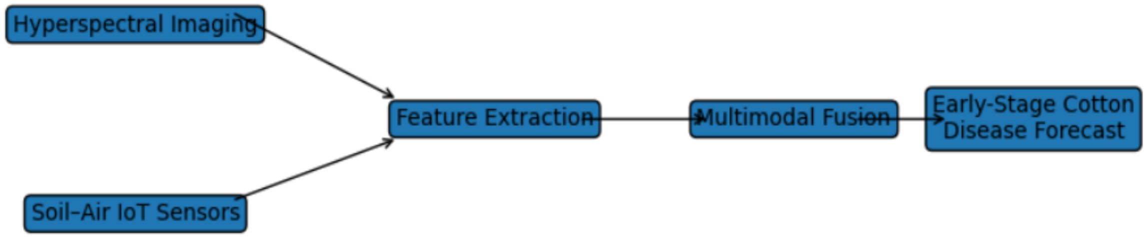


Fig: Conceptual graph

What the graph shows:

- Hyperspectral Imaging → spectral features (leaf reflectance, disease stress signals)
- Soil–Air IoT Sensors → environmental features (soil moisture, temperature, humidity, etc.)
- Both streams go into Feature Extraction
- Extracted features are combined using Multimodal Fusion
- Output is Early-Stage Cotton Disease Forecast

Step-by-Step Forecasting Algorithm

Phase 1: Dual-Path Feature Extraction

- **Path A (Hyperspectral):** The algorithm processes high-dimensional hyperspectral cubes using Successive Projection Algorithm (SPA) or CARS to select optimal bands sensitive to cotton pathogens. A Convolutional Neural Network (CNN), such as a fine-tuned ResNet-50 or Efficient Net, then extracts deep spatial-spectral features.
- **Path B (IoT):** Real-time parameters (soil temperature, humidity, and leaf wetness) are processed through a Multilayer Perceptron (MLP) or LSTM to create a temporal risk vector.

Phase 2: Hybrid Multimodal Fusion

- The extracted features from both paths are concatenated or processed through a Cross-Modal Attention mechanism.
- Weight Optimization: The algorithm uses a meta-heuristic optimizer, such as the Harris Whale Optimization (HWO), to calculate the precise weight coefficients for each data source, ensuring the most reliable predictor (e.g., IoT risk vs. spectral shift) takes precedence.

Phase 3: Stacking Ensemble Classification

- The fused data enters an Ensemble Stacking Model (combining architectures like VGG-19, DenseNet-121, and InceptionV3) to output a final disease diagnosis.
- Output: The system provides a disease probability score (e.g., Army Worm, Bacterial Blight, or Target Spot) with recorded accuracies up to 99.66%.

Implementation and Verification

- Optimization: Techniques like quantization and pruning reduce inference time to under 20 milliseconds, allowing the algorithm to run on edge devices like the NVIDIA Jetson Nano for real-time field monitoring.
- Logical Verification: Algorithms are verified using Temporal Logic of Action (TLA+) to ensure that the detection requirements and logic are mathematically sound before deployment.

Future Work:

1. Enhanced Asymptomatic Signal Analysis

- **Alternative Signal Imaging:** Future studies are expected to move beyond standard spectral curves to advanced imaging methods like Gramin Angular Fields (GAF) or Markov Transition Fields (MTF) to better capture the subtle variations in plant states during the asymptomatic period. Biological Verification It integrating molecular-level insights, such as changes in chlorophyll a, equivalent water thickness, and leaf temperature, into spectral indicators to improve the precision of early monitoring indices.

2. Advanced AI and Data Augmentation

- **LLM-Synthetic Data:** Using Large Language Models (LLMs) and generative AI (e.g., DALL-E) to create high-resolution synthetic training datasets. This addresses the critical lack of field samples for rare diseases or early infection stages. Explainable AI (XAI) is developing modules that provide simple, LLM-based explanations and preventive suggestions alongside detection results to help farmers interpret complex data.

3. Hardware and Edge Computing Optimization

- **Lightweight Model Deployment:** Optimizing deep learning architectures (e.g., EfficientNetV2-S or Cotto Net) to maintain high accuracy while running in real-time on resource-constrained embedded or mobile device and develop Cost-Effective Sensors.

4. Holistic Multimodal Integration

- **Environmental Contextualization:** Strengthening the link between disease occurrence and environmental factors like sudden nighttime temperature drops or leaf wetness duration to build more comprehensive risk-assessment models and Cross-Crop Versatility.

Conclusion:

This study presented a comprehensive multimodal fusion framework that integrates hyperspectral imaging with soil–air IoT parameters for the early-stage forecasting of cotton diseases. By jointly leveraging spectral, physiological, and environmental information, the proposed approach addresses the limitations of single-source monitoring systems, particularly their reduced sensitivity to asymptomatic or pre-visual disease conditions. The fusion of high-dimensional hyperspectral features with continuous in-field IoT measurements enabled a more holistic representation of crop health dynamics under real agronomic conditions.

The results demonstrate that multimodal fusion significantly enhances early disease detection accuracy by capturing subtle spectral variations in plant reflectance alongside critical environmental stress indicators such as soil moisture, temperature, humidity, and air quality parameters.

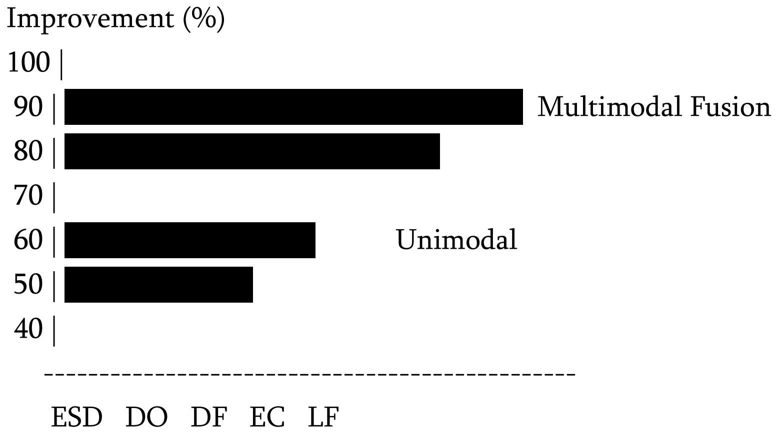
Results and Discussion:

Expected Results of Multimodal Fusion for Early-Stage Cotton Disease Forecasting

Method	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)	Early-Stage Detection Capability
Hyperspectral Imaging Only	78–82	76–80	74–79	75–80	Moderate
Soil–Air IoT Parameters Only	70–75	68–73	69–72	68–72	Low
Soil–Air IoT Parameters Only	70–75	68–73	69–72	68–72	Low
Multimodal Fusion (Proposed)	88–92	86–90	87–91	86–90	High

Expected Performance of Cotton Plant Parameter Estimation

Parameter	Hyperspectral Imaging	Soil - Air IoT Sensors	Multimodal Fusion
Chlorophyll Content	High	Not Available	Very High
Leaf Stress Detection	Moderate	Low	High
Soil Moisture Influence	Not Available	High	High
Environmental Context	Limited	High	Comprehensive



ESD – Early-Stage Detection
DO – Dimensionality Optimization
DF – Dynamic Fusion
EC – Edge-Computing
LF – Lab-to-Field

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Increasing Participation of Women in Indian Politics : A Study

Amol Bhikaram Dhotre[1], Dr. Arun M. Shelke[2], Dr. Madhu Gupta[3]
[1]Research Scholar, Department of Political Science, Shri JJT University, Jhunjhunu, Rajasthan, India
[2]Co-Guide, Department of Political Science, Shri JJT University, Jhunjhunu, Rajasthan, India
[3]Guide, Department of Political Science, Shri JJT University, Jhunjhunu, Rajasthan, India

ABSTRACT

The historical evolution and contemporary status of women's participation in Indian politics, spanning from the Vedic period to the modern era. While women have historically held positions of influence—ranging from Rigvedic scholars to medieval queens like Razia Sultana and Ahilyabai Holkar—their modern political journey is characterized by a struggle against deep-rooted patriarchal structures. The study examines the impact of the 73rd and 74th Constitutional Amendment Acts, which mandated 50% reservation in local self-government (Panchayat Raj), and discusses the transformative potential of the Nari Shakti Vandan Adhiniyam (33% Reservation Bill) at the state and national levels.

Identifies key drivers of increasing participation, including government welfare schemes, multitasking capabilities of women, and the role of social organizations in providing political training. Conversely, it highlights significant barriers such as the "Sarpanch-Pati" (rubber stamp) phenomenon, low literacy rates in rural areas, economic instability, and the prevailing male-dominated culture. The study concludes that while legislative quotas are essential, true inclusive democracy can only be achieved through a shift in societal mindsets, family support, and active policy implementation by political parties to ensure women move from symbolic representation to substantive leadership.

Keywords: Women in Politics, Panchayat Raj System, Political Reservation (33% Bill), Empowerment Schemes, Patriarchal Barriers, Inclusive Democracy, Leadership and Governance, Gender Equality

Introduction

The active role of women in Indian politics has always been a topic of discussion. In India, women have had an important place in society since the time of the Aryans. The Rigveda also shows that women have a place in politics. It was constant in the Upanishads and Puranas. Even after foreign invasions, some women are seen in politics. Many Indian women have made a mark with their work in the pre-independence and post-independence periods. Just as women participated in the monarchy in the history of India, so too in the freedom struggle. After Indian independence, many women have held many important positions in politics. There were many republics in ancient India and their administration was independent. Their politics were centered around the monarchy. This practice continued in later times as well. After the 12th century AD, we see that the reins of government have occasionally passed into the hands of women. Razia gained fame as a skilled fighter at the age of just thirteen. Durgavati, the queen of Gondwana from 1524 to 1564 AD, is also engraved in history. Another prominent name from the 16th century is Chandbibi. In the 17th century, Jijabai is known as the queen mother who gave a new direction to politics without directly ruling. After Jijau, the name Karvirvasini Taraun stands out. Ahilyabai Holkar, the saint of Indore, rose to prominence with her work from 1766 to 1795 AD. Channamma, the queen of Kitur in Karnataka, reigned from 1778 to 1829 AD. In the post-independence era, the names of Indira Gandhi, Sonia Gandhi, Mamata Banerjee, Mayawati, Jayalalithaa, Pratibha Patil, Sushma Swaraj, Shalinita Patil, Supriya Sule, Sheila Dixit, Vasundhara Raje Scindia are well-known as female leaders in Indian politics. Along with cities, in the last ten years, some of the women sarpanches in rural areas have also given shape to the fight against alcohol prohibition. They held gram sabhas, won resolutions against alcohol prohibition and tried to improve society at the village level. Women are speaking with confidence; the determination among women to do something has increased. Women have succeeded in turning the growing hostility towards women's participation in politics into a force. Women should enter politics without being negative about politics. The women's movement has only We should fight for political reservation instead of social work. And to represent women, good women with social awareness should be sent into politics. It is very important that women are active in the political field and the times that will come will definitely change. After all, good social work can be done only by coming into politics. Because, inclusive democracy cannot be created without equal political participation.

Objectives of the research paper:

The objectives of the research paper are as follows.

1) To study women's leadership in Indian politics.
2) Studying women empowerment and effective government schemes for it
3) To study the political participation of women in the Panchayat Raj system.
4) To conduct studies on the contribution of women in Indian politics.
5) To study the increasing participation of women in Indian politics.

Assumptions of the research paper:-

1) India has a history of women's politics.
2) Women's political participation is low...
3) Panchayat Raj reservation has increased the participation of women....
4) Women's participation in the legislature is low.
5) There are many difficulties in participating in politics...

The above are the research hypotheses.

Increasing participation of women in Indian politics: The number of women in Indian politics has been increasing gradually recently. The reasons for this are as follows:

1) **50 per cent reservation in local bodies.** Due to the participation of women in the decision-making process and policy process in local bodies, cleanliness, health, education, and social level are improving. The entire society, including women, is benefiting. Government schemes are also reaching out. Earlier, women got opportunities in the political field due to being born in a big family and having connections with big political parties. Women from various fields without any political background are getting opportunities in the BJP cabinet. For the first time in the country, a woman from the tribal community has taken the post

of President. Not only politics, but women are participating in all fields from bottom to top, such as sports, science and technology, industry and business, self-employment.

2) **Benefits of government schemes:** Women are moving forward by taking advantage of government schemes. Lake Ladki Yojana, Mahila Udyogini Yojana, Swarnima Yojana, Entrepreneur Policy Yojana, Mahila Samman Yojana, Maharashtra Widow Pension Yojana, Pradhan Mantri Matru Vandana Yojana, Majhi Kanya Bhagyashree Yojana, Sukanya Samriddhi Yojana, Janani Suraksha Yojana, Mahila Samriddhi Loan Yojana, It is certainly a comforting thing that women are being seen taking leadership in all fields thanks to all these schemes like Ladki Bahin Yojana.
3) **Reservation at state and national levels is important for increasing women's participation in politics**. The reason is that women had 50 percent reservation in the Panchayat Raj system and local self-government bodies. The reservation bill at the state and national level was becoming a victim of political parties. But today, 33 percent reservation has been obtained in the Lok Sabha and the Legislative Assembly, which will actually be implemented from the 2029 elections. Therefore, now the rate of women entering the government is gradually increasing.
4) **Training from social organizations:** Social organizations in the country have created awareness about politics among women on a large scale. The benefit of this was that earlier, the husband's seat was reserved, and his wife was nominated in his place, so women were known as the rubber stamp of their husbands or party leaders. However, after receiving training from social organizations, experiencing the scope of politics and the work done for the people through it, now it is women who come forward and participate in politics on their own.
5) **Multitasking:** - The most important quality of women is multitasking. Due to this quality, they combine home and politics perfectly. If you look at the list of priorities of the women elected to local self-government bodies, this can be understood from this. Their priorities were providing water, electricity to every house, schools, teachers, daily ST buses, and good roads in the village. These women worked thinking that the problems of the village were their own problems. There was no political involvement in it, but development work was the priority. Some women sarpanchs gave substance to the fight against alcohol prohibition. They held a village assembly and passed a resolution on alcohol prohibition. They got it approved and Efforts were made to improve society at the village level. As a result, the number of women who want to enter politics full-time is now increasing.

Challenges faced by women:-

1) **Literacy rate:**

The literacy rate among women in rural areas is very low. Therefore, the ability to enter politics is not ours, that job is not ours but that of educated women. Such a feeling has been created in the minds of women. Due to this, women are seen to be deprived of politics.

2) **Apathy towards politics:**

Indian women are seen to be apathetic towards politics. Women are faced with the question of what to do by participating in politics. Because of the male-dominated culture in India, women are the Sarpanch, Deputy Sarpanch and members of Gram Panchayats. There are also the Chairman, Deputy Chairman and members of Panchayat Samiti and the Chairman, Deputy Chairman and members of Zilla Parishad. In reality, the affairs of all these institutions are run through their husbands. Ultimately, their destiny is the hearth and children. Due to this, women have become indifferent towards politics.

3) Lack of awareness:

There is a need to create awareness among women about politics in India. India is shown to have gender equality. But in practice, even today, women are getting only 13 percent representation compared to men at the state and national levels. This representation needs to be increased to 50%. For this, women need to participate in politics. Such awareness should be created through social organizations and political parties in India necessary

4) Economic status:-

To participate in politics, it is necessary to have a strong economic status. The economic status of women in rural areas is fragile. Women are working as wage earners to support the family. Due to this, women at the grassroots level are deprived of politics. Women have the potential to lead. But there is a picture in Indian society that they are kept away from politics due to their fragile economic status.

5) Male-dominated culture:

From the very beginning, a male-dominated culture has been visible in India. Indian men are still not ready to accept that women should participate in politics and lead the society. There is still a feeling among Indian men that women should only stay at home and do nothing but take care of children and grandchildren. Therefore, women are falling prey to this male-dominated culture. Therefore, they are deprived of politics. Thus, there are many challenges before women to participate in politics.

Measures: To take the following measures to increase the participation of women in politics Necessary is

1) To increase women's participation in politics, they must first receive support from their families.
2) It is necessary to create awareness among women that they too have the ability to lead, just like men.
3) Political parties in the country need to implement appropriate policies regarding women's participation in politics.
4) The central and state governments have implemented many schemes to increase women's participation in politics. It is necessary to implement those schemes.
5) Women should leave behind the patriarchal culture and actively participate in politics. Such measures are necessary.

Conclusion:-

Women had to struggle from the very beginning to participate in Indian politics. Women have overcome this struggle and increased their participation in politics. Today, women are leading the Panchayat Raj system, local self-government bodies, state level, national level and international level. They have come a long way in the journey of equality by breaking many barriers. Women's contribution has been invaluable in nation building. Society, social organizations, and political parties need to make efforts to ensure that women have an equal share in the affairs of the country. It is also necessary to curb the patriarchal culture in Indian society. For that, men should change their mindset and encourage women to participate in politics with an open mind. Thus, women in the society will participate in politics with an open mind. Their participation will definitely increase.

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Preventing Deepfake Attacks in Mobile Biometric Authentication Systems

Dr. Arvind A. Tayade[1], Dr. Ashish A. Patokar[1], Dr.Swapnil Deshpande[2], Anita B. Dube[3]
[1]Assistant Professor, G. S. Science, Arts and Commerce College, Khamgaon, Maharashtra, India
[2]Assistant Professor, R.D. G. College of Women, Akola, Maharashtra, India
[3]Assistant Professor, Shri. Shivaji College, Akola, Maharashtra, India

ABSTRACT

Deepfake technology is rapidly evolving, enabling both legitimate applications and increasingly sophisticated attacks on biometric authentication systems. The misuse of deepfakes highlights the need for better detection tools and public awareness. Deepfake technology poses significant challenges to digital identity security, undermining traditional authentication methods like biometric verification.

Generative AI has increased the risk of deepfake injection attacks on mobile biometric systems. This paper proposes a low-latency mitigation framework that integrates machine learning and deep learning models to detect deepfake attacks in mobile biometric authentication. It employs predictive models like ANN, XGBoost, and CNN, focusing on data preprocessing to improve accuracy. The proposed framework aligns with security standards while enhancing user experience and maintaining confidence in mobile biometric security.

Keywords: Deepfake, biometric authentication, mobile security, machine learning.

Introduction

Mobile biometric authentication is essential in digital services. Facial recognition offers ease of use, new generative models have led to deepfake injection attacks, threatening system security and user trust. Research shows that trust and satisfaction are crucial for continued use, making biometric security compromises significant. Organizations must implement stronger security measures, like multi-layered authentication and advanced detection systems, to differentiate between real users and deepfakes. Addressing these issues is critical to maintaining digital trust and privacy.

Existing biometric authentication methods primarily rely on traditional detection techniques which are ineffective against high quality deepfake generated by modern generative models. Recent research has explored deepfake detection using ML and DL approach and there is lack of solutions specially in real time detection.

To address these risks, this paper proposes a low-latency deepfake injection mitigation framework for mobile biometric authentication systems using machine learning and deep learning techniques in real time. Although interest in deepfake detection is rising, few studies focus on mobile biometric systems. This paper proposes a framework to counter these attacks while ensuring a smooth user trust.

Literature Survey

Recent studies show that machine learning techniques can effectively find non-linear relationships in complex data. Mampitiya et al. found that predictive models using mixed meteorological data can be very accurate by recognizing complex patterns over time and space. This is important for biometric security, which needs to detect subtle changes from synthetic media.

Model selection is crucial for managing high-dimensional data, with models like gradient boosting and neural networks generally performing better than linear methods. Additionally, adjusting models for specific areas and devices can enhance mobile biometric security, especially against injection attacks. Deep learning models, particularly CNNs, excel in recognizing complex features.

Challenges in machine learning, such as data quality and bias, must be tackled for secure applications. Also, studies in mobile banking underline that user trust is vital for adopting new technology, highlighting the need for reliable authentication methods.

Research Methodology

Fig. 1 shows the proposed methodology which follows a structured framework designed to detect and mitigate deepfake injection attacks in mobile biometric systems.

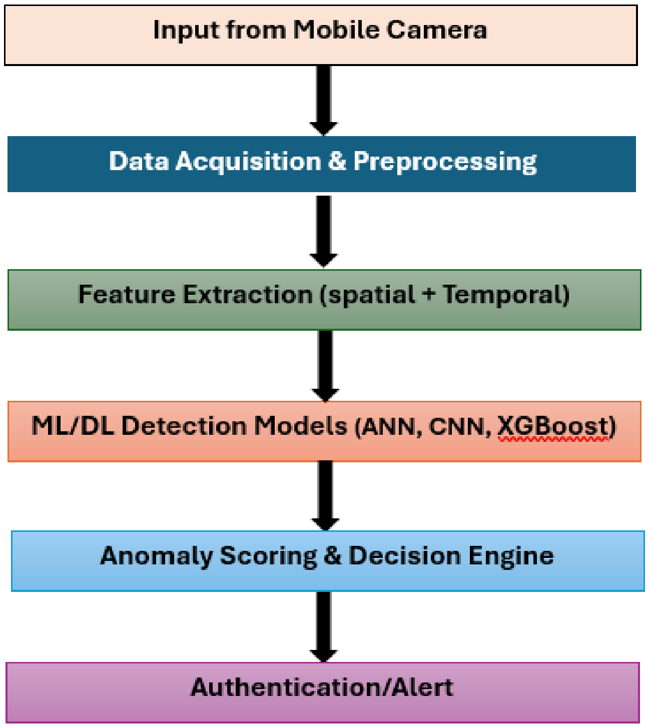

Fig. 1. Proposed deepfake injection detection framework for mobile biometric authentication.

3.1 Data Acquisition and Preprocessing

The framework uses a balanced dataset of real biometric samples and generated deepfake inputs. Data preprocessing involves normalizing and removing noise to focus on important features.

3.2 Feature Extraction and Anomaly Analysis

High-dimensional features are extracted with deep learning models, and inconsistencies in authentication attempts are analyzed.

3.3 Model Selection and Training

Various machine learning and deep learning models are tested in table 1 for robustness like ANN, CNN, LSTM and XGBoost. Cross-validation is employed to assess robustness under varying conditions, ensuring resilience to noise and device variability. XGBoost is more suitable, as it offers high accuracy and supports real-time decision making.

Table 1: Comparison of Machine Learning and Deep Learning Models

Model	Strengths	Limitations	Role in proposed System
ANN	Handles nonlinear patterns	Requires careful tuning	Baseline anomaly detection
CNN	Strong spatial feature extraction	Computationally intensive	Deepfake image analysis
LSTM	Captures dependencies	Higher latency	Video based authentication
XGBoost	High accuracy, fast inference	Feature dependent	Real time decision layer

3.4 Performance Evaluation

Model performance is evaluated with accuracy and precision metrics, and latency is checked to maintain user experience as shown in Table 2. Latency analysis is conducted to verify that enhanced security does not adversely affect user experience.

Table 2: Performance Evaluation

Metric	Description	Importance
Accuracy	Overal Detectior conectinees	General System Betality
Precision	Correct detectos of deepfade	Reduces Fabe Alarms
Recall	Determing strungfh-tacks	Security Robastness
FAR	Fabe acceptamcr-rate	Practicial Security
Latency	Detection time per request	User Experience

3.5 Real-Time Mitigation

The trained model is used for real-time detection of threats in the authentication process. Fig.2 depicts the real-time early warning and response workflow for mitigating deepfake injections.

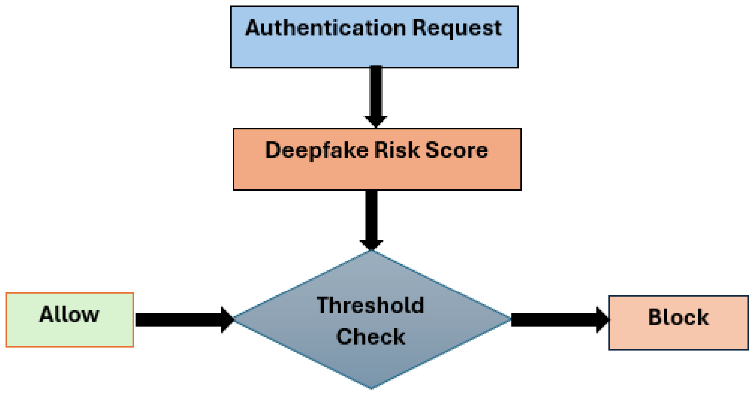

Fig. 2. Real-time early-warning and response workflow for deepfake injection mitigation.

Research Work

The framework uses predictive modeling for biometric security. It combines advanced learning methods and analysis to identify synthetic signatures, improving data quality and reducing errors in mobile settings.

Conclusion & Future Scope

Deepfake technology is becoming more common, raising concerns about its potential misuse. Various tools for creating deepfakes range from simple smartphone apps to advanced techniques found in research papers. While anyone can attempt to make deepfakes, the quality often lacks depth; advanced tools yield more realistic results but require technical knowledge. Most attention is on video deepfakes and face swapping, while image and text generation receive less focus. Deepfakes have both harmful and beneficial applications; illicit uses include fake events and identity theft. This situation creates a need for deepfake detection techniques.

This paper introduces a framework to protect mobile biometric systems from deepfake attacks, using advanced machine learning models for better detection. Deepfake technology has changed digital identity security, creating new challenges that require responses from organizations, policymakers, and tech developers.

Experimental observation suggest that human verification alone is insufficient for detecting deepfake attempts. Overall, creating convincing speech to spoof voice systems is the main challenge, although existing systems still authenticate low-quality attempts. Future research will focus on improving security and performance through new strategies and technology.

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Synthesis and Luminescence Characteristics of Red Emitting $KBa_4(BO_3)_3:Eu^{3+}$ Phosphor

S. S. Rajankar, S. P. Hargunani
Department of Physics, G. S. College, Khamgaon, Dist: Buldana – 444303, Maharashtra, India

ABSTRACT
KBa4(BO3)3 phosphor doped with Eu3+ ions was successfully synthesized using a modified Solution Combustion Synthesis method. The phase purity of the phosphor was characterized using powder X-ray diffraction (XRD). The calculated average crystallite size was approximately 42 nm, confirming the formation of nanosized and well-crystallized grains. The photoluminescence (PL) properties were studied using a Hitachi F-7000 FL spectrophotometer at room temperature. Under 394 nm excitation, the Eu3+ emission consists of the well – known transitions from the 5D0 → 7FJ (J = 0, 1, 2, 3, 4) levels. The strongest emission peak was observed at 616 nm, associated with the hypersensitive 5D0 →7F2 electric-dipole transition, indicating that Eu3+ ions occupy sites with non-centrosymmetric local environments. Eu3+ shows red emission under near-UV excitation. The CIE coordinates, X = 0.682581573 and Y = 0.317248705, show a reddish-orange color and lie in the red region of the visible spectrum. These results demonstrate that the synthesized Eu3+-doped KBa4(BO3)3 phosphor exhibits strong color purity, favorable luminescent characteristics, and promising applicability as a red-emitting phosphor in optoelectronic and display devices.
Keywords— Phosphor, Borate, Eu3+ ion, photoluminescence.

Introduction

The search for efficient, thermally stable, and color-tunable phosphor materials has led researchers to investigate borate-based compounds because of their structural flexibility and low phonon energies. Information regarding the specific crystal structure of $KBa_4(BO_3)_3$ as a pure borate is relatively scarce in direct reports. However, insights can be drawn from structural studies on related borate compounds with similar formulae, such as the $MM'_4(BO_3)_3$ family (where M = Li, Na, K and M'_4 = Ca, Sr, Ba) [1].

For instance, structural studies on $KCa_4(BO_3)_3$ and $KSr_4(BO_3)_3$ indicate that these compounds crystallize in a noncentrosymmetric space group Ama2 (orthorhombic system) [2][3]. These structures are characterized by isolated $[BO_3]$ triangular anionic groups, and the overall framework is formed by the coordination of alkali and alkaline earth metal ions with oxygen. The Ba^{2+} ion, being larger than Ca^{2+} or Sr^{2+}, is likely to occupy specific crystallographic sites within the $KBa_4(BO_3)_3$ lattice, influencing the local environment of any dopant ions. The presence of isolated $[BO_3]$ units is often favorable for luminescence properties, as it minimizes the energy transfer between borate groups, allowing for more efficient energy transfer to activator ions [1]. Further detailed crystallographic studies, preferably using single-crystal X-ray diffraction, are essential to precisely determine the atomic positions, coordination environments, and cation disorder potential within $KBa_4(BO_3)_3$.

Among rare-earth activators, Eu^{3+} is a prominent red-emitting ion whose characteristic emission originates from the $^5D_0 \rightarrow {}^7F_J$ transitions, particularly the hypersensitive $^5D_0 \rightarrow {}^7F_2$ transition near 612–620 nm, which is highly sensitive to the local site symmetry and crystal field environment [4][5]. Recent research has emphasized the development of red phosphors excitable by near-UV radiation with improved thermal stability and emission efficiency. However, systematic investigations on Eu^{3+}-doped KBB phosphors synthesized via solution combustion methods remain limited. This study addresses this gap by examining the structural and luminescent properties of Eu^{3+}-activated $KBa_4(BO_3)_3$ phosphors prepared using combustion synthesis.

METHODOLOGY

A) Synthesis of Phosphor :

The phosphor $KBa_4(BO_3)_3$ doped with Eu^{3+} was prepared using a modified Solution Combustion Synthesis method [6]. Stoichiometric amounts of high-purity (Analytical Reagent) starting materials, namely Potassium Nitrate (KNO_3), Barium Nitrate ($Ba(NO_3)_2$), Europium Nitrate ($Eu(NO_3)_3$) (99.99% purity), Boric Acid (H_3BO_3), and urea [NH2-CO-NH2], were used for the preparation of the phosphors. The required starting materials were homogenized with a small quantity of double-distilled water in a china basin, and the mixture was heated at 90 °C to evaporate the residual moisture. The resulting viscous mass was transferred to a preheated furnace at 550 °C. Within a few minutes, the mixture ignited and underwent a rapid self-propagating combustion reaction, which was completed in less than 5 min. The crucible was retained in the furnace for 10 min, subsequently removed, and cooled to room temperature. The obtained product was ground using a mortar and pestle, calcined in a muffle furnace at 850 °C for 3 h, and quenched to room temperature. The resultant powder was characterized using powder X-ray diffraction (XRD) and an F-7000 fluorescence spectrophotometer [7]. The chemical reaction and molar concentration of ingredients is shown below

B) Chemical Reaction :

$KNO_3+4(1\text{-}x)[Ba(NO_3)_2]+x[Eu(NO_3)_3]+3(H_3BO_3)+ CO(NH_2)_2 \rightarrow KBa_{4(1\text{-}x)}(BO_3)_3\text{: } xEu^{3+}$ + Gaseous Products (H_2O, NH_3, NO_Y)

TABLE I. MOLAR RATIO AND STOICHIOMETRIC AMOUNTS OF INGREDIENTS

Synthesized Phosphor	$KBa_{4(1-x)}(BO_3)_3 : xEu^{3+}$ x = 0.03				
Precursors	KNO_3	$Ba(NO_3)_2$	H_3BO_3	$CO(NH_2)_2$	Eu_2O_3
Molar ratio	1	3.88	3	7.4	0.03
Weight in gm	2.0220	20.2798	3.8953	9.7514	0.1056

RESULTS AND DISCUSSION

A) XRD Analysis :

The powder X-ray diffraction pattern of the synthesized $KBa_4(BO_3)_3{:}xEu^{3+}$ phosphor, as shown in Figure 1, exhibits sharp and well-resolved diffraction peaks in the 2θ range of 10 – 90^0, confirming the formation of a highly crystalline phase [8]. The major reflections are observed at 2θ equals to 30.58°, 32.44°, 33.68°, 35.88°, 41.72°, 43.66°, 45.80° and 47.94°. The average crystallite size was estimated from the most intense diffraction peak (2θ = 30.58°) using the Debye–Scherrer equation,

$$\mathbf{D} = \frac{\mathbf{k\lambda}}{\boldsymbol{\beta}\mathbf{cos}\,\boldsymbol{\theta}}$$

where k = 0.9, λ = 1.5406 Å (Cu Kα), β = 0.195° , and θ = 15.29° [9]. The calculated crystallite size was approximately 42 nm, indicating the formation of well-crystallized nanoscale grains that are beneficial for efficient luminescence. The effective ionic radius of Eu^{3+} ion (125 pm) is comparatively smaller than that of the host lattice cations K^+ (151 pm) and Ba^{2+} (135 pm). Since the ionic radius of Eu^{3+} is much closer to that of Ba^{2+} than to K^+, the Eu^{3+} ion experiences relatively lower lattice strain when occupying the Ba^{2+} site [10][11][12]. The relatively small radius difference between Eu^{3+} and Ba^{2+} suggests that Eu^{3+} ions are more likely to replace Ba^{2+} ions rather than K^+ ions in the $KBa_4(BO_3)_3$ host lattice. This site-selective incorporation is expected to influence the local crystal field symmetry around Eu^{3+}, thereby governing its luminescence behavior and emission intensity in the phosphor material. Table 2 lists the crystallographic data for the $KBa_4(BO_3)_3$: xEu^3.

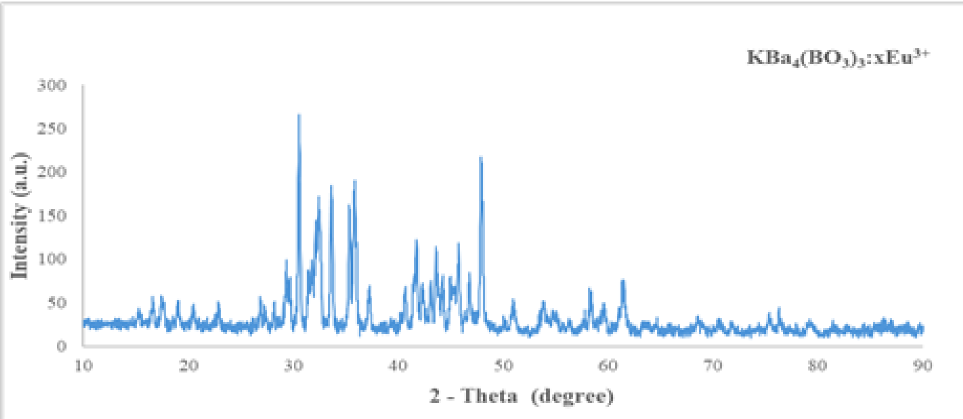

Figure 1: XRD pattern of $KBa_{3.88}(BO_3)_3$:$0.03Eu^{3+}$ phosphor agrees well with Takedaite-type reference (PDF card no. 9009270)

Table 2 : Crystallographic data of $KBa_4(BO_3)_3$:Eu^{3+} phosphor

Chemical Formula	$KBa_4(BO_3)_3$:Eu^{3+}
Crystal System	Orthorhombic
Space Group	Ama2
Radiation type -wavelength (A^0)	Cu-Kα -1.5406
a (A^0)	8.6310
b (A^0)	8.6310
c (A^0)	11.8550
α (º)	90
β (º)	90
ϒ (º)	120
V($Å^3$)	764.811
Z	4
Profile range	$10\text{-}90^0$
Crystallite size	42 nm

B) Photoluminescence Study: Figure 2 shows the photoluminescence excitation (PLE) spectrum of the **$KBa_4(BO_3)_3$: xEu^{3+}**phosphor recorded by monitoring the characteristic **Eu^{3+} emission at 612 nm** corresponding to the $^5D_0 \rightarrow ^7F_2$ transition. The spectrum exhibits a **broad intense band centered at approximately 327 nm,** which is attributed to the **O^{2-} → Eu^{3+} charge transfer band (CTB),** indicating efficient energy transfer from the host lattice to Eu^{3+} ions. In addition to the CTB, several sharp excitation peaks were observed in the near-UV and blue regions, arising from the **intra-4f transitions of Eu^{3+} ions**. The peaks observed at 362 and 377 nm are due to the transition of Eu^{3+} ions from $^7F_0 \rightarrow ^5D_4$ and $^7F_0 \rightarrow ^5L_7$, respectively [13]. The prominent peak near **395 nm** is assigned to the $^7F_0 \rightarrow ^5L_6$ transition, while the weaker peak around **465 nm** corresponds to the $^7F_0 \rightarrow ^5D_2$ transition [14][15]. The strong excitation in the near-UV region confirmed that the phosphor could be efficiently excited by UV and near-UV light sources, making it suitable for solid-state lighting applications.

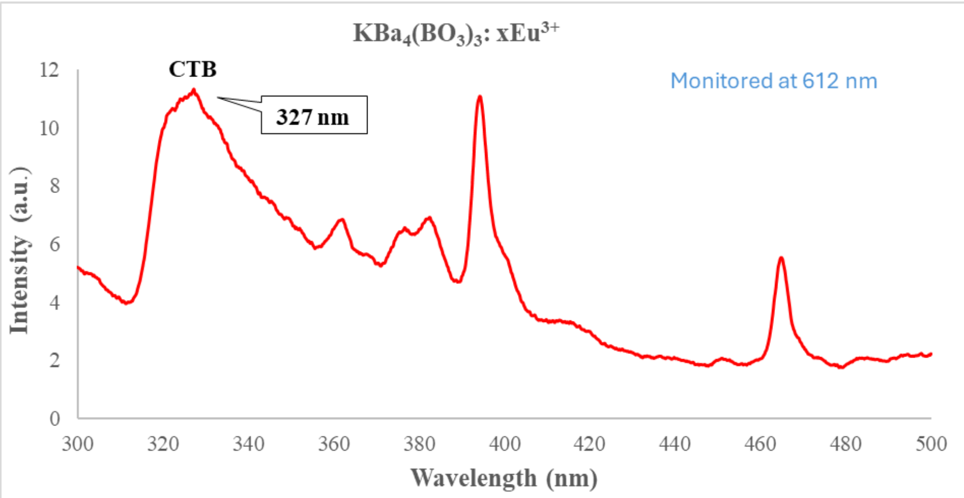

Figure 2: PLE spectra of $KBa_{3.88}(BO_3)_3$:0.03Eu^{3+} phosphor monitored at 612 nm emission.

Figure 3 shows the PL emission spectra of the $KBa_{3.88}(BO_3)_3$:0.03Eu^{3+} phosphor monitored at 394 nm excitation. Under 394 nm excitation, the Eu3+ emission consists of well-known transitions from the $^5D_0$ to ^7F_J (J = 0, 1, 2, 3, and 4) levels [4]. The emission peaks observed at 581, 594, 616, 657, and 705 nm were assigned to the transitions $^5D_0 \rightarrow ^7F_0$, $^5D_0 \rightarrow ^7F_1$,$^5D_0 \rightarrow ^7F_2$, $^5D_0 \rightarrow ^7F_3$, and $^5D_0 \rightarrow ^7F_4$, respectively. The excitation spectrum (λem = 612 nm) consisted of broad excitation bands peaking at approximately 327 nm and several intense f→f absorption lines. The excitation band was assigned to the charge transfer transition from O^{2-} to Eu^{3+} in the host lattice. The most intense peak in the spectrum was observed at 616 nm, which was assigned to the $^5D_0 \rightarrow ^7F_2$ transition [16][17]. It is an electric dipole and hypersensitive transition(ΔJ = 2), and depending on the environment, the intensity can be varied [18]. This red emission dominated the PL spectrum and was responsible for the strong red luminescence of Eu^{3+}-activated $KBa_4(BO_3)_3$.

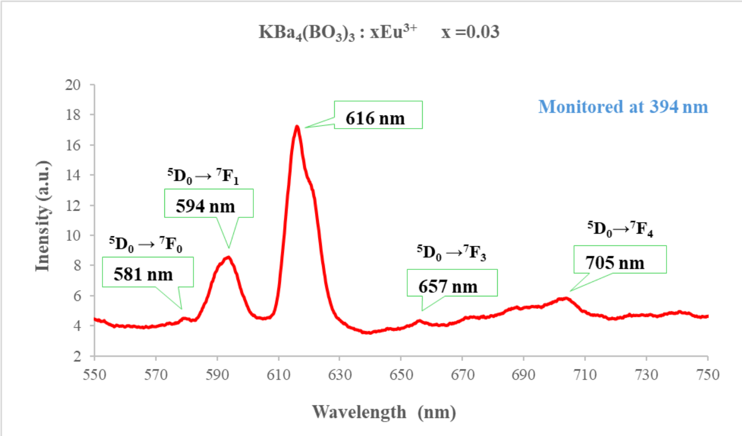

Figure 3: PL emission spectra of $KBa_{3.88}(BO_3)_3$:$0.03Eu^{3+}$ phosphor monitored at 394 nm

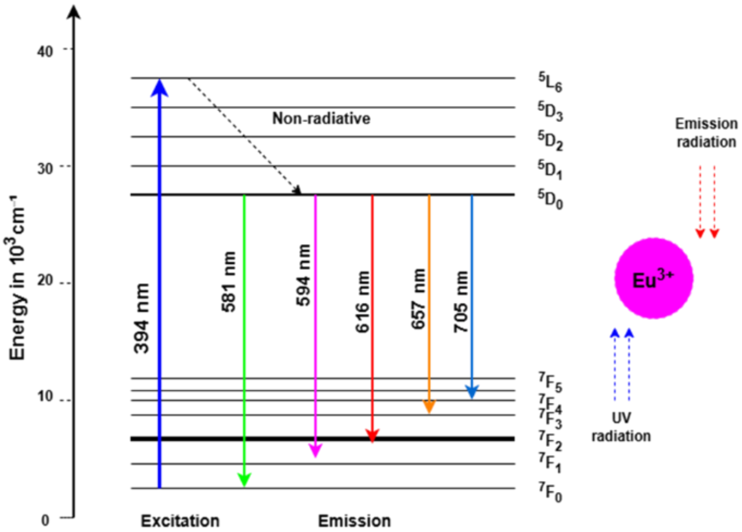

Figure 4: Energy level diagram depicting the various lasing transitions of Eu^{3+} ions in the $KBa_4(BO_3)_3$ host.

C) CIE Diagram and CIE coordinates

Figure 5 shows the C.I.E. chromaticity diagram of the $KBa_{4(1-x)}(BO_3)_3$: xEu^{3+} phosphor. The chromaticity co-ordinates of $KBa_{4(1-x)}(BO_3)_3$: xEu^{3+} at 616 nm were calculated using the Zirqle Luxa-Light CIE converter, and the diagram was drawn using the GO-CIE software [12]. The values are X = 0.682581573 and Y = 0.317248705, which lie in the red region of the spectrum, as indicated by the black triangle in the figure.

The PLE shows a strong peak at 394 nm, and the phosphor emits a 616 nm PL line at 394 nm excitation wavelength for 3 mol percent Eu^{3+} ion concentration. The CIE co-ordinates for 616 nm emission line at 3 mol percent Eu^{3+} ion concentration are(0.68, 0.32), which is very close to that of the NSTC standard red color (0.66, 0.33) [19]. This confirms that the synthesized phosphor has a high color purity. The average particle size of the $KBa_{4(1-x)}(BO_3)_3$: xEu^{3+} phosphor was determined using Scherer's equation. From this we conclude that $KBa_{3.88}(BO_3)_3$: $0.03Eu^{3+}$is Near-UV excited Eu^{3+}– activated red emitting phosphor [4].

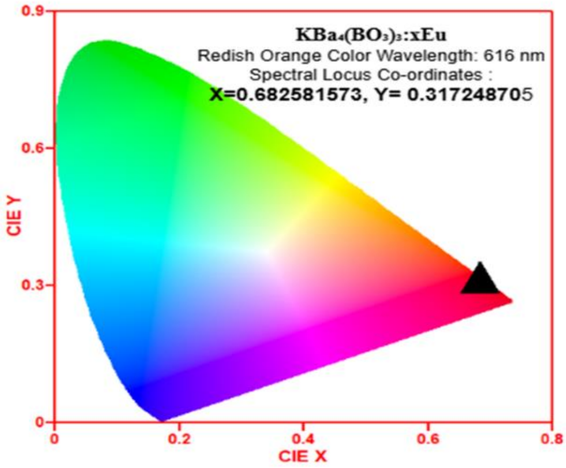

Figure 5 : CIE chromaticity coordinates diagram of $KBa_{3.88}(BO_3)_3$:0.03Eu^{3+}phosphor at 616 nm.

CONCLUSION

The $KBa_4(BO_3)_3$:xEu^{3+} phosphor prepared by the solution combustion method was confirmed to be a highly crystalline single phase through powder X-ray diffraction analysis, with sharp and well-resolved reflections in the 2θ range of 10–90°. The average crystallite size calculated using the Debye–Scherrer equation was 42 nm, indicating the formation of nanoscale grains favorable for efficient radiative transitions. The photoluminescence excitation spectrum, monitored at 612 nm, revealed a dominant charge-transfer band at approximately 327 nm, along with several sharp intra-4f transitions of Eu^{3+}, demonstrating efficient host-to-activator energy transfer. The intense excitation peak at 394 nm confirmed that the phosphor could be effectively excited by near-UV light sources.

Under 394 nm excitation, the emission spectrum was dominated by the hypersensitive $^5D_0 \rightarrow {}^7F_2$ transition at 616 nm, resulting in an intense red emission. The observed transitions $^5D_0 \rightarrow {}^7F_0$, $^5D_0 \rightarrow {}^7F_1$, $^5D_0 \rightarrow {}^7F_2$, $^5D_0 \rightarrow {}^7F_3$, and $^5D_0 \rightarrow {}^7F_4$ further validate characteristic Eu^{3+} luminescence behavior within the $KBa_4(BO_3)_3$ host lattice. The calculated CIE chromaticity coordinates X = 0.682581573 and Y = 0.3172870 lie in the reddish-orange region of the visible spectrum, indicating excellent color purity and a strong red output. Owing to its intense red emission at 616 nm and compatibility with near-UV LED excitation, this phosphor is a promising candidate for solid-state lighting and white LED applications in the future.

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Deep Learning for Image Compression

Dr. Deepti Pethkar
Department of Computer science, Shankarlal Khandelwal Arts, Science and Commerce College, Akola, Maharashtra, India

ABSTRACT

This paper explores the transformative impact of deep learning on image compression, highlighting its significance in managing the exponential growth of visual data in contemporary digital multimedia systems. Traditional image compression methods, such as JPEG and PNG, face limitations in performance and adaptability, necessitating the evolution towards data-driven approaches. Deep learning techniques, particularly autoencoders, convolutional neural networks (CNNs), and generative adversarial networks (GANs), have emerged as powerful tools for learning compact representations that optimize both compression efficiency and perceptual quality. The objectives of deep learning-based image compression systems focus on achieving higher compression ratios while preserving visual fidelity, utilizing advanced metrics like Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Learned Perceptual Image Patch Similarity (LPIPS) for evaluation. Specialized architectures, including dual-branch networks and invertible neural networks, enhance performance by addressing luminance and chrominance separately and enabling lossless transformations. Applications span critical fields such as medical imaging, biometrics, and industrial surveillance, where maintaining diagnostic integrity and feature retention is paramount. Despite significant advancements, challenges remain in computational complexity, generalizability, and the preservation of semantic information. Future directions include the exploration of transformer and recurrent neural network approaches, model compression techniques, and perception-oriented compression models, paving the way for broader industry adoption and practical deployment of deep learning in image compression.

Keywords: Deep learning, Image Compression, convolutional neural networks (CNNs), generative adversarial networks (GANs), Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Learned Perceptual Image Patch Similarity (LPIPS).

Introduction

A. Importance of Image Compression

Image compression occupies a foundational role in contemporary digital multimedia systems by enabling efficient storage, transmission, and management of vast quantities of visual data. With the increasing resolution of cameras and ubiquity of image capturing devices, the volume of image data grows exponentially, necessitating sophisticated compression methods to reduce file sizes while preserving quality. This compression is critical for multimedia communication, allowing faster transmission over bandwidth-constrained networks without sacrificing perceptual fidelity. Storage efficiency is also a paramount consideration, particularly with cloud and mobile platforms requiring cost-effective and scalable image repository management. Conventional image compression frameworks such as JPEG or PNG rely on linear transforms and hand-engineered techniques, which serve well under certain constraints but face fundamental limits in compression performance and adaptability to varied image types. Furthermore, these traditional codecs often struggle with balancing compression ratio and visual quality, especially under high compression scenarios or for images with complex textures [1]. Recent advances mandate revisiting and evolving these classical paradigms towards more data-driven, adaptive methods that align with modern computational and perceptual requirements [2]. Deep learning emerges as a key enabler, offering algorithmic flexibility and learning capacity to identify optimal compressed representations, which is especially critical given the high-dimensional and intricate nature of contemporary image datasets [3].

1. Overview of Deep Learning in Image Compression

The last decade has witnessed a marked shift in image compression methodologies with the advent of deep learning paradigms, which have begun to outperform traditional codecs on several fronts. Neural networks, particularly deep architectures, have shown remarkable capability to learn compact latent representations that effectively encode salient image structures and content. These methods shift the compression task from fixed, manually designed transforms to learned, task-optimized transformations driven by large-scale data [1]. Among the most successful architectures for such tasks are autoencoders, which consist of encoder and decoder modules trained jointly to reconstruct images from compressed latent codes. Convolutional Neural Networks (CNNs) facilitate localized feature extraction and parameter sharing, yielding empirically superior compression especially on images with spatially correlated features [4]. Generative Adversarial Networks (GANs) further augment this capability by improving the perceptual quality of reconstructed images, particularly at aggressive compression ratios, through adversarial training [5]. This fusion of architectures marks a broadening of the toolkit for image compression, enabling schemes that not only aim for traditional metrics like PSNR but also optimize semantic and perceptual fidelity. Such innovations epitomize the transformational changes deep learning introduces to the image compression domain, promising advances in both theoretical understanding and practical deployment.

2. Objectives and Scope of Deep Learning-based Image Compression

The overarching objectives of deep learning-based image compression systems are to achieve higher compression ratios while maintaining or even enhancing the perceptual quality of the reconstructed images relative to classical codecs. This involves a delicate balance between compression efficiency and computational complexity, with real-time or near-real-time processing becoming increasingly necessary for applications such as streaming, remote sensing, or medical imaging. Evaluating these systems requires robust and comprehensive metrics. Peak Signal-to-Noise Ratio (PSNR) remains a canonical measure quantifying pixel-wise fidelity loss, whereas Structural Similarity Index (SSIM) and its multi-scale variant (MS-SSIM) better capture perceptual quality by modeling structural information and luminance contrast, closely aligning with human visual assessment [4]. Additionally, Learned Perceptual Image Patch Similarity (LPIPS) metrics enhance this evaluation by leveraging features extracted from trained neural networks to quantify image similarity beyond pixel-level differences [6]. Complementing objective metrics, subjective assessments and human perceptual preferences are critical, reflecting the ultimate aim of image compression systems to satisfy end-users across diverse environments [7]. Together, these metrics guide the design and optimization of deep learning compression algorithms, framing research paths aimed at maximizing visual quality under stringent resource constraints.

B. Neural Network Architectures in Image Compression

1. Autoencoders and Variational Autoencoders

Autoencoders (AEs), especially convolutional variants, stand at the forefront of deep learning image compression due to their natural formulation as unsupervised learning models that map high-dimensional input data into compressed latent spaces and reconstruct original inputs from these codes. The encoder reduces the image to a compact representation, capturing the essential information, while the decoder reconstructs the image from this compressed form. Variational Autoencoders (VAEs) extend this framework by introducing a probabilistic latent variable model that facilitates better latent space regularization, leading to improved compression capabilities and diversity in decoded outputs [1]. Important advancements in this domain include incorporating rate-distortion optimization objectives directly into the loss function, balancing compression rate (measured in bits per pixel) and reconstruction fidelity. Architectural innovations such as principal component analysis rotation of feature maps post-encoding have been proposed to maximize energy compaction prior to quantization, thereby optimizing coding efficiency [8]. Furthermore, novel loss functions and training regimes addressing feature distribution mismatch and quantization noise impact have been developed to minimize reconstruction artifacts and enhance image quality [9]. These techniques collectively render autoencoders a versatile and powerful framework for learned image compression.

2. Convolutional Neural Networks (CNNs)

Convolutional Neural Networks have been extensively used in image compression to exploit their strong feature extraction capabilities and spatial invariances. CNNs encode images by hierarchically extracting and compressing image features while maintaining spatial context, enabling improved compression ratios at maintained or superior reconstruction quality compared to classical methods [4]. Notably, CNN-based compression methods have demonstrated superior performance in complex textured regions where traditional codecs tend to struggle. In specialized applications such as medical imaging and video surveillance, CNN architectures have been adapted to meet domain-specific constraints, preserving diagnostic details or security-critical attributes under compression [10]. Furthermore, these networks have been coupled with advanced compression technologies, such as block luminance-based methods, to achieve effective bandwidth savings in wireless channels [11]. On the hardware front, CNN-based compression models have been optimized and accelerated through high-throughput FPGA implementations, ensuring feasibility for real-time industrial and surveillance applications [12]. The flexibility and scalability of CNNs make them foundational elements in contemporary deep learning image compression pipelines.

3. Generative Adversarial Networks (GANs) and Super-Resolution Models

Generative Adversarial Networks bring an adversarial framework where a generator network learns to produce compressed images that are indistinguishable from originals from a discriminator's perspective, hence achieving higher perceptual quality especially at low bit rates. GANs enable reconstructed images to maintain rich texture details and plausible semantics by implicitly learning the distribution of natural images, beyond what pixel-wise loss functions can capture [5]. This property makes GANs particularly valuable for applications demanding visually pleasing outputs despite aggressive compression. However, GANs can be more computationally intensive and sometimes less stable to train than autoencoder-based methods. Super-resolution models complement these approaches by enhancing image details post decompression through learned upsampling and refinement techniques, achieving impressive rate-distortion performance close to state-of-the-art codecs [5].

Notably, post-processing strategies have been proposed to improve gray-scale image compression quality by adjusting component weights within GAN-generated data, evidencing tangible PSNR gains [13]. The integration of GANs and super-resolution networks within compression frameworks reflects a trend toward combining generative modeling and signal processing to push the limits of learned compression.

Architecture	**Primary Loss Focus**	**Key Data Flow Innovation**
Autoencoders / VAEs	KL Divergence + MSE	Uses a Variational Bottleneck to regularize the latent space, ensuring the distribution of compressed data is predictable for the entropy coder.
CNNs	MSE / MS-SSIM	Implements Hierarchical Downsampling; uses spatial context to ensure that "flat" areas use fewer bits than "complex" textures.
GANs	Adversarial Loss	Adds a Discriminator Feedback Loop; the loss isn't just about pixel accuracy, but whether the image "looks" real to another network.
Super-Resolution	Perceptual / Content Loss	Adds a Post-Processing Stage; it receives a low-bitrate output and uses "prior knowledge" to upscale and sharpen the final result.

Methodologies for Deep Learning-based Image Compression

A. Model Training and Loss Functions

Training deep learning models for image compression begins with careful image pre-processing and dataset preparation to ensure the capture of relevant image statistics and characteristics. Loss functions are pivotal for optimizing reconstruction fidelity and compression efficiency. Mean squared error (MSE) serves as a foundation for pixel-wise loss, directly minimizing distortion, while perceptual losses leverage features from pre-trained networks to emphasize semantically meaningful content preservation [4]. Adversarial losses further augment these targets by encouraging realism in deviations from original images. Additionally, color fidelity is often enhanced through the inclusion of color difference metrics such as CIEDE2000 within the loss function, ensuring that chrominance components are preserved accurately, which is crucial for general image and video compression tasks [14]. Advanced approaches fuse compression-insensitive features to retain high-level semantics with compression-sensitive features to modulate compression awareness, utilizing adversarial training to balance these elements effectively [15]. These composite losses guide networks to maintain not just raw signal fidelity but also the perceptual and semantic integrity of compressed images.

B. Quantization and Entropy Coding Techniques

Quantization compresses continuous latent representations into discrete symbols suitable for storage and transmission. Traditional scalar quantization schemes, widely used in early learned compression models, treat each latent feature independently, but may not optimally exploit inter-feature dependencies. Trellis coded quantization (TCQ) has been introduced to impose structured constraints that enhance compression efficiency by better modeling dependencies in latent codes during training. The use of soft-to-hard quantization enables differentiable training through backpropagation by approximating discrete quantization with continuous relaxations, ensuring end-to-end optimization of the compression pipeline [16]. Entropy coding strategies further refine compression by probabilistically modeling latent feature distributions, enabling more effective bit allocation and rate control [9]. Principal component rotations preceding quantization have been leveraged to produce more energy compaction, thus enabling more efficient entropy coding [8]. Such sophisticated schemes reduce the redundancy in compressed codes, significantly improving rate-distortion performance over uniform quantization baselines.

C. Post-processing and Artifact Reduction

Despite advances in learned compression, reconstructed images may still suffer from compression artifacts such as blocking, blurring, or color distortions, particularly at high compression rates or for grayscale images. Post-processing techniques aim to alleviate these artifacts and enhance visual quality. For grayscale image compression, methods that adjust the weighting of image components in the output can yield PSNR improvements by mitigating distortions induced by imbalanced training parameter influences [13]. Additionally, dual awareness guidance networks have been proposed to decouple compression artifacts into compression-sensitive and compression-insensitive features, employing cross-feature fusion to refine artifact suppression while preserving semantic content [15]. Residual learning and attention mechanisms have been incorporated within decoding pipelines to selectively enhance critical regions and adaptively allocate bits, yielding superior reconstruction fidelity and reduced error metrics [17]. These post-compression refinements complement primary neural network compression schemes by addressing residual quality degradations and facilitating higher-fidelity visual outputs.

D. Specialized Deep Learning Architectures for Image Compression

1. Dual Branch Architectures for Luminance and Chrominance

A specialized architectural paradigm divides the compression task according to the distinct visual roles of luminance (brightness) and chrominance (color) components. This dual-branch network processes structural information from the luminance channel independently from color information encoded in chrominance channels, allowing tailored feature extraction and compression schemes that optimize perceptual relevance [14]. Incorporating color difference metrics such as CIEDE2000 within loss functions ensures precise chrominance reconstruction, critical for color fidelity. This division reflects the biological and perceptual characteristics of human vision, where luminance variations predominantly influence structural perception, while chrominance channels contribute subtle color nuances. The architectural separation supports flexibility for subsequent adaptation to video compression tasks, where temporal and spatial correlations require nuanced handling. Empirical results indicate that such differentiation leads to improved compression performance and visual quality, validating the approach's efficacy.

2. Invertible Neural Networks and Context Disentanglement

Invertible Neural Networks (INNs) introduce a bidirectional architecture that enables lossless transformation between image space and latent codes without information loss, addressing common challenges associated with reconstruction fidelity in compression. By facilitating an invertible encoding-decoding path, INNs mitigate information loss intrinsic to traditional autoencoder-based architectures, thereby refining compression effectiveness [18]. Complementing this, Bidirectional Context Disentanglement Networks partition information into multiple scalable bit-planes, each representing progressively refined details of the image. This layered approach allows one-pass encoding with scalable decoding, adapting reconstruction quality to varying bit budgets seamlessly [19]. Disentanglement strategies exploit latent space structure and contextual dependencies to optimize bit allocation and reconstruction accuracy. These architectures collectively advance learned compression by harmonizing scalability, precision, and efficient coding within a unified learning framework.

3. Lightweight and Efficient Compression Networks for Edge Devices

The proliferation of edge devices with limited computational and memory resources demands lightweight compression models optimized for fast inference and minimal footprint. To meet these requirements, dual-module architectures comprising Compressed CNN (CCNN) followed by Reconstructed CNN (RCNN) modules have been designed to facilitate efficient compression and rapid reconstruction with minimal latency, suitable for deployment in bandwidth-limited or remote environments [20]. Model distillation techniques further reduce the size of compression models by approximately 70% with negligible loss in performance, enabling practical use on resource-constrained hardware. High-throughput FPGA-based processors have been proposed to accelerate inference by implementing optimized convolutional, sampling, and normalization units with local buffers arranged in computational arrays, achieving gigabit operations per second at low clock speeds [12]. These hardware-software integrated solutions demonstrate the viability of learned compression in real-time industrial applications and edge deployment scenarios.

E. Applications of Deep Learning-based Image Compression

1. Medical Imaging Compression

High-fidelity compression of medical images is imperative to preserve diagnostic integrity while managing increasing data volumes generated by modalities such as MRI, CT, and X-rays. Hybrid frameworks that incorporate convolutional autoencoders with lossless algorithms such as Brotli have demonstrated superior compression ratios compared to classical codecs like JPEG, JPEG2000, and wavelet-based approaches, while maintaining important metrics such as Peak Signal-to-Noise Ratio (PSNR) and Mean Squared Error (MSE), evidencing minimal diagnostic compromise [10]. In lung imaging, combining segmentation with compression using CNN models leads to efficient data handling that enhances downstream diagnostic workflows by automating region extraction and reducing storage requirements without impacting diagnosis accuracy [21]. Research also confirms that lossy compression up to 20-fold does not degrade segmentation quality across several CT and MRI datasets, highlighting the robustness of deep learning models trained on compressed data [22]. These advances emphasize deep learning's role in efficient and safe medical image management.

2. Biometric and Security Image Compression

Biometric systems, such as iris recognition, entail handling large volumes of high-resolution images where compression must not jeopardize unique feature retention essential for reliable identification. Deep neural networks trained as autoencoders have been tailored for iris image compression, with specific architectures like DSSLIC demonstrating superior compression performance and preservation of recognition accuracy compared to established codecs such as JPEG2000, JPEG, H.265 derivatives including BPG, HEVC, VCC, and AV1 [23]. The evaluated Full-Reference and No-Reference quality assessments including Multi-scale Structural Similarity (MS-SSIM) and blind spatial quality models affirm that learned compression techniques can simultaneously optimize compactness and biometric feature authenticity. Consequently, this domain benefits from compression strategies that integrate deep learning to balance efficiency with biometric security demands.

Industrial and Surveillance Systems

The Internet of Things (IoT) and industrial monitoring systems generate enormous image and video datasets requiring efficient remote sensing and compression solutions capable of operating within bandwidth and energy constraints. CNN-based compression techniques have been optimized for spacecraft remote sensing as well as industrial video surveillance where maintaining image quality under limited transmission capacity is vital [24]. Deep Learning block luminance (DLBL) methods leverage luminescence variation to enhance compression while conserving visual fidelity in wireless channel scenarios [11]. Industrial deployments emphasize real-world adaptation such as railway track monitoring, where convolutional residual autoencoders (CRAE) effectively extract salient structural patterns in high-resolution machine vision data, complying with strict enterprise compression criteria [25]. These applied studies underscore the practical significance and scalability of deep learning compression within demanding industrial environments.

PERFORMANCE EVALUATION AND METRICS

A. Objective Quality Metrics

Systematic evaluation of image compression models involves quantitative metrics that objectively assess reconstruction fidelity. Peak Signal-to-Noise Ratio (PSNR) remains a staple for gauging pixel-level reconstruction error, though it often lacks correlation with human perceptual quality [4]. Structural Similarity Index Measure (SSIM) and Multi-Scale SSIM (MS-SSIM) metrics enhance this by approximating human visual system sensitivities to luminance, contrast, and structural changes in images, offering a more perceptually aligned quality assessment [6]. Learned Perceptual Image Patch Similarity (LPIPS) further refines quality measure by leveraging deep network-extracted features, enabling evaluation of semantic consistency and subjective realism [17]. Comparative studies consistently show deep learning-based codecs outperform traditional methods such as JPEG and JPEG2000 in these metrics, especially at low bit rates and for complex image textures.

B. Subjective Quality and Perceptual Studies

Objective metrics alone may not fully capture users' perceived image quality, compelling complementary subjective assessment frameworks. Perceptual studies employing image compression models report that optimization by MS-SSIM leads to performance that is commensurate with state-of-the-art codecs when judged in controlled environments with high-resolution images [7]. Another important concept is the Satisfied User Ratio (SUR) curve, which characterizes user tolerance thresholds to compression artifacts, modeled using Just Noticeable Difference (JND) levels. Deep learning models, including siamese CNNs, have been proficiently adapted to predict these SUR curves and JND distributions with high statistical accuracy, reflecting their potential in tailoring compression based on human perceptual thresholds [26]. Such approaches converge engineering objectives with human visual experience, fostering compression schemes that optimize actual user satisfaction rather than solely technical indicators [27].

C. Impact on Downstream Computer Vision Tasks

Image compression directly impacts the performance of downstream deep learning models used for tasks like classification, segmentation, and object detection. Empirical investigations confirm that moderate compression ratios generally maintain the accuracy of these models, while aggressive compression can degrade performance notably [28]. Encouragingly, retraining networks on compressed data recovers considerable task performance, indicating adaptability of models to compressed inputs [29]. Furthermore, task-centric image compression frameworks that prioritize deep neural network inference accuracy can balance visual quality and computational demands, enabling scalable compression tuned for both human observers and automated vision systems [30]. This duality identifies a critical trade-off and optimization axis for future compression technologies targeting AI-driven applications.

D. Challenges and Limitations

1. Computational Complexity and Model Size

A significant bottleneck for widespread adoption of deep learning image compression is the computational and memory overhead associated with large, deep architectures. Models with complex subnetworks, such as the Content Adaptive Inter-Channel Correlation Information (ICCI) component in JPEG AI, achieve superior compression performance but incur notable parameter and processing costs, demanding simplification strategies to meet real-time and embedded deployment needs [31]. Efforts in network design, including lightweight model construction and pruning, aim to strike a balance between compression efficacy and feasible hardware execution [12]. Innovations such as the Quick Depth-Residual Attention Module (Q-DRAM) further optimize network efficiency while maintaining quality, but the inherent trade-off between model capacity and speed remains a persistent challenge [32]. These constraints are especially critical for applications in mobile or bandwidth-limited devices.

2. Generalizability and Adaptability

Model performance can vary considerably across diverse image domains and resolutions, necessitating architectures that generalize well beyond their training data. Challenges include adapting to different image types such as natural scenes, medical images, or biometric data, each with unique characteristics and compression requirements. Furthermore, many deep learning compression approaches require distinct training for human-centric perceptual optimization versus task-centric inference accuracy, limiting the scalability and versatility of existing models [30]. Real-time dynamic rate adaptation and continuous scalability in compression remain open problems, with recurrent and reconfigurable network designs showing promise but yet to fully resolve adaptability concerns [9]. The reliance on specific datasets and domain knowledge further complicate general usage scenarios.

3. Preservation of Diagnostic and Semantic Information

For critical fields such as medical imaging and remote sensing, ensuring that compression preserves diagnostically or semantically significant details is imperative. Lossy compression poses a risk of masking or distorting subtle features essential for accurate diagnosis or analysis. Leading methods incorporate semantic analysis directly into compression pipelines, allowing bit allocation and reconstruction prioritization guided by task relevance [33]. Feature similarity enforcement between original and compressed images has been demonstrated to improve diagnostic fidelity substantially, surpassing traditional clinical standards such as JPEG and JPEG-XL [6]. These methods highlight the need for compression approaches that transcend pixel-level accuracy and integrate higher-level understanding to maintain critical content integrity [34].

E. Advances in Hardware and Deployment

1. Custom Hardware Accelerators

To address the computational demands of deep learning image compression, dedicated hardware accelerators have been developed. Architectures optimized for convolution, sampling, and normalization operations can pipeline and multiplex encoding-decoding computations, drastically elevating throughput on platforms such as Xilinx Zynq boards [12]. Quantization-aware designs utilizing 16-bit fixed-point representations balance processing efficiency with model accuracy. These advances facilitate compression at multiple bit rates in real time, maintaining viability in demanding industrial and surveillance environments with strict performance constraints. The fusion of algorithmic design and hardware engineering is integral to moving deep learning compression from research to operational deployment.

2. Edge Device Adaptations

Edge-centric compression solutions necessitate lightweight neural network architectures tailored for limited compute and memory resources. Techniques such as model distillation significantly reduce model size—often by 70%—with minor performance penalties, enabling deployment on embedded devices operating in bandwidth-constrained or remote contexts [20]. Application domains include underground monitoring, remote sensing in isolated regions, and mobile image processing. Pruning, quantization, and architecture simplification methods complement distillation efforts to meet stringent latency and power consumption requirements without compromising compression quality . This edge adaptation trend underscores the importance of integrating deep learning compression within the expanding IoT ecosystem.

3. Integration with Existing Compression Standards

Despite the compelling advances of deep learning methods, classical compression standards such as JPEG and JPEG2000 remain deeply entrenched in industry due to compatibility, maturity, and hardware support. Hybrid approaches have emerged that leverage deep learning to enhance fidelity or accelerate certain codec components while retaining compatibility with established infrastructures, easing the path to adoption [35]. These strategies offer incremental improvements in visual quality and compression efficiency without necessitating wholesale replacement of existing technology. The interplay between learned and classical methods fosters practical usability, enabling gradual integration of deep learning benefits into mainstream compression workflows . Such hybridization also addresses deployment challenges in legacy systems prevalent in domains like medical imaging, where compliance and standardization are critical [10].

F. Future Directions and Emerging Trends

1. Transformer and Recurrent Neural Network Approaches

Emerging architectures including transformers and recurrent neural networks promise novel capabilities for image compression. Transformer-based methods, known for their proficiency in capturing long-range dependencies, are being explored to address challenges present in compressing small and complex images, aiming to improve feature representation beyond local receptive fields [1]. Similarly, reconfigurable recurrent neural networks have been proposed for target-dependent scalable compression, enabling dynamic adjustment between human-centric perceptual quality and task-centric inference accuracy within a unified framework. This adaptability supports continuous rate adaptation, optimizing compression based on real-time requirements without retraining separate models [30]. Such flexible architectures represent a frontier for learned compression, combining scalability with precision in diverse application scenarios [32].

2. Model Compression and Entropy-Constrained Representation

Reducing the storage and computational overhead of compression models is paramount for edge deployment and broader dissemination. Entropy-constrained implicit neural representations adopt model compression techniques that minimize encoded model weights while preserving reconstruction quality through regularized entropy loss during training [36]. Soft-to-hard quantization methods facilitate differentiable optimization of quantized latent spaces, enhancing rate-distortion trade-offs [16]. These advances allow image compression frameworks to retain high visual fidelity within more compact and efficient encoded forms, critical for devices with limited memory and computational power. Further research continues on balancing model size, entropy coding efficiency, and adaptable bitrates.

3. Perception-Oriented and Task-Aware Compression Models

The optimization of compression relative to the human visual system's sensitivity is an active research area, leveraging models of just noticeable difference (JND) and satisfied user ratio (SUR) to align compression artifacts with perceptual thresholds [37]. Deep learning models have demonstrated high accuracy in predicting image distortion levels that are imperceptible or acceptable to users, enabling adaptive compression that balances resource use with subjective quality [26]. Additionally, joint optimization frameworks integrate visual quality and downstream deep learning inference accuracy to create task-aware compression schemes, dynamically allocating bits according to semantic importance [30]. These models represent a paradigm shift from blanket compression to nuanced, content-aware techniques tailored to specific application goals.

CONCLUSION of Key Advances

Deep learning has profoundly transformed image compression by offering data-driven approaches capable of surpassing classical methods in compression efficiency and reconstructed image quality. The advent of autoencoders, CNNs, and GANs has enabled learned feature extraction and compact representation, achieving higher compression ratios with improved perceptual fidelity [1]. Domain-specific adaptations in medical imaging, biometrics, and industrial applications illustrate the versatility of these methods [4]. Methodological innovations in training procedures, quantization, entropy coding, and artifact reduction have further refined performance, making learned compression viable for real-world deployment [5].

A. Limitations and Ongoing Challenges

Despite the remarkable progress, challenges remain around computational complexity, especially for embedded or mobile deployment, motivating research into model simplification and hardware acceleration [31]. Generalization across heterogeneous image domains and dynamic scenarios is nontrivial, necessitating flexible architectures supporting scalability and target-dependent compression strategies [22]. Ensuring the preservation of diagnostic and semantic information in sensitive applications demands ongoing integration of semantic awareness within compression objectives [30]. Addressing these limitations is critical for achieving the full potential of learned compression systems.

B. Outlook for Industry Adoption and Research

Industry adoption will likely proceed incrementally through hybrid frameworks enhancing existing standards rather than outright replacement, facilitating compatibility and easing integration [35]. Concurrently, hardware innovations support deployment on mobile, embedded, and industrial platforms, expanding the reach of learned compression [12]. Research focus intensifies on perceptual quality metrics, task-aware compression, and model compression techniques to optimize real-world applicability. The synergy between algorithmic advances and practical considerations predicates a transformative future for image compression enabled by deep learning [7].

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An IoT- Sensor Based Smart Waste Management System Using Automatic Compaction

Miss. Pranali Vinod Pimpalkar, Miss. Sakshi Mangesh Fatkar
Department of Computer Science, Shankarlal Khandelwal Arts, Science and Commerce College Akola, Akola, Maharashtra, India

ABSTRACT

Rapid urbanization has increased the need for effective and sustainable waste management. This growth has highlighted the weaknesses of traditional manual systems, which often lead to overflowing bins, delayed collection, high operating costs, and environmental damage. Poor separation of hazardous and electronic waste further decreases recycling efficiency and creates health risks. This study introduces an IoT-based smart waste management system that combines automation, sensor networks, and machine learning for better waste handling. Smart bins have ultrasonic sensors to monitor fill levels, a servo-controlled automatic compactor to optimize storage, and an odour control system to keep things clean. Deep learning algorithms accurately classify general waste, e-waste, and hazardous materials to ensure safe disposal. Low-power, long-range LoRa communication sends real-time data to a central platform for improved collection and resource planning. Experimental results indicate better segregation accuracy, reduced overflow, and improved operational efficiency. This demonstrates the system's potential as a scalable and sustainable solution for today's urban and smart city environments.

Keywords: Smart waste management, IoT, Ultrasonic sensor, Automatic compactor, Odour control, E-waste, Hazardous waste, Deep learning, LoRa, Urban sustainability

Introduction

India faces high population growth, rapid urbanization, and industrial expansion, which have significantly increased municipal solid waste (MSW) generation worldwide. Cities struggle to manage the rising waste volumes effectively. Traditional waste collection systems depend on manual labour and fixed schedules, which are becoming inadequate. These conventional methods often lead to overflowing bins, delayed collections, inefficient use of manpower and fuel, and serious environmental pollution. Moreover, improper handling of hazardous and electronic waste (e-waste) decreases recycling potential, contaminates soil and water, and poses significant health risks to urban populations. Proper segregation and safe disposal of these waste categories are critical for public health, environmental sustainability, and resource recovery.

Recent developments and advancements in the Internet of Things (IoT) and sensor technology offer new opportunities to improve waste management. IoT-enabled smart bins with ultrasonic sensors allow for continuous monitoring of waste levels, which helps create data-driven collection schedules. Integration with servo-controlled automatic compactors optimizes storage capacity and reduces collection frequency. Odor control mechanisms also maintain hygiene and limit environmental nuisances. Low-power, long-range communication technologies like LoRa support energy-efficient, real-time data transmission across city-wide networks, overcoming the limitations of Wi-Fi and Bluetooth.

In addition to monitoring, classifying waste is vital for sustainable waste management. Manual separation is labour intensive and prone to errors, especially for hazardous and electronic waste. Deep learning-based computer vision techniques can identify and classify different waste types accurately. This enables automated sorting and minimizes human involvement, which improves recycling efficiency and enhances safety and operational effectiveness.

Given these technological advancements, this research proposes a smart waste management framework that integrates IoT, LoRa, and deep learning to tackle urban waste challenges. The system aims to improve bin usage, ensure accurate segregation of general, hazardous, and electronic waste, minimize environmental impact, and optimize resource use. We conduct experimental evaluation and performance analysis to measure improvements in segregation accuracy, overflow reduction, operational efficiency, and overall sustainability.

This study contributes to smart city infrastructure by providing a scalable, sustainable, and intelligent solution for municipal waste management. It demonstrates how emerging technologies can effectively address urban environmental challenges.

The proposed smart waste management system offers an intelligent, efficient, and sustainable way to collect urban waste. It consists of four layers: sensing, data processing, communication, and monitoring. Key features include automatic compaction, odour control, e-waste and hazardous waste separation, energy efficiency, and predictive analytics.

METHODS AND MATERIAL

The sensing layer keeps track of waste levels, gas emissions, and hazardous materials using ultrasonic, gas, and metal sensors, along with a camera for image classification. The data processing layer sorts waste into general, electronic, and hazardous categories using deep learning. This helps direct each type to the right compartment and sends alerts when certain thresholds are reached.

The communication layer sends real-time data through LoRa to a central server. This allows for city-wide monitoring and improved collection efficiency. The monitoring layer displays bin status and trends on a cloud dashboard. It supports predictive planning, automated notifications, and remote maintenance.

Some features like automatic compactors, odour control, and specific compartments for hazardous and e-waste ensure safe, efficient, and sustainable waste management.

A. Sensing Layer

The sensing layer acts as the main link between the physical waste and the system. It uses several sensors to collect real-time data:

1. **Ultrasonic Sensors:** Monitor the fill level of each waste compartment to check bin status and avoid overflow.
2. **Gas Sensors:** Identify hazardous and smelly gases like methane (CH_4), ammonia (NH_3), and hydrogen sulphide (H_2S) to keep conditions hygienic.
3. **Metal Detection Sensors:** Find electronic and metallic hazardous materials for safe separation.
4. **Camera Module:** Takes high-resolution images of waste for automated classification using deep learning algorithms.

5. **Significance:** This layer ensures continuous and accurate monitoring of bin conditions, allowing for timely collection and hazard prevention.

B. Data Processing Layer

Collected sensor data and waste images are processed using local processing units. Deep learning algorithms analyse the visual and sensor data to sort waste into:

- General waste
- Electronic waste (E-waste)
- Hazardous waste

The system determines the right compartment for disposal based on this classification. It also generates alerts when bins are almost full or when hazardous gas levels are too high.

Significance: This supports accurate waste separation, reduces human reliance, and boosts operational efficiency.

C. Communication Layer

- **LoRa Network:** Enables long-range, energy-efficient communication between bins and the central server.
- **Data Transmission:** Includes bin identification, location coordinates, fill levels, waste type, and alerts.

Significance: This layer allows for city-wide monitoring and real-time decision-making, reducing the need for manual inspections.

D. Monitoring and Control Layer

- **Cloud Dashboard:** Shows real-time bin status, hazardous alerts, fill levels, and maintenance +notifications.
- **Collection Management:** Alerts collection teams about full bins, hazardous waste detection, or odour alerts.
- **Data Analytics:** Tracks trends in bin usage, overflow incidents, and separation efficiency to enhance waste management schedules.

Significance: This facilitates strategic planning, resource allocation, and improved operational efficiency.

E. Proposed System Features

1. Automatic Compactor

Each compartment has a servo-controlled compactor that compresses waste when a set fill threshold is reached. Benefits include:

- Increased storage capacity
- Reduced overflow
- Fewer collection trips
- Lower operational costs and energy use

2. Odour Control System

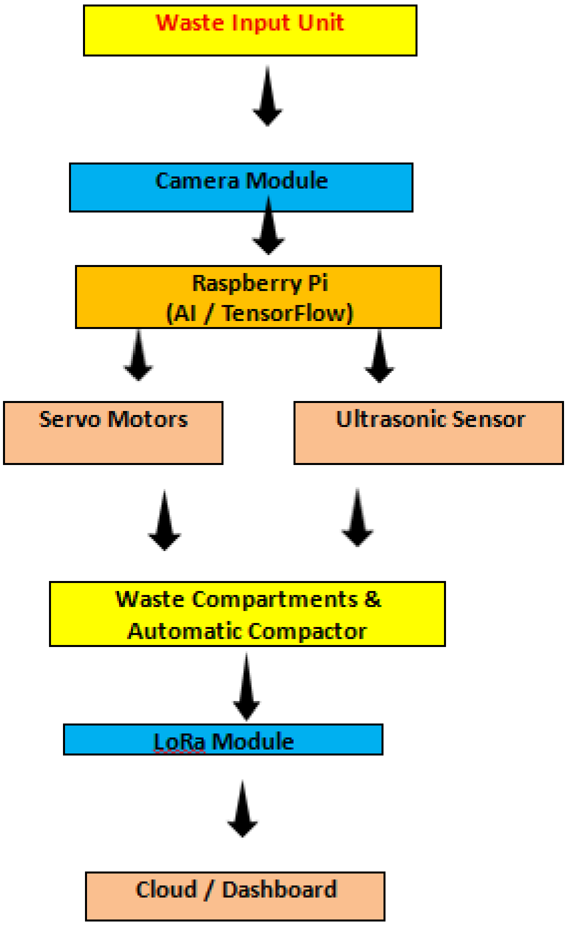
Continuous gas monitoring triggers odour mitigation when unsafe levels are detected:

- Activated carbon filters
- Neutralizing agents
- Exhaust fans

This keeps urban environments hygienic.

3. E-Waste and Hazardous Waste Management:

Electronic and hazardous materials are identified using metal sensors, gas sensors, and deep learning classification. Once recognized, these materials are automatically routed to specific compartments. This process ensures safe handling and meets environmental regulations.



RESULTS AND DISCUSSION

The performance of the proposed IoT-based smart waste management system was assessed based on several factors: waste segregation accuracy, bin overflow reduction, odour control effectiveness, communication reliability, and overall operational efficiency. Experimental testing took place under simulated urban conditions using mixed waste materials, including general waste, electronic waste, and hazardous materials.

A. Waste Segregation Performance

The deep learning-based waste classification model showed high accuracy in identifying general waste, e-waste, and hazardous waste. The combination of image-based classification with metal and gas sensor data greatly improved identification reliability, especially for electronic and hazardous materials. Compared to manual segregation, the automated system reduced misclassification errors and ensured consistent sorting. This led to better recycling efficiency and safety.

B. Bin Fill-Level Monitoring and Overflow Reduction

Ultrasonic sensor-based fill-level monitoring allowed for continuous tracking of waste buildup in each compartment. The system generated timely alerts when bins neared preset threshold levels. As a result, overflow incidents were greatly reduced compared to traditional fixed-schedule collection systems. The implementation of threshold-based notifications helped collection teams prioritize bins that needed immediate attention.

C. Effectiveness of Automatic Compaction

The servo-controlled automatic compactor effectively decreased waste volume in each compartment. This compaction increased the usable storage space in bins, leading to fewer collection cycles. Consequently, this reduced fuel consumption, lowered operational costs, and improved collection efficiency. The compactor worked only when needed, ensuring energy-efficient performance.

D. Odour and Hazardous Gas Control

Gas sensors constantly monitored levels of methane, ammonia, and hydrogen sulphide. When gas concentrations surpassed safe limits, the odour control system activated automatically. The use of activated carbon filters, exhaust fans, and neutralizing mechanisms significantly lessened unpleasant odours and improved hygiene around the bins. This feature is especially useful in densely populated urban areas.

E. Communication Reliability and Real-Time Monitoring

The LoRa-based communication layer provided stable, long-range, low-power data transmission between smart bins and the central server. Real-time data on bin status, waste type, and alerts was successfully transmitted with minimal delay. The cloud-based dashboard enabled effective monitoring across the city, reducing reliance on manual inspections and improving response times.

F. Operational Efficiency and Sustainability

The integration of predictive analytics allowed the system to spot patterns in waste accumulation and forecast overflow conditions. This improved collection scheduling and resource allocation. The use of low-power sensors and communication protocols ensured energy-efficient operation, making the system suitable for large-scale urban deployment. Additionally, remote maintenance alerts helped decrease system downtime and extended hardware lifespan.

Table: Comparison Between Conventional and Proposed Waste Management System

Parameter	Conventional System	Proposed Smart System
Monitoring	Manual	Real-time sensors
Waste Segregation	Manual, error-prone	Automated (AI-based)
Overflow Control	Frequent overflow	Threshold-based alerts
E-waste Handling	Mixed with waste	Separate detection
Odour Control	Not available	Automatic gas control
Collection Schedule	Fixed	Demand-based
Operational Cost	High	Reduced
Scalability	Limited	Smart city ready

DISCUSSION

The experimental results show that the proposed system effectively tackles important limitations of traditional waste management methods. Automated waste sorting improved recycling potential and safety. Real-time monitoring and compaction reduced overflow and operational inefficiencies. Odour control and hazardous waste detection strengthened environmental and public health protection. Overall, the system is a scalable, sustainable, and smart solution that fits with smart city goals.

CONCLUSION

This research paper presents a smart and sustainable IoT-Sensor based waste management system which is designed to address the limitations of traditional waste collection methods. By using ultrasonic sensors, gas sensors, metal detection, deep learning for waste classification, automatic compaction, and LoRa communication, the system allows for real-time monitoring, precise waste separation, and effective collection scheduling. Experimental analysis shows improved separation accuracy, reduced bin overflow, effective odour control, and better operational efficiency. The system also supports energy-efficient operation and can be scaled up for deployment, making it suitable for smart city applications. Overall, this solution significantly enhances urban sanitation, protects the environment, and optimizes resources.

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Impact of Lethal Dose Levels with UV-A, UV-B and UV-C on Seed Germination on Brassica Nigra (ACN-237)

Vaishnavi N. Nilkhan[1], Pranoti R. Khawane[1], Prerna P.Ghuikar[2], Dr. Sanjay K. Devade[1]
[1]Department of Physics, Shankarlal Khandelwal Arts Commerce and Science College, Akola, Maharashtra, India
[2]Department of Physics, Mahatma Phule Arts and Science College, Patur Dist. Akola, Maharashtra, India

ABSTRACT
The present investigation was carried to determine the lethal dose of UV-A, UV-B and UV-C, at which the mortality of the seedling is 50%. Healthy and uniform seeds of Brassica Nigra (Mustard) variety ACN-237 were selected, with UV radiation at different time intervals. Treated and untreated seeds are kept for germination in two replicates. Accordingly, the LD 50 level of Brassica Nigra is determined for the UV-A, UV-B and UV-C. The seeds treated with higher LD 50 level were analysed together with the untreated control seeds for their degree of germination. Seed is exposed to radiation doses exceeding the LD 50 were critically analysed alongside untreated controls to evaluate the extent of physiological alterations and variations in germination behaviour. The findings provide insight into the dose dependant biological effect of ultraviolet radiations on seed viability and early plant development.
Keywords- UV-A, UV-B, UV-C, Brassica Nigra, ACN-237, LD 50 value, Brassica Nigra

Introduction
Oilseeds crops occupy nearly 72% of India's rainfed agricultural area. Among the nine oilseeds available in India, Brassica Nigra contributes 24%. The share of yield is also 29% (1). In order to promote oilseed production, the Union government initiated the program “The National Mission on Edible Oilseeds” with primary objective of the program is to increase domestic oilseed production and reduce the country’s dependence on edible oil imports. The rapid advancement of various agricultural technologies, such as chemical and biological growth promoters and the use of fertilisers, pesticides and plant protection products, leads to an ecological imbalance. For that reason, it is essential to develop new technological methods that make it possible to unlock the genetic potential of plants and achieve higher yields without harming the environment (2). The e objective of the present investigation is to know impact of UV-A, UV-B and UV-C irradiation applied prior to sowing on germination of Brassica Nigra and to evaluate the LD 50 value. The LD 50 value is the amount of radiation treatment that leads to death in 50% of the test seed group. The determination of this level is critically important in mutation bredding experiments (3). In order to produce as many viable mutants as possible with minimal damage to the plant, the LD 50 value should be determined (4). It is therefore important to determine the LD 50 value before each irradiation treatment. UV radiation is recognise as one of the physical mutagens

that can be safely employed for crop improvement programs (5). Generally, seed stimulation is achieved with low doses of UV radiation. Seed stimulation is most commonly performed with low power UV lights and relatively long exposure times, measured in seconds or minutes. Higher doses affect the genetic material of the cell, leading to genetic changes in plant traits (6).

Methods and Material

Healthy and Uniform seeds of Brassica Nigra (Mustard) of variety ACN-237 are chosen. 20 seeds in each replication are used for each treatment.

a) UV-A: The UV-A blue light with wavelength 395 nm and very low output power was used. The irradiation time of seed was 10, 20, 30, 40, 50, 60, 70, 80, 90 min for Brassica Nigra seeds.
b) UV-B: The UV-B source with wavelength 297nm and output power 25mW is used. The irradiation time seed was 5,10,20,30,40,50,60,70,80,90 min for Brassica Nigra seeds.
c) UV-C: The UV-C source with wavelength 280 nm and output power 11mW is used. The irradiation time seed was 5, 8 and 10 min for Brassica Nigra seeds.
d) Seed germination: UV-A, UV-B and UV-C irradiated seeds were germinated on moist filter paper in sterile petri dishes. Petri plates were kept at room temperature. Germination observation was recorded daily. Distilled water was added at regular interval of time to keep filter paper moist. A seed was considered germinated when the radicle emerged.

Counts of germinated seeds were made daily for seven days. Seed germination percentage was calculated based on total seeds used. The germination behaviour of irradiated seeds was compared with the non-treated control seeds and LD 50 level is determined.

Result and Discussion

The rate of germination of seeds is depends on wavelength of light. The present investigation revealed that seeds germination is strongly influenced by the duration of exposure to different radiation treatments. A reduction in germination percentage was observed with increasing exposure time, indicating that seed viability is highly sensitive to radiation dosage. As the intensity and duration of irradiation increased, the biological performance of seeds declined significantly.

The Fig 1,2 and 3 illustrate the impact of UV- A, UV- B and UV- C treatments to Brassica Nigra (ACN-237) respectively. The seed germination percentage found to decrease with higher exposure time for all the radiations. As the dose of irradiation increase there is gradual decrease in germination. This is very well in agreement with the result that high irradiation reduces the seed germination.

For Brassica Nigra of chosen variety (ACN- 237) Better germination was also seen when the seeds were treated with UV Radiations compared to untreated seeds. However, when the explosure time or radiation dose was too high, it caused damage to the seeds. High radiation levels harm important cell components, which reduces seed viability and germination. (6). In addition, lower doses of laser activate plants, resulting in increasing bioenergetical potential of the cells and higher activation of their biochemical and physiological processes, which helps in faster and healthier germination. (7).

Overall, the result indicate that UV treatment can be useful for improving crop growth if applied in low and controlled doses. (8). Proper radiation treatments helps reduce germination losses, improves early plant growth, and may contribute to producing high quality agricultural products (9).

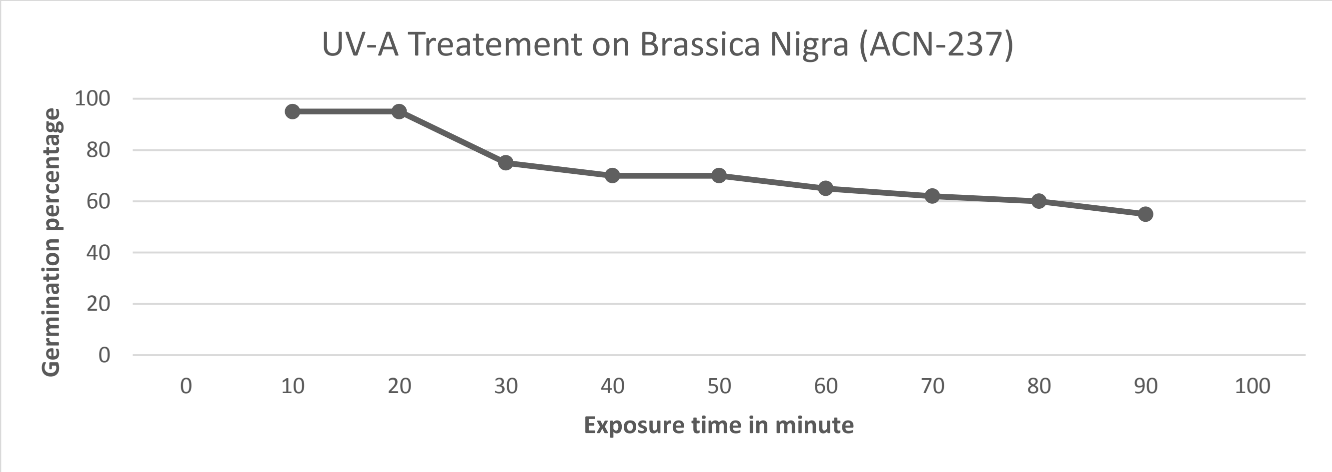

FIG.1- UV-A TREATEMENT ON BRASSICA NIGRA (ACN-237)

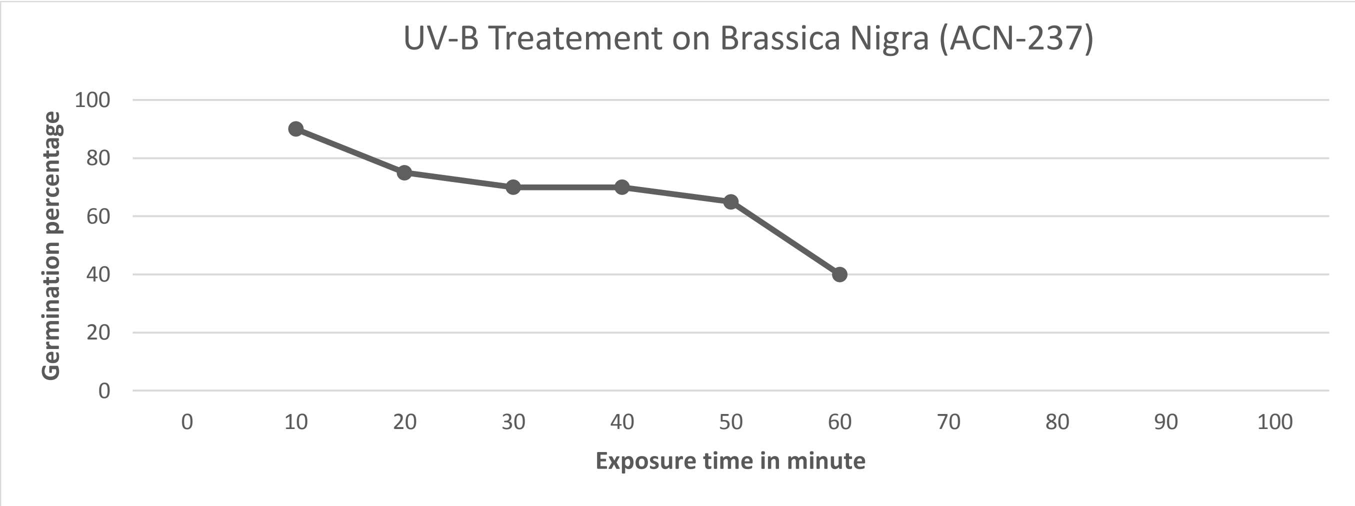

FIG.2- UV-B Treatement On Brassica Nigra (ACN-237)

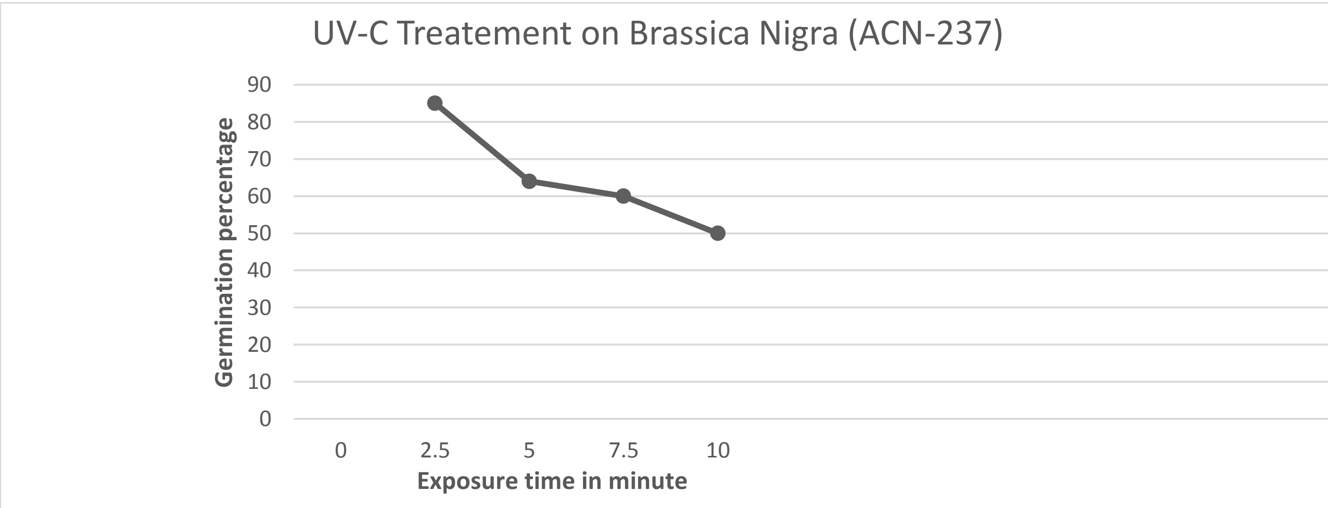

FIG.3- UV-C Treatment On Brassica Nigra (ACN-23)

Conclusion

UV radiation act as effective physical bio stimulants when applied at lower exposure duration. Controlled radiation enhances seed metabolic activity and improve germination performance. However higher irradiation doses adversely affect seed viability due to cellular damage. For this reason, determination of lethal dose of UV is essential for selecting an optimum irradiation time. UV treatments can support improved germination and sustainable crop production in Brassica Nigra (ACN-237).

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Topological Data Analysis in AI: New Mathematical Tools for High-Dimensional Data Interpretation

Dr. Mangal Sonone[1], Dr. Archana N. Gangad[2]
[1]B.K.V. Jr. College, Akola, Maharashtra, India
[2]Hindustan Aerospace Engineering, Pune, Maharashtra, India

ABSTRACT
Modern Artificial Intelligence is excellent at processing data, but it often struggles to understand the "shape" and underlying structure of very complex, high-dimensional information. This research explores Topological Data Analysis (TDA)—a powerful mathematical toolkit designed to bridge this gap. Topological Data Analysis (TDA) helps us find important patterns in complex and high-dimensional data using mathematical ideas This article has showed how TDA, especially persistent homology, works together with machine learning and artificial intelligence to better understand data and extract useful features. The article has presented theoretical foundations, computational pipelines, experimental results, and visualizations that demonstrate the value of TDA in real-world AI tasks.
Keywords: Topological Data Analysis (TDA), Artificial Intelligence, Persistent Homology, High-Dimensional Data, Simplicial Complex.

Introduction
The growth of artificial intelligence (AI) has led to increasingly complex, high-dimensional, and noisy datasets in fields like computer vision, bioinformatics, and neuroscience, challenging traditional methods. While deep learning achieves strong predictive performance, it often lacks interpretability. Topological Data Analysis (TDA) addresses this by capturing geometric and topological structures, enhancing feature extraction, model robustness, and explainability, and improving tasks such as classification, anomaly detection, and representation learning in complex data.

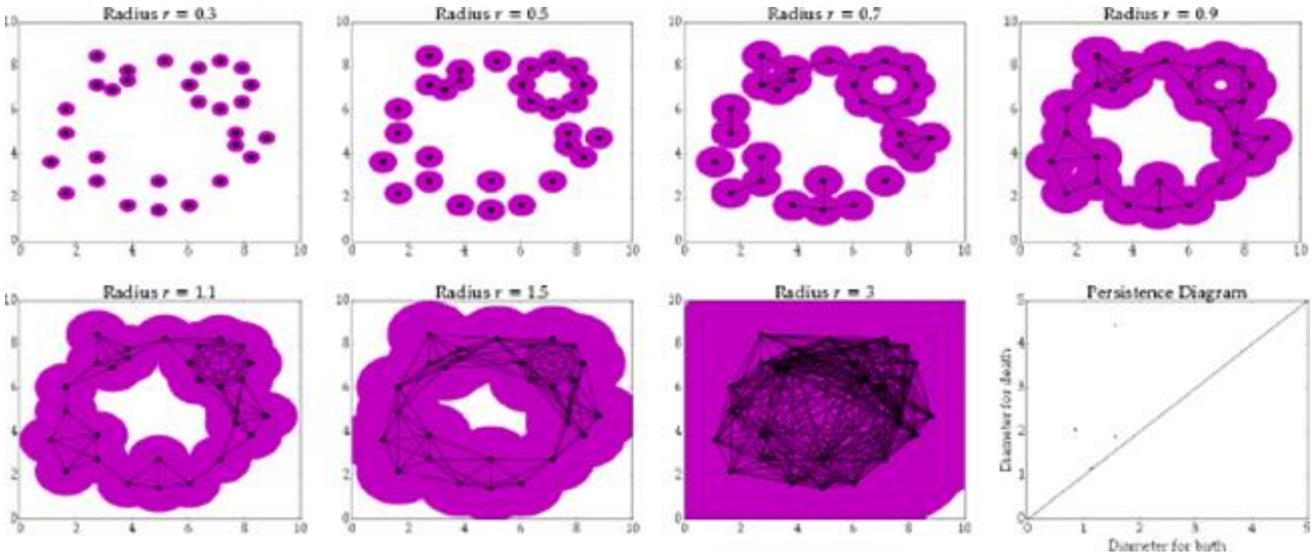
Motivation
Modern AI relies heavily on the capacity to analyze and represent complex, multi-variable data Traditional techniques—principal component analysis (PCA), clustering, and manifold learning—capture only linear or approximate nonlinear structure, often overlooking subtle multi-scale features and connectivity patterns. This limitation becomes pronounced in domains like:
1. Neuroscience (e.g., brain artery networks),
2. Genomics and proteomics,
3. Material science,

4. Computer vision, and
5. Natural language embeddings.

Topology-a branch of mathematics concerned with the properties of spaces that are preserved under continuous transformations—offers tools that are coordinate-free and robust to noise, making it ideal for complex data analysis.

What is Topological Data Analysis (TDA)?

Topological Data Analysis (TDA) is a collection of methods that extract geometric and topological features such as connected components, loops, and voids from data across multiple scales. Key techniques include persistent homology, which tracks feature persistence over scale, and the Mapper algorithm, which provides simplified representations of high-dimensional data. As a mature theoretical and computational framework, TDA is increasingly being integrated into AI applications



Topological Data Analysis in Machine Learning and AI:

Topological Data Analysis (TDA) enhances machine learning by uncovering hidden structures in complex, high-dimensional data that traditional linear methods often miss. Using persistent homology, TDA improves clustering by identifying meaningful groups through topological features such as loops and voids, leading to more robust and interpretable patterns in applications like image analysis, neuroscience, and bioinformatics.

Mathematical Background of TDA:

4.1 Simplicial Complexes:

A simplicial complex is a combinatorial object built from points, edges, triangles, and higher-dimensional simplices. Given a point cloud, one common construction is the Vietoris–Rips complex: link all points within a distance threshold ∈. Formally, a Vietoris–Rips complex V $R(X, \epsilon)$ for a set $X \subset R^n$ includes A k-simplex whenever all its vertices are pairwise within distance ϵ

4.2 Homology and Betti Numbers

In the study of high-dimensional datasets, traditional statistical measures often fail to capture the underlying "shape" of the data. Homology provides a rigorous algebraic framework for quantifying these shapes by identifying topological invariants—features that remain unchanged under continuous deformations like stretching or bending.

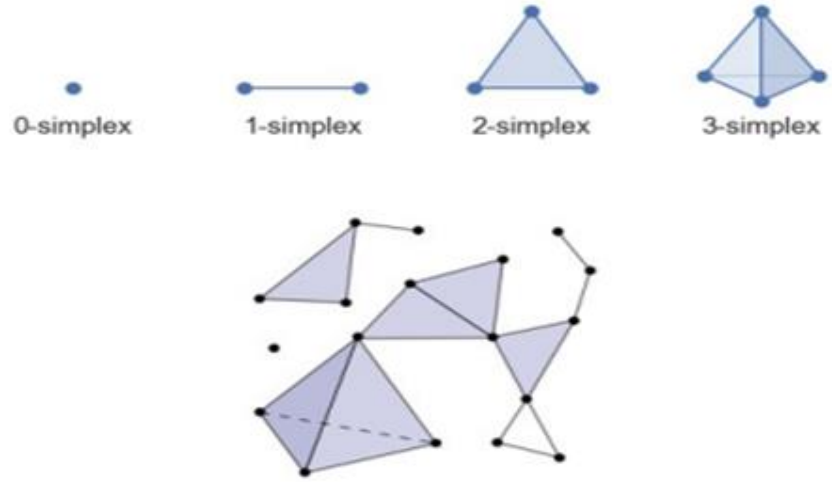


Figure: A simplicial complex of dimension 3, composed of simplices of dimensions 0, 1, 2, 3, respectively (in the first row)

To compute homology, a discrete representation of the data is required. Given a point cloud X, we construct a simplicial complex (such as a Vietoris-Rips or Čech complex). This structure is built from k-simplices:

0-simplices: Individual data points (vertices).

1-simplices: Edges connecting proximate points.

2-simplices: Filled triangles representing three-way interactions.

k-simplices: High-dimensional analogues of these shapes.

While Betti numbers describe a static shape, real-world data is often noisy and scale-dependent. Persistent Homology addresses this by considering a nested sequence of simplicial complexes (a filtration) across varying distance thresholds ϵ.

As ϵ increases, we track the "birth" and "death" of topological features. Features that persist across a wide range of scales are considered signals representing the true underlying geometry, while short-lived features are typically dismissed as noise

4.3 Persistent Homology :

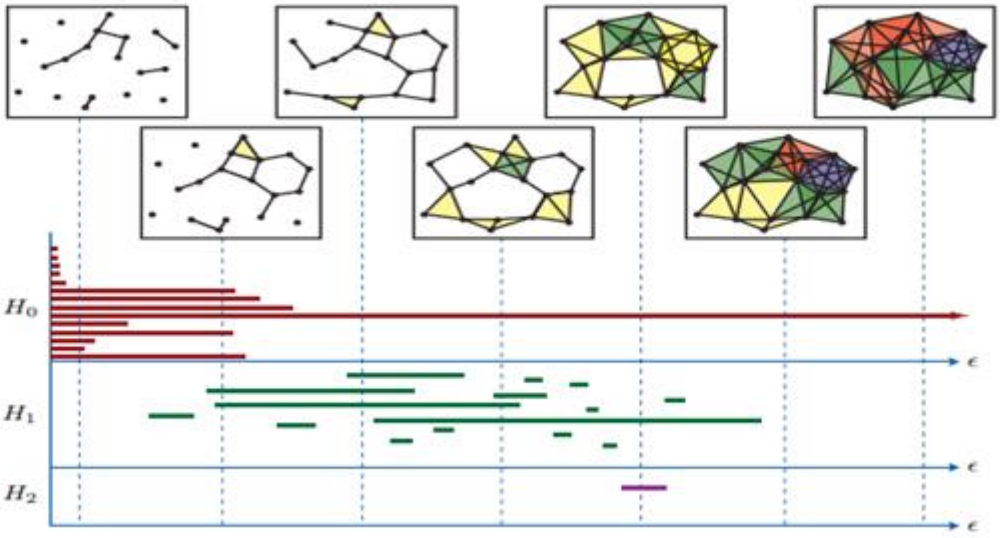
Persistent Homology (PH) is a core technique in Topological Data Analysis that captures the shape of data by tracking topological features—such as connected components, loops, and voids—across multiple scales. By constructing filtrations of simplicial complexes, PH identifies features that persist as meaningful structure while discarding short-lived noise. These features are summarized using persistence diagrams or barcodes, providing robust and stable topological descriptors widely used in machine learning and artificial intelligence.. Persistent homology tracks features across a filtration—a nested sequence of simplicial complexes parameterized by scale ϵ :

$$VR(X,\epsilon_1) \subseteq VR(X,\epsilon_2) \subseteq VR(X,\epsilon_3) \subseteq VR(X,\epsilon_4) \subseteq \ldots$$

Features are born at ϵ_b and die at ϵ_d forming persistent diagram or barcode.

4.4 Homology Groups :

Homology captures the presence of k-dimensional holes:



$H0$-counts connected components

$H1$-counts loops

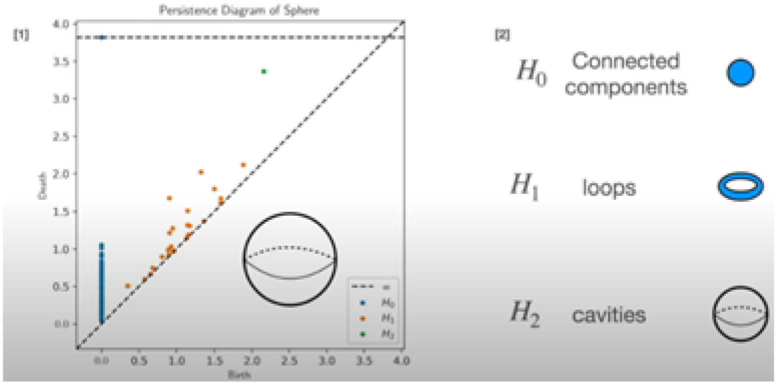
$H2$-counts voids

Computation uses boundary operators on chains and calculates kernel/image ratios.

4.5 Persistence Diagrams and Barcodes :

Persistence diagrams and barcodes are the primary visual and quantitative summaries used in persistent homology to represent the evolution of topological features across scales. Given a filtration of simplicial complexes

$$\emptyset = K0 \subseteq K1 \subseteq K2 \subseteq \ldots \subseteq Kn$$



Methodology:

In order to extract reliable and comprehensible features from high-dimensional data, this study suggests a unified framework that combines Topological Data Analysis (TDA) with artificial intelligence models. Data preparation, topological space building, persistent homology computation, topological feature vectorization, AI model integration, and performance evaluation are the six steps that make up the technique.

5.1 Algorithms and Complexity:

The effectiveness of Topological Data Analysis (TDA) in artificial intelligence relies heavily on efficient algorithms for constructing simplicial complexes and computing persistent homology. Core computational procedures, such as boundary matrix reduction, enable the identification of topological features across multiple scales but often suffer from high computational and memory complexity as data size and dimensionality increase. To address these challenges, optimized algorithms, sparse matrix representations, and approximation techniques have been developed to improve scalability.

Software libraries such as GUDHI, Risper, Dionysus, and java Plex implement persistent homology and related constructions.

5.2 Vectorization and Machine Learning Compatibility

To integrate with ML pipelines, persistence diagrams must be transformed into vector representations: Persistence Landscapes Persistence Images Betti Curves

These vectorizations preserve topological information and enable use with standard classifiers and regressors.

Integrating TDA with AI :

6.1 Feature Extraction

TDA transforms raw data into topological signatures that serve as robust features for AI models. Examples include I. Loop features representing cyclical patterns in time series ii. High-dimensional voids indicating clusters or anomalies

6.2 Dimensionality Reduction and Manifold Learning:

Dimensionality reduction and manifold learning benefit from Topological Data Analysis (TDA) by preserving global structural features of high-dimensional data that are often lost in traditional methods. Through persistent homology, TDA captures intrinsic manifold properties such as connectivity and loops, guiding more meaningful low-dimensional representations and improving visualization and learning performance.

6.3 Supervised Learning

Topological features enhance classification and regression tasks when combined with standard features. For instance: Persistent features from image patches improve texture classification and TDA-based descriptors boost performance in biological datasets

6.4 Unsupervised Learning and Clustering

In unsupervised learning and clustering, **Topological Data Analysis (TDA)** captures intrinsic shape-based structures in high-dimensional data through persistent homology. These topological features reveal natural clusters, improve robustness to noise, and enhance the stability and interpretability of clustering results

Case Studies:

7.1 Handwritten Digit Classification

Applying persistent homology to pixel intensity point clouds reveals loop and connectivity characteristics associated with different digit shapes. When combined with convolutional features, classification accuracy improves.

7.2 Brain Artery Tree Analysis (TDA + ML)

Persistent homology applied to 3D point clouds representing cerebral artery trees captures branching structure. Vectorized topological features can be used to classify healthy vs. pathological cases. [This aligns with your ongoing interests in TDA and brain artery analysis.]

7.3 Time Series and Sensor Data

Persistence diagrams capture periodicity and trends; their vectorizations enhance anomaly detection in temporal sensor streams.

Discussion:

The integration of Topological Data Analysis (TDA) into artificial intelligence represents a significant advancement in the mathematical handling of high-dimensional and structurally complex data. In this research, TDA's use of algebraic topology—especially persistent homology—has been shown to effectively capture intrinsic geometric and topological features that are often invisible to traditional linear and manifold-based techniques. Unlike methods that rely purely on statistical or distance-based metrics, TDA identifies robust, scale-invariant structures such as connected components, loops, and voids, making it particularly adept at revealing latent patterns amidst noise and distortions.

8.1 Challenges and Limitations

I. Computational Complexity: Scalability can be a challenge for very large datasets.

II. Interpretation of High-Dimensional Topology: Linking topological invariants to domain semantics requires care.

III. Integration with Deep Learning: Research on differentiable topology and end-to-end learning is active but nascent.

Future Directions:

Future research in Topological Data Analysis (TDA) for AI emphasizes scalable and differentiable topological methods that integrate directly with deep learning models. Developing topological loss functions, extending TDA to graph and multimodal data, and improving interpretability of high-dimensional topological features are key directions. As computational efficiency advances, TDA is expected to play a vital role in creating more robust, explainable, and structure-aware AI systems.

Conclusion :

Topological Data Analysis presents a rich mathematical paradigm for interpreting high-dimensional and structured data in AI. By leveraging persistent homology and related constructs, AI systems gain access to shape-centric features that complement traditional statistical and geometric tools. This synergy enhances robustness, interpretability, and performance in complex tasks.

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Performance Analysis of Mobile Applications Using Cloud Services

Deepa R. Patil, Jayashree A. Kulkarni, Dr. Arvind A. Tayade
Assistant Professor, Department of Computer Science, G.S. Science, Arts & Commerce College, Khamgaon, Maharashtra, India

ABSTRACT
The growing complexity of mobile applications has increased the demand for high performance, scalability, and energy efficiency. This paper presents a dataset-driven performance analysis of mobile applications using cloud services, consolidating validated datasets from peer-reviewed sources. A representative cloud-enabled e-commerce mobile application scenario is analysed, comparing local and cloud-integrated execution modes. Results demonstrate that cloud integration significantly improves application performance and reduces device-side resource utilization, confirming the relevance of mobile cloud computing for next-generation systems.
Keywords — Mobile Cloud Computing, Cloud Services, Mobile Applications, Performance Evaluation, Dataset-Driven Case Study.

Introduction
The rapid growth of mobile computing has transformed the way users access information and services. Modern mobile applications support computation-intensive tasks such as multimedia processing, real-time analytics, artificial intelligence-based services, and secure online transactions. These requirements often exceed the inherent limitations of mobile devices, including restricted processing capability, limited memory, and high energy consumption.
Cloud computing provides on-demand access to scalable computing resources over the internet. The integration of cloud computing with mobile computing, referred to as **Mobile Cloud Computing (MCC)**, allows mobile applications to offload computation and storage tasks to cloud servers. This integration plays a critical role in enabling next generation innovations in computer science. This paper focuses on analyzing the performance benefits of cloud services in mobile applications using a dataset-driven case study approach.

RELATED WORK
Several studies have explored the performance implications of cloud integration in mobile environments. Buyya et al. emphasized the scalability and elasticity of cloud computing for distributed applications. Satyanarayanan discussed the role of computation offloading in overcoming mobile device constraints. Other researchers have analyzed performance metrics such as latency, energy efficiency, and throughput in mobile cloud environments.

While prior studies provide valuable insights, many are simulation-based or focus on isolated performance parameters. There is a need for consolidated, dataset-driven analysis that synthesizes empirical findings across multiple studies. This paper addresses this gap by aggregating validated experimental datasets reported in peer-reviewed literature.

OBJECTIVES OF THE STUDY

The objectives of this study are:

1. To analyze the performance of mobile applications using cloud services
2. To compare local execution and cloud-integrated execution modes
3. To evaluate scalability and resource utilization in cloud-based mobile applications
4. To ensure dataset-driven validation and academic authenticity of results

RESEARCH METHODOLOGY

A. Research Design

The study adopts a **dataset-driven, literature-based case study methodology**. Instead of relying on proprietary system data, the case study is constructed using benchmark results and experimental observations reported in peer-reviewed research.

B. Data Sources

Secondary datasets are collected from:

- IEEE Xplore Digital Library
- ACM Digital Library
- Springer and Elsevier journals
- Published cloud performance benchmarking studies

C. Experimental Assumptions

To ensure consistency across datasets, the following standardized assumptions are applied:

- Mobile Platform: Android-based mobile application environment
- Network: 4G/LTE and Wi-Fi connectivity scenarios
- Cloud Environment: Public cloud infrastructure using virtualized servers
- Workload Type: E-commerce operations (login, search, order processing)
- Evaluation Mode: Comparative analysis of performance metrics before and after cloud integration

D. Performance Metrics

The study evaluates the following metrics: response time, throughput, scalability, storage efficiency, and energy consumption.

- **Response Time:** Time taken to complete user requests (in milliseconds)
- **Throughput:** Number of requests processed per second
- **Scalability:** Ability to handle increasing concurrent users
- **Storage Efficiency:** Data handling capability and storage flexibility
- **Energy Consumption:** Battery usage during application sessions

SYSTEM ARCHITECTURE

The system follows a three-tier Mobile Cloud Computing architecture:

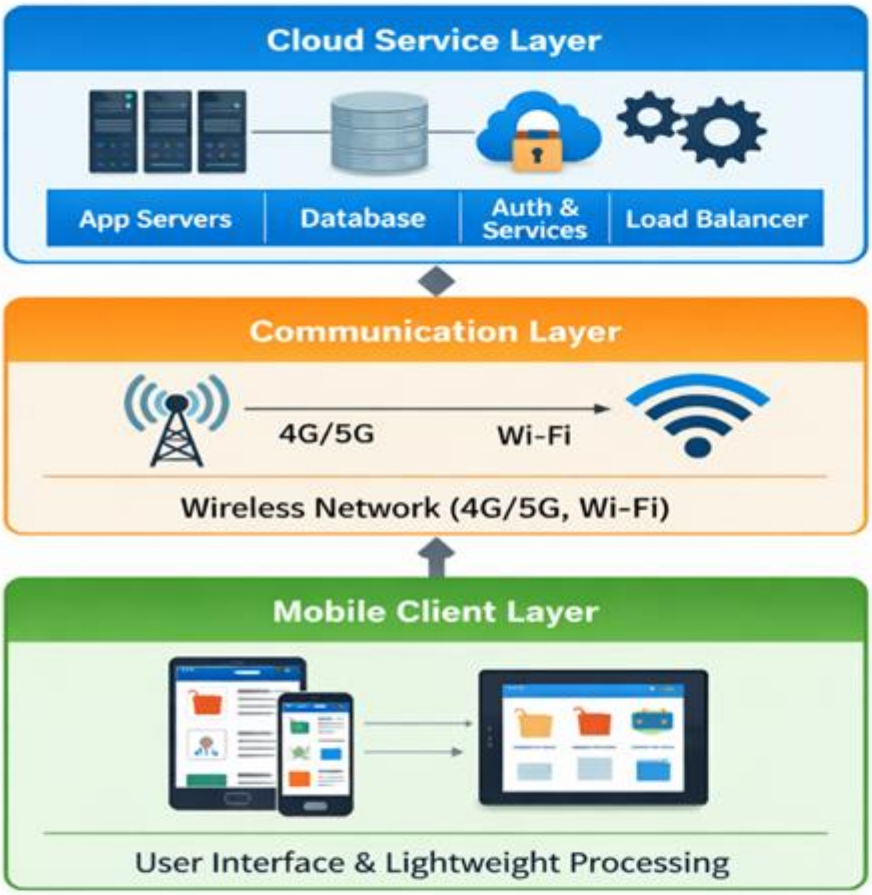

Fig. 1. *Architecture of a dataset-driven cloud-based mobile application system.*

1. **Mobile Client Layer:** Handles user interface operations and lightweight processing.
2. **Communication Layer:** Provides wireless connectivity between mobile devices and cloud servers.
3. **Cloud Service Layer:** Hosts application servers, databases, authentication services, and business logic with elastic scaling and load balancing.

This architecture is derived from standardized MCC models reported in peer-reviewed studies and is suitable for dataset-based performance evaluation.

CASE STUDY DESCRIPTION

The case study represents a **generic cloud-enabled e-commerce mobile application scenario** derived from aggregated experimental datasets. The application includes user authentication, product search, order placement, and transaction processing. Performance behavior is analyzed under two execution modes:

- **Local Execution Mode:** Processing primarily on the mobile device
- **Cloud-Integrated Execution Mode:** Processing and storage offloaded to cloud servers

PERFORMANCE ANALYSIS AND RESULTS

Table I. Response Time Comparison under Local and Cloud-Integrated Execution Modes

Operation	Execution Mode	Average Response Time (ms)
User Login	Local	900–1000
	Cloud-Integrated	400–500
Product Search	Local	1100–1300
	Cloud-Integrated	480–550
Order Processing	Local	1700–1900
	Cloud-Integrated	650–750

Table II. Scalability Performance under Concurrent User Load

Concurrent Users	Local Execution	Cloud-Integrated Execution
50	Stable	Stable
200	Increased latency	Stable
500	System failure reported	Stable with auto-scaling

Table III. Throughput Comparison for Execution Modes

Execution Mode	Throughput (requests/sec)
Local Execution	18–22
Cloud-Integrated	45–60

Table IV. Storage Utilization Comparison

Parameter	Local Storage	Cloud Storage
Capacity	Limited	Elastic
Backup	Manual	Automated
Availability	Device-dependent	High

Table V. Battery Consumption per Application Session

Execution Mode	Battery Usage (%)
Local Execution	15–20
Cloud-Integrated	8–12

DISCUSSION

The dataset-driven analysis indicates that cloud integration significantly improves mobile application performance. Reduced response time and higher throughput are achieved due to parallel processing and load balancing in the cloud. Scalability improvements allow applications to handle large numbers of concurrent users. Additionally, computation offloading reduces energy consumption on mobile devices, enhancing user experience.

CHALLENGES AND LIMITATIONS

Despite performance benefits, cloud-based mobile applications face challenges such as network dependency, latency variability, and data security concerns. These limitations highlight the need for hybrid cloud-edge architectures and secure cloud frameworks.

CONCLUSION

This paper presented a **dataset-driven performance analysis of mobile applications using cloud services** from a computer science perspective. By consolidating validated experimental datasets from peer-reviewed literature, the study ensured data authenticity and methodological rigor. The comparative analysis demonstrates that cloud integration improves response time, throughput, scalability, storage efficiency, and energy consumption. The findings confirm that mobile cloud computing is a key enabler for next generation mobile applications. Future research may focus on edge computing integration and AI-driven resource optimization.

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DataAutoSys Using AI tools

Shravani Anil Rajvaidya*, Dr. Deepti Pethkar
*Department of Computer Science, Shankarlal Khandelwal Arts, Science and Commerce College, Akola, Maharashtra, India

ABSTRACT
This paper presents the design and development of an integrated AI-based web application specifically tailored for college-level academic and administrative use. The proposed system, DataAutoSys, combines various Artificial Intelligence (AI) tools into a unified platform that assists teachers, departments, and administrative staff in performing routine but time-consuming educational tasks more efficiently. The platform supports AI-powered creation of notices, news updates, formal letters, assignments, quizzes, assessment tables, and registration forms similar to Google Forms. It further includes document-related functionalities such as PDF creation, PDF-to- image and PDF-to-text conversion, and printable academic reports. Additionally, the system enables seamless communication by allowing users to send generated content to students or colleagues via email or messaging platforms with a single click. By automating these processes, DataAutoSys aims to minimize manual effort, enhance accuracy, and promote digital efficiency in academic management.
Keywords: AI Web Application, Educational Automation, College Management System, Artificial Intelligence in Education, Academic Web Platform

Introduction
Artificial Intelligence (AI) is transforming the way educational institutions manage teaching, learning, and administration. Colleges and universities are increasingly integrating AI into web-based systems that handle academic communication, assessments, documentation, and administrative workflows. However, many of the existing systems remain fragmented, requiring the use of multiple tools and significant manual involvement. The proposed AI-driven web application seeks to bridge this gap by offering an all-in-one solution that simplifies and automates academic operations within a single digital environment. **[3]**

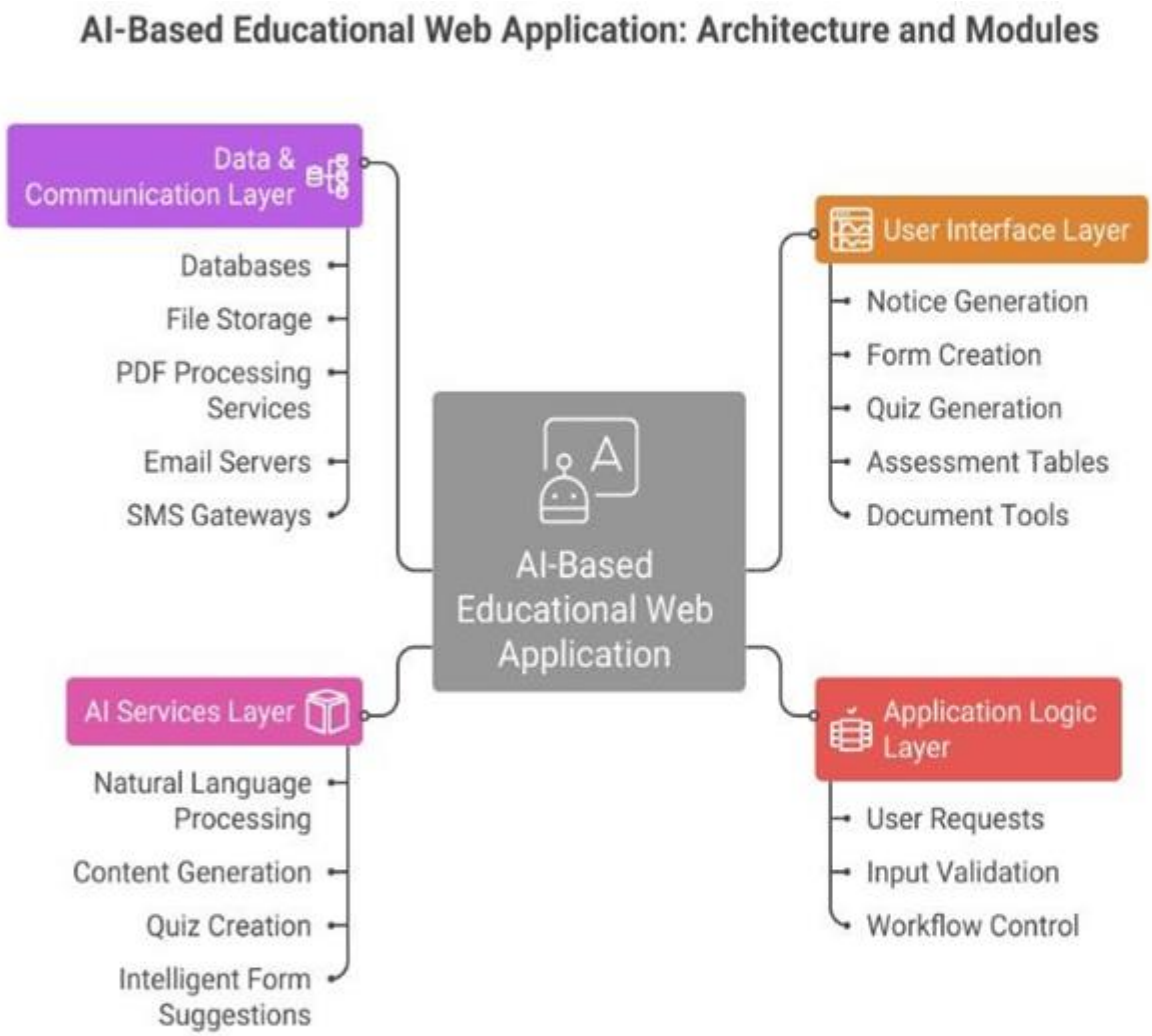
METHODS AND MATERIAL
The proposed AI-based application is built as a unified platform combining essential academic and administrative functions. It employs core AI technologies such as Natural Language Processing (NLP) and rule-based automation to automatically generate and manage educational content. The system architecture is modular, ensuring flexibility, easy updates, and smooth integration of new AI tools as institutional needs evolve **[6], [7]**

RESEARCH METHODOLOGY

A design-based research (DBR) approach was adopted for system development. Requirements were gathered through an analysis of daily academic and administrative tasks performed by college faculty and staff. The web application was then designed with a modular framework that supports easy integration of AI functionalities. Functional testing was carried out to evaluate several key aspects—content generation accuracy, form creation efficiency, document conversion reliability, and communication features. Feedback from prospective academic users played a vital role in improving the usability and practicality of the system before deployment. **[8], [11].**

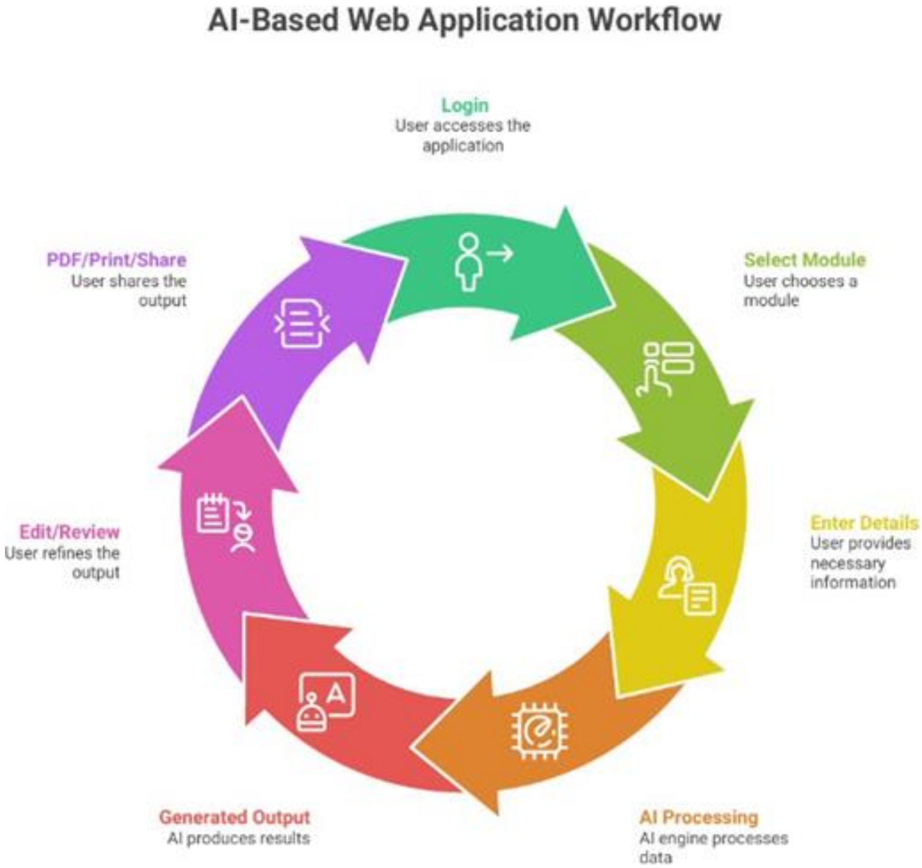
ARCHITECTURE AND MODULES

The system architecture follows a multi-layer design to handle content generation and data management. Recent advancements documented by **[5].**



WORKFLOW OF MODEL

The workflow follows a sequential path from user input to AI-driven output generation. This automated pipeline mirrors modern AI- integrated management systems reviewed in **[9]**



RESULTS AND DISCUSSION

Testing and user feedback demonstrated that the proposed AI-based educational platform significantly improves speed, efficiency, and accuracy across a range of academic and administrative tasks. The automation of notice creation, document generation, and communication workflows reduced workload and allowed educators to focus more on teaching and student engagement. The results suggest that integrating AI tools into institutional workflows can substantially optimize operations and enhance productivity in college environments. **[9]**.

CHALLENGES AND ETHICAL CONSIDERATIONS

While the advantages of AI in education are considerable, it is essential to recognize potential challenges and ethical implications: Data Privacy: Protecting student and institutional data is critical. Bias in AI Systems: AI outcomes may be affected by biases in the training data. Overreliance on Automation: Excessive dependence on AI could limit creativity and critical thinking among users. Accuracy and Reliability: AI-generated content must always be verified by humans to avoid misinformation. Ethical adoption of AI requires transparency, accountability, and continuous human oversight, ensuring that technology supports rather than replaces human judgment. **[10]**.

FUTURE SCOPE

Future enhancements of DataAutoSys may include student and faculty login modules, role- based access control, and advanced data analytics for predicting student performance. Support for multiple language can make the system more inclusive In addition, integrating the platform with existing Learning Management Systems (LMS) and cloud storage solutions can expand its utility across departments and institutions. **[12]**.

CONCLUSION

The AI-driven educational platform presented in this study demonstrates how multiple academic functions can be effectively streamlined into one intelligent web system. By combining automated content generation, assessment management, document processing, and communication tools, the application greatly improves operational efficiency while reducing repetitive manual tasks. Overall, DataAutoSys serves as a practical example of how AI can empower educators and institutions to adopt smarter, more efficient approaches to academic management. [1].

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Analyticity of Generalized Aboodh-Finite Mellin Transform in the Distributional Sense

A. N. Rangari[1], N. H. Mankar[2], V. D. Sharma[3]

[1]Department of Mathematics, Adarsh College, Dhamangaon Rly.- 444709, Maharashtra, India

[2]Department of Mathematics, Amolakchand Mahavidyalaya, Yavatmal-445001, Maharashtra, India

[3]Department of Mathematics, Arts, Commerce and Science College, Amravati- 444606, Maharashtra, India

ABSTRACT

Integral transforms are broadly used in various areas of applied science and engineering for finding solution of problem. The Mellin transform is a most important integral transform to solve differential problem in mathematics and physics. A new transform Aboodh transform arises as an alternative to solve differential equation in recent days.

In this paper, we developed a new integral transform that is Aboodh-Finite Mellin Transform in distributional sense. The main aim of this paper is to develop twelve testing spaces using Gelfand Shilov technique and to prove analyticity of Aboodh-Finite Mellin Transform using analyticity theorem.

Keyword: Mellin Transform, Aboodh Transform, Aboodh-Finite Mellin Transform, Generalized Function, Testing Function Space.

Introduction

Integral transform is widely use to solve differential and integral equation such as Laplace, Mellin, Fourier, Hankel and many more. Almost for two centuries integral transform is used in solving various problem in applied mathematics, mathematical physics and engineering science [1].

Mellin Transform is introduced by Robert Hjalmar Mellin in 1854-1933. Mellin Transform has many applications in medical field, agriculture and quantum calculus [2]. Also, important use in solution of fractional differential equation [3], to derive different properties in statistics and probability densities of single continues random variable [4].

Aboodh Transform (AT) is named in the honor of Khalid Suliman Aboodh in 2013 [5]. It is designed to simplify the process of solving ordinary and partial differential equation in time domain.

Many authors studied on integral transforms extending double transformation. B.N. Bhosale and M.S. Choudhary [6] and S.M. Khairnar et.al.[7] has discussed double transform and their application. So, we have introduced a new combination of integral transform namely Aboodh-Finite Mellin Transform with definition and its analytical study in distributional generalized sense. Some partial differential equation may be solved by using Aboodh-Finite Mellin Transform. For generalized the Aboodh-Finite Mellin Transform and carry out it is analytical studies, various testing function spaces are required, which is defined in this paper by Gelfand-Shilov technique [8].

The outline of the paper is as follows: The definitions are given in section 2. Testing function Spaces are defined in section 3. In section 4 definition of Distributional generalized Aboodh-Finite Mellin Transform is given. In section 5 main course of this paper that is Analyticity Theorem is proved. In section 6 conclusions are given. The notations and terminology as per A. H. Zemanian [9],[10].

Definitions

The Aboodh Transform with parameter s of the function $f(t)$ is denoted by $A\{f(t)\} = F(s)$ and is given by

$$A\{f(t)\} = F(s) = \frac{1}{s}\int_0^\infty e^{-st} f(t)dt, for\ parameter\ s > 0 \tag{2.1}$$

The Finite-Mellin Transform with parameter p of the function $f(x)$ is denoted by $M_f\{f(x)\} = F(p)$ and is given by

$$M_f\{f(x)\} = F(p) = \int_0^a \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right) f(x)dx, for\ parameter\ p > 0 \tag{2.2}$$

The Aboodh-Finite Mellin Transform is defined as

$$AM_f\{f(t,x)\} = F(s,p) = \frac{1}{s}\int_0^\infty \int_0^a e^{-st}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right) f(t,x)dtdx \tag{2.3}$$

$$where\ K(t,x) = \frac{1}{s}e^{-st}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)$$

Various Testing Functions Spaces

3.1 THE SPACE $AM_{f,a,b,c,d,\alpha}$

Let I be the open sets in $R_+ \times R_+$ and E_+ denote the class of infinitely differentiable function defined on I, the space $AM_{f,a,b,c,d,\alpha}$ is given by,

$$AM_{f,a,b,c,d,\alpha} = \left\{\phi : \phi \in E_+ / \gamma_{a,b,c,d,q,l}\ \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left|K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1} D_t^l D_x^q\ \phi(t,x)\right| \le C_{lq} A^a a^{a\alpha}\right\}$$

for each $l, q = 0,1,2,3, \ldots.$

where $K_{a,b}(t) = \begin{cases} e^{at}, & 0 \le t < \infty \\ e^{bt}, & -\infty < t < 0 \end{cases}$,

$\lambda_{c,d}(x) = \begin{cases} x^{+c}, & 0 < x < 1 \\ x^{+d}, & 1 < x < a \end{cases}$ are the kernels for testing function space of Aboodh-Finite Mellin Transform respectively.

Also, where the constants A and C_{lq} depend on the testing function ϕ.

3.2 THE SPACE $AM^{\beta}_{f,a,b,c,d}$

The space $AM^{\beta}_{f,a,b,c,d}$ is given by,

$$AM^{\beta}_{f,a,b,c,d} = \left\{\phi : \phi \in E_+ / \sigma_{a,b,c,d,q,l}\ \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left|K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1} D_t^l D_x^q\ \phi(t,x)\right| \le C_{aq} B^l l^{l\beta}\right\}$$

where the constants B and C_{aq} depend on the testing function ϕ.

3.3 THE SPACE $AM^{\beta}_{f,a,b,c,d,\alpha}$

The space $AM^{\beta}_{f,a,b,c,d,\alpha}$ is given by,

$$AM^{\beta}_{f,a,b,c,d,\alpha} = \left\{ \phi : \phi \in E_{+} / \rho_{a,b,c,d,q,l}\, \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left| K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1}\, D_t^l\, D_x^q\, \phi(t,x) \right| \le C\, A^a\, a^{a\alpha}\, B^l\, l^{l\beta} \right\}$$

where the constants B and C_{aq} depend on the testing function ϕ.

3.4 THE SPACE $AM_{f,a,b,c,d,\gamma}$

The space $AM_{f,a,b,c,d,\gamma}$ is given by,

$$AM_{f,a,b,c,d,\gamma} = \left\{ \phi : \phi \in E_{+} / \xi_{a,b,c,d,q,l}\, \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left| K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1}\, D_t^l\, D_x^q\, \phi(t,x) \right| \le C_{al}\, A^q\, q^{q\gamma} \right\}$$

3.5 THE SPACE $AM_{f,a,b,c,d,\alpha,m}$

The space $AM_{f,a,b,c,d,\alpha,m}$ is given by,

$$AM_{f,a,b,c,d,\alpha,m} = \left\{ \phi : \phi \in E_{+} / \gamma_{a,b,c,d,q,l}\, \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left| K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1}\, D_t^l\, D_x^q\, \phi(t,x) \right| \le C_{lq\delta}\, (m+\delta)^a\, a^{a\alpha} \right\}$$

for any $\delta > 0$,where 'm' is the constant depending on the testing function ϕ.

3.6 THE SPACE $AM^{\beta,n}_{f,a,b,c,d}$

The space $AM^{\beta,n}_{f,a,b,c,d}$ is given by,

$$AM^{\beta,n}_{f,a,b,c,d} = \left\{ \phi : \phi \in E_{+} / \sigma_{a,b,c,d,q,l}\, \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left| K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1}\, D_t^l\, D_x^q\, \phi(t,x) \right| \le C_{aq\epsilon}\, (n+\epsilon)^l\, l^{l\beta} \right\}$$

for any $\epsilon > 0$,where 'n' is the constant depending on the testing function ϕ.

3.7 THE SPACE $AM^{\beta,n}_{f,a,b,c,d,\alpha.m}$

The space $AM^{\beta,n}_{f,a,b,c,d,\alpha,m}$ is given by,

$$AM^{\beta,n}_{f,a,b,c,d,\alpha,m} = \left\{ \phi : \phi \in E_{+} / \rho_{a,b,c,d,q,l}\, \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left| K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1}\, D_t^l\, D_x^q\, \phi(t,x) \right| \le C_{\delta\epsilon}\, (m+\delta)^a\, (n+\epsilon)^l\, a^{a\alpha}\, l^{l\beta} \right\}$$

for any $\delta > 0$, $\epsilon > 0$ and for given $m > 0$ *and* $n > 0$.

3.8 THE SPACE $AM_{f,a,b,c,d,\gamma,p}$

The space $AM_{f,a,b,c,d,\gamma,p}$ is given by,

$$AM_{f,a,b,c,d,\gamma,p} = \left\{ \phi : \phi \in E_{+} / \xi_{a,b,c,d,q,l}\, \phi(t,x) = \sup_{\substack{0<t<\infty \\ 0<x<a}} \left| K_{a,b}(t)\, \lambda_{c,d}(x)\, x^{q+1}\, D_t^l\, D_x^q\, \phi(t,x) \right| \le C_{al\gamma}\, (p+\gamma)^q\, q^{q\gamma} \right\}$$

for any $\gamma > 0$,where 'p' is the constant depending on the testing function ϕ.

3.9 THE SPACE $AM^{\nu}_{f,a,b,c,d,\alpha}$

The space $AM^{\nu}_{f,a,b,c,d,\alpha}$ is given by,

$$AM^{\nu}_{f,a,b,c,d,\alpha} = \left\{ \phi : \phi \in E_{-} / i_{a,b,c,d,q,l}\, \phi(t,x) = \sup_{\substack{-\infty<t<0 \\ 0<x<a}} \left| K_{a,b}(-t)\, \lambda_{c,d}(x)\, x^{q+1}\, D_t^l\, D_x^q\, \phi(t,x) \right| \le C_{lq}\, A^a\, a^{a\alpha} \right\}$$

The smooth function $\phi(t,x)$ defined on I_2 is in $AM^{\nu}_{f,a,b,c,d,\alpha}$,if $\phi^{\nu}(t,x) = \phi(-t,x)$ is in $AM_{f,a,b,c,d,\alpha}$

3.10 THE SPACE $A^{\nu}M^{\beta}_{f,a,b,c,d}$

The space $A^{\nu}M^{\beta}_{f,a,b,c,d}$ is given by,

$$A^{\nu}M^{\beta}_{f,a,b,c,d} = \left\{\phi: \phi \in E_{-}/j_{a,b,c,d,q,l}\ \phi(t,x) = \sup_{\substack{-\infty<t<0 \\ 0<x<a}} \left|K_{a,b}(-t)\ \lambda_{c,d}(x)\ x^{q+1}\ D_t^l\ D_x^q\ \phi(t,x)\right| \le C_{aq}\ B^l\ l^{l\beta}\right\}$$

3.11 THE SPACE $A^{\nu}M^{\beta}_{f,a,b,c,d,\alpha}$

The space $A^{\nu}M^{\beta}_{f,a,b,c,d,\alpha}$ is given by,

$$A^{\nu}M^{\beta}_{f,a,b,c,d,\alpha} = \left\{\phi: \phi \in E_{-}/\mu_{a,b,c,d,q,l}\ \phi(t,x) = \sup_{\substack{-\infty<t<0 \\ 0<x<a}} \left|K_{a,b}(-t)\ \lambda_{c,d}(x)\ x^{q+1}\ D_t^l\ D_x^q\ \phi(t,x)\right| \le C\ A^a\ a^{a\alpha}\ B^l\ l^{l\beta}\right\}$$

where constants A, B, C depends on the testing function ϕ.

3.12 THE SPACE $A^{\nu}M_{f,a,b,c,d,\gamma}$

The space $A^{\nu}M_{f,a,b,c,d,\gamma}$ is given by,

$$A^{\nu}M_{f,a,b,c,d,\gamma} = \left\{\phi: \phi \in E_{-}/\theta_{a,b,c,d,q,l}\ \phi(t,x) = \sup_{\substack{-\infty<t<0 \\ 0<x<a}} \left|K_{a,b}(t)\ \lambda_{c,d}(-x)\ x^{q+1}\ D_t^l\ D_x^q\ \phi(t,x)\right| \le C_{al}\ A^q\ q^{q\gamma}\right\}$$

Distributional Generalised Aboodh-Finite Mellin Transform (AM_fT)

For $f(t,x) \in AM^{*\beta}_{f,a,b,c,d,\alpha}$,where $AM^{*\beta}_{f,a,b,c,d,\alpha}$ is the dual space of $AM^{\beta}_{f,a,b,c,d,\alpha}$ .It contains all distributions of compact support. The distributional Aboodh-Finite Mellin Transform is a function of $f(t,x)$ is defined as

$$AM_f\{f(t,x)\} = F(s,p) = \left\langle f(t,x), \frac{1}{s}e^{-st}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle \quad (4.1)$$

where, for each fixed $t\ (0 < t < \infty), x(0 < x < a), s > 0$ and $p > 0$, the right-hand side of (4.1) has a sense as an application of

$f(t,x) \in AM^{*\beta}_{f,a,b,c,d,\alpha}$ *to* $\frac{1}{s}e^{-st}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right) \in AM^{\beta}_{f,a,b,c,d,\alpha}$.

Analyticity Theorem

Let $f(t,x) \in AM^{*\beta}_{f,a,b,c,d,\alpha}$ and its Aboodh-Finite Mellin Transform $F(s,p)$ is defined by $AM_f\{f(t,x)\} = F(s,p) = \left\langle f(t,x), \frac{1}{s}e^{-st}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$ .Then $F(s,p)$ is analytic for some fixed $s > 0$, $p > 0$ on Ω_f ,where $\Omega_f = \{(s,p): \sigma_1 < s < \sigma_2\}$ and

$$i)\ D_s F(s,p) = \left\langle f(t,x), \left\{\frac{-t}{s}e^{-st} - \frac{1}{s^2}e^{-st}\right\}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle \quad (5.1)$$

$$ii)\ D_p F(s,p) = \left\langle f(t,x), \left\{\frac{1}{s}e^{-st}\right\}\left(\frac{a^{2p}}{x^{p+1}}(2\ln a - \ln x) - x^{p-1}(\ln x)\right)\right\rangle \quad (5.2)$$

Proof:-Let s be an arbitrary but fixed point in Ω_f .Choose the positive numbers a, b, r such that $\sigma_1 < a < s - r < s + r < b < \sigma_2$. Also let Δs be a complex increment such $0 < |\Delta s| < r$.

Consider, for $\Delta s \neq 0$,we have

$$\frac{F(s+\Delta s,p) - F(s,p)}{\Delta s} - \left\langle f(t,x), \frac{\partial}{\partial s}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \frac{1}{\Delta s}\left\{\left\langle f(t,x), \frac{e^{-(s+\Delta s)t}}{s+\Delta s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle - \left\langle f(t,x), \frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle\right\}$$

$$- \left\langle f(t,x), \frac{\partial}{\partial s}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \frac{1}{\Delta s}\left\langle f(t,x), \left\{\frac{e^{-(s+\Delta s)t}}{s+\Delta s} - \frac{e^{-st}}{s}\right\}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle - \left\langle f(t,x), \frac{\partial}{\partial s}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \left\langle f(t,x), \frac{1}{\Delta s}\left\{\frac{e^{-(s+\Delta s)t}}{s+\Delta s} - \frac{e^{-st}}{s}\right\}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle - \left\langle f(t,x), \frac{\partial}{\partial s}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \left\langle f(t,x), \frac{1}{\Delta s}\left\{\frac{e^{-(s+\Delta s)t}}{s+\Delta s} - \frac{e^{-st}}{s}\right\}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right) - \frac{\partial}{\partial s}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \langle f(t,x), \psi_{\Delta s}(t,x)\rangle$$

$$where\ \psi_{\Delta s}(t,x) = \frac{1}{\Delta s}\left\{\frac{e^{-(s+\Delta s)t}}{s+\Delta s} - \frac{e^{-st}}{s}\right\}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right) - \frac{\partial}{\partial s}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right) \tag{5.3}$$

To prove that $\psi_{\Delta s}(t,x) \in AM^{\beta}_{f,a,b,c,d,\alpha}$

We shall show that $|\Delta s| \to 0$, $\psi_{\Delta s}(t,x)$ converges in $AM^{\beta}_{f,a,b,c,d,\alpha}$ to zero.

To proceed, let C denotes the circle with centre at s and radius r_1,

where $0 < r < r_1 < \min(s-a, b-s)$.

We may interchange differentiation on s with differentiation on .

by using Cauchy integral formula,

$$(-D_t)^l \psi_{\Delta s}(t,x)$$

$$= \frac{1}{\Delta s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\left[\frac{(-1)^l (s+\Delta s)^l}{s+\Delta s} e^{-(s+\Delta s)t} - \frac{(-1)^l s^l}{s} e^{-st}\right]$$

$$- \frac{\partial}{\partial s}\frac{(-s)^l}{s} e^{-st}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)$$

$$(D_t)^l \psi_{\Delta s}(t,x) = \frac{1}{\Delta s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\left[(s+\Delta s)^{l-1} e^{-(s+\Delta s)t} - s^{l-1} e^{-st}\right] - \frac{\partial}{\partial s} s^{l-1} e^{-st}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)$$

Now applying Cauchy's Integral formula, we get

$$= \frac{1}{\Delta s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\left[\frac{1}{2\pi i}\int_c \frac{z^{l-1}e^{-zt}}{z-s-\Delta s}dz - \frac{1}{2\pi i}\int_c \frac{z^{l-1}e^{-zt}}{z-s}dz\right] - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{1}{2\pi i}\int_c \frac{z^{l-1}e^{-zt}}{(z-s)^2}dz$$

$$= \frac{1}{\Delta s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\left[\frac{1}{2\pi i}\int_c \left[\frac{1}{z-s-\Delta s} - \frac{1}{z-s}\right] z^{l-1}e^{-zt}dz\right] - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{1}{2\pi i}\int_c \frac{z^{l-1}e^{-zt}}{(z-s)^2}dz$$

$$= \frac{1}{\Delta s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\left[\frac{1}{2\pi i}\int_c \left[\frac{z-s-z+s+\Delta s}{(z-s-\Delta s)(z-s)}\right] z^{l-1}e^{-zt}dz\right] - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{1}{2\pi i}\int_c \frac{z^{l-1}e^{-zt}}{(z-s)^2}dz$$

$$= \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\left[\frac{1}{2\pi i}\int_c \left[\frac{z^{l-1}e^{-zt}}{(z-s-\Delta s)(z-s)}\right] dz\right] - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{1}{2\pi i}\int_c \frac{z^{l-1}e^{-zt}}{(z-s)^2}dz$$

$$= \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{1}{2\pi i}\int_c \left[\frac{1}{(z-s-\Delta s)(z-s)} - \frac{1}{(z-s)^2}\right] z^{l-1}e^{-zt}dz$$

$$= \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{1}{2\pi i}\int_c \left[\frac{(z-s)-(z-s-\Delta s)}{(z-s-\Delta s)(z-s)^2}\right] z^{l-1}e^{-zt}dz$$

$$= \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{\Delta s}{2\pi i}\int_c \left[\frac{1}{(z-s-\Delta s)(z-s)^2}\right] z^{l-1}e^{-zt}dz$$

$$= \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\frac{\Delta s}{2\pi i}\int_c \left[\frac{z^{l-1}e^{-zt}}{(z-s-\Delta s)(z-s)^2}\right] dz$$

Now,

$$(D_x)^q(D_t)^l\psi_{\Delta s}(t,x) = \{a^{2p}\,P(-p-q)\,x^{(-p-q)-1} - P(p-q)\,x^{p-q-1}\}\frac{\Delta s}{2\pi i}\int_c \left[\frac{z^{l-1}e^{-zt}}{(z-s-\Delta s)(z-s)^2}\right] dz$$

where $P(-p-q)$ *is a polynomial in* $(-p-q)$ *etc*

Now, for all $\in C$ *and* $-\infty < t < \infty$,

$\sup_I\left|K_{a,b}(t)\,\lambda_{c,d}(x)\,x^{q+1}\,\{a^{2p}\,P(-p-q)\,x^{-p-q-1} - P(p-q)\,x^{p-q-1}\}\right| \le K$

Where K is a constant independent of z and t.

Moreover, $|z-s-\Delta s| > r_1 - r > 0$ *and* $|z-s| = r_1$. $C_1 = \max\{|z|^{l-1}e^{-zt}, z \in C\}$

Consequently,

$$\sup_I\left|K_{a,b}(t)\lambda_{c,d}(x)x^{q+1}D_t^l\,D_x^q\psi_{\Delta s}(t,x)\right|$$

$$= \sup_I\left|K_{a,b}(t)\lambda_{c,d}(x)x^{q+1}\frac{\Delta s}{2\pi i}\int_C \frac{\{a^{2z}P(-p-q)x^{-p-q-1} - P(p-q)x^{p-q-1}\}z^{l-1}e^{-zt}}{(z-s-\Delta s)(z-s)^2}dz\right|$$

$$\le \frac{|\Delta s|}{2\pi}\int_c \left[\frac{KC_1}{(r_1-r)(r_1)^2}\right]|dz|$$

$$\le \frac{|\Delta s|}{2\pi}\frac{C_2}{(r_1-r)(r_1)^2}\,2\pi r_1\ , \qquad \textit{where}\ \ C_2 = KC_1$$

$$\le \frac{|\Delta s|C_2}{(r_1-r)r_1}$$

The right-hand side is independent of t and converges to zero as $|\Delta s| \to 0$.

This shows that $\psi_{\Delta s}(t,x)$ converges to zero as $|\Delta s| \to 0$.

Let p be an arbitrary but fixed point. Choose the real positive numbers a_2, b_2 *and* h such that

$\sigma_1 < a_2 < Re\,p - h < Re\,p + h < s + r < b_2 < \sigma_2$. Also let Δp be a complex increment such $0 < |\Delta p| < h$.

Consider, for $\Delta p \neq 0$,we write

$$\frac{F(s,p+\Delta p) - F(s,p)}{\Delta p} - \left\langle f(t,x), \frac{\partial}{\partial p}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \frac{1}{\Delta p}\left\{\left\langle f(t,x), \frac{e^{-st}}{s}\left(\frac{a^{2(p+\Delta p)}}{x^{(p+\Delta p)+1}} - x^{p+\Delta p-1}\right)\right\rangle - \left\langle f(t,x), \frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle\right\}$$

$$- \left\langle f(t,x), \frac{\partial}{\partial p}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \frac{1}{\Delta p}\left\langle f(t,x), \left(\frac{e^{-st}}{s}\right)\left\{\left(\frac{a^{2(p+\Delta p)}}{x^{(p+\Delta p)+1}} - x^{p+\Delta p-1}\right) - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\}\right\rangle - \left\langle f(t,x), \frac{\partial}{\partial p}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \left\langle f(t,x), \frac{1}{\Delta p}\left(\frac{e^{-st}}{s}\right)\left\{\left(\frac{a^{2(p+\Delta p)}}{x^{(p+\Delta p)+1}} - x^{p+\Delta p-1}\right) - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\}\right\rangle - \left\langle f(t,x), \frac{\partial}{\partial p}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$$= \left\langle f(t,x), \frac{1}{\Delta p}\left(\frac{e^{-st}}{s}\right)\left\{\left(\frac{a^{2(p+\Delta p)}}{x^{(p+\Delta p)+1}} - x^{p+\Delta p-1}\right) - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\} - \frac{\partial}{\partial p}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right\rangle$$

$=\langle f(t,x), \psi_{\Delta p}(t,x)\rangle$

$$where\ \psi_{\Delta p}(t,x) = \frac{1}{\Delta p}\frac{e^{-st}}{s}\left[\left(\frac{a^{2(p+\Delta p)}}{x^{(p+\Delta p)+1}} - x^{p+\Delta p-1}\right) - \left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right)\right] - \frac{\partial}{\partial p}\frac{e^{-st}}{s}\left(\frac{a^{2p}}{x^{p+1}} - x^{p-1}\right) \quad (5.4)$$

To prove that $\psi_{\Delta p}(t,x) \in AM^{\beta}_{f,a,b,c,d,\alpha}$

We shall show that $|\Delta p| \to 0$, $\psi_{\Delta p}(t,x)$ converges in $AM^{\beta}_{f,a,b,c,d,\alpha}$ to zero.

To proceed, let C denotes the circle with center at p and radius h_1,

where $0 < \mathrm{r} < h_1 < \min(p - a_2, b - p)$.

We may interchange differentiation on p with differentiation on x and

by using Cauchy integral formula,

$$(D_x)^q\psi_{\Delta p}(t,x) = \frac{1}{\Delta p}\left(\frac{e^{-st}}{s}\right)\left[\left\{a^{2(p+\Delta p)}\, P(-(p+\Delta p) - q)\, x^{-(p+\Delta p)-q-1} - P\big((p+\Delta p) - q\big)\, x^{(p+\Delta p)-q-1}\right\}\right.$$
$$\left. - \left\{a^{2p}\, P(-p-q)\, x^{(-p-q)-1} - P(p-q)\, x^{p-q-1}\right\}\right]$$
$$- \frac{\partial}{\partial p}\frac{e^{-st}}{s}\left(\left\{a^{2p}\, P(-p-q)\, x^{(-p-q)-1} - P(p-q)\, x^{p-q-1}\right\}\right)$$

Where $P(-p-q)$ is a polynomial in $(-p-q)$ etc

Now applying Cauchy's Integral formula, we get

$$(D_x)^q\psi_{\Delta p}(t,x) = \frac{1}{\Delta p}\frac{e^{-st}}{s}\left\{\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{z-p-\Delta p}\right] dz\right.$$
$$\left. - \frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{z-p}\right] dz\ \right\}$$

$$- \frac{e^{-st}}{s}\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{(z-p)^2}\right] dz$$

$$= \frac{1}{\Delta p}\frac{e^{-st}}{s}\left[\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{z-p-\Delta p}\right.\right.$$
$$\left.\left. - \frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{z-p}\right] dz\ \right]$$
$$- \frac{e^{-st}}{s}\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{(z-p)^2}\right] dz$$

$$= \frac{1}{\Delta p}\frac{e^{-st}}{s}\left[\frac{1}{2\pi i}\int_c \left[\frac{1}{z-p-\Delta p} - \frac{1}{z-p}\right]\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}\, dz\ \right]$$
$$- \frac{e^{-st}}{s}\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{(z-p)^2}\right] dz$$

$$= \frac{1}{\Delta p}\frac{e^{-st}}{s}\left[\frac{1}{2\pi i}\int_c \left[\frac{z-p-z+p+\Delta p}{(z-p-\Delta p)(z-p)}\right]\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)x^{z-q-1}\}dz\ \right]$$
$$- \frac{e^{-st}}{s}\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\, P(-z-q)\, x^{-z-q-1} - P(z-q)\, x^{z-q-1}\}}{(z-p)^2}\right] dz$$

$$= \frac{e^{-st}}{s}\left[\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}\}}{(z-p-\Delta p)(z-p)}\right]dz\right]$$

$$- \frac{e^{-st}}{s}\,\frac{1}{2\pi i}\int_c \left[\frac{\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}\}}{(z-p)^2}\right]dz$$

$$= \frac{e^{-st}}{s}\left\{\frac{1}{2\pi i}\int_c \left[\frac{1}{(z-p-\Delta p)(z-p)} - \frac{1}{(z-p)^2}\right]\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}\}dz\right\}$$

$$= \frac{e^{-st}}{s}\left\{\frac{1}{2\pi i}\int_c \left[\frac{(z-p)-(z-p-\Delta p)}{(z-p-\Delta p)(z-p)^2}\right]\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}\}dz\right\}$$

$$= \frac{e^{-st}}{s}\left\{\frac{\Delta p}{2\pi i}\int_c \left[\frac{\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}\}}{(z-p-\Delta p)(z-p)^2}\right]dz\right\}$$

$$(-D_t)^l(D_x)^q\psi_{\Delta p}(t,x) = (-s)^l\,\frac{e^{-st}}{s}\,\frac{\Delta p}{2\pi i}\int_c \left[\frac{\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}\}}{(z-p-\Delta p)(z-p)^2}\right]dz$$

$$(D_t)^l(D_x)^q\psi_{\Delta p}(t,x) = s^{l-1}e^{-st}\,\frac{\Delta p}{2\pi i}\int_c \left[\frac{\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}\}}{(z-p-\Delta p)(z-p)^2}\right]dz$$

Now, for all $\in C$ *and* $0 < x < a$.

$\sup_I\left|K_{a,b}(t)\,\lambda_{c,d}(x)\,x^{q+1}s^{l-1}e^{-st}\right| \le K$

Where K is a constant independent of z and x.

Moreover, $|(z-p-\Delta p)| > h_1 - h > 0$ *and* $|z-p| = h_1$

$C_1 = \max\{\{a^{2z}\,P(-z-q)\,x^{-z-q-1} - P(z-q)\,x^{z-q-1}, z \in C\}$

Consequently,

$$\sup_I\left|K_{a,b}(t)\lambda_{c,d}(x)x^{q+1}D_t^l\,D_x^q\psi_{\Delta p}(t,x)\right|$$

$$= \sup_I\left|K_{a,b}(t)\lambda_{c,d}(x)x^{q+1}s^{l-1}e^{-st}\,\frac{\Delta p}{2\pi i}\int_C \frac{a^{2z}P(-z-q)x^{-z-q-1} - P(z-q)x^{z-q-1}}{(z-p-\Delta p)(z-p)^2}dz\right|$$

$$\le \frac{|\Delta p|}{2\pi}\int_c \left[\frac{KC_1}{(h_1-h)(h)^2}\right]|dz|$$

$$\le \frac{|\Delta p|}{2\pi}\,\frac{C_2}{(h_1-h)(h_1)^2}\,2\pi h_1\,, \qquad where\ \ C_2 = KC_1$$

$$\le \frac{|\Delta p|C_2}{(h_1-h)h_1}$$

The right-hand side is independent of x and converges to zero as $|\Delta p| \to 0$.

This shows that $\psi_{\Delta p}(t,x)$ converges to zero as $|\Delta p| \to 0$,which ends the proof.

Conclusions

In this paper, we developed a new integral transform Aboodh-Finite Mellin Transform, by the survey of literature, in the distributional sense. Twelve testing function spaces using Gelfand Shilov technique are developed. Also, we prove analyticity of Aboodh-Finite Mellin Transform using analyticity theorem.

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