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Adaptive Neuro Fuzzy Expert System for Diagnosing HIV

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ABSTRACT

Human Immunodeficiency Virus (HIV) is a retrovirus that causes Acquired Immune Deficiency Syndrome (AIDS) by infecting helper T cells or Lymphocyte of the immune system. HIV is transmitted primarily by exposure to contaminated body fluids, especially blood and semen. Other means of transmission of HIV include sharing contaminated sharp objects and blood transfusion. HIV symptoms can include a headache, chronic cough, diarrhoea, swollen glands, lack of energy, and loss of appetite, weight loss, frequent fevers, frequent yeast infections, skin rashes, pelvic/abdominal cramps, sores on certain parts of your body and short-term memory loss. The focal point of this research is to describe and illustrate the application of fuzzy logic system to the diagnosis of HIV. It involves a sequence of methodological and analytical decision steps that enhance the quality and meaning of the logic produced. The system eliminates the uncertainties often associated with the analysis of HIV test data. To actualize the objective of this study, data collected from University Teaching Hospital, Ibadan, Nigeria were used as a set of parameters for diagnosis, and the software used for the development of necessary Graphical User interfaces (GUI), for fuzzy modelling, fuzzy inference system editor, membership function editor, rule editor, rule editor, rule viewer and surface viewer was MATLAB, while MAMDANI editor GUI; a type of an Adaptive Neural Fuzzy Inference Systems was used for building and analyzing Mamdani

Keywords: HIV Disease, Fuzzy Expert System, Fuzzy Logic, Medical Diagnosis.

I. INTRODUCTION

Human Immunodeficiency Virus (HIV) is a retrovirus that causes Acquired Immune Deficiency Syndrome (AIDS) by infecting helper T cells or Lymphocyte of the immune system. HIV is transmitted primarily by exposure to contaminated body fluids, especially blood and semen. Other means of transmission of HIV include sharing contaminated sharp objects and blood transfusion. HIV symptoms can include a headache, chronic cough, diarrhoea, swollen glands, lack of energy, and loss of appetite, weight loss, frequent fevers, frequent yeast infections, skin rashes, pelvic/abdominal cramps, sores on certain parts of your body and short-term memory loss. HIV is a virus that attacks immune cells called CD-4 cells, which are a subset of T cells. AIDS is the syndrome, which may or may not appear in the advanced stage of HIV infection [1]. HIV infection can cause AIDS to develop. However, it is possible to contract HIV without developing AIDS. Without treatment, HIV can progress and, eventually, it will develop into AIDS in the vast majority of cases. HIV can, however, be spread through;

a. Sexual transmission — it can happen when there is contact with infected sexual fluids (rectal, genital, or oral mucous membranes). This can happen while having sex without a condom, including vaginal, oral, and anal sex, or sharing sex toys with someone who is HIV-positive.

b. Perinatal transmission — a mother can transmit HIV to her child during childbirth, pregnancy, and through breastfeeding.

c. Blood transmission — the risk of transmitting HIV through blood transfusion is extremely low in developed countries, thanks to meticulous screening and precautions. However, among people who inject drugs, sharing and reusing syringes contaminated with HIV-infected blood is extremely hazardous.

Since the beginning of the epidemic, more than 70 million people has been infected with the HIV virus and about 35 million people have died of HIV. Globally, 36.7 million [30.8–42.9 million] people were living with HIV at the end of 2016. An estimated 0.8% [0.7-0.9%] of adults aged 15–49 years worldwide are living with HIV, although the burden of the epidemic continues to vary considerably between countries and regions. Sub-Saharan Africa remains most severely affected, with nearly 1 in every 25 adults (4.2%) living with HIV and accounting for nearly two-thirds of the people living with HIV worldwide [2].

These statistics were corroborated by the latest statistics on the status of the AIDS epidemic [3]. In the report it was stated that; 20.9 million people were accessing antiretroviral therapy in June 2017, 36.7 million [30.8 million–42.9 million] people globally were living with HIV in 2016, 1.8 million [1.6 million–2.1 million] people became newly infected with HIV in 2016, 1 million [830 000–1.2 million] people died from AIDS-related illnesses in 2016, 76.1 million [65.2 million–88.0 million] people have become infected with HIV since the start of the epidemic and 35.0 million [28.9 million–41.5 million] people have died from AIDS-related illnesses since the start of the epidemic. As presented in the report children were not left out because in 2016 alone 2.1 million [1.7 million–2.6 million] children (<15 years) were living with HIV. The consequence of HIV infection is presented in [4].

Fuzzy logic is a convenient way to map an input space to an output space. For example, the user tells the controller how hot he wants the water to be and the controller adjusts the faucet valve to the right setting, the user tells the camera control how far away the subject of the photograph is, and the controller adjusts the focus the lens etc. It is all just a matter of mapping inputs to the appropriate outputs. Between the input and the output, a black box does the work. The black box may contain any number of things like fuzzy systems, linear systems, expert systems, neural networks, differential equations, interpolated multidimensional lookup tables, or even a spiritual advisor. A knowledge-based online diagnosis system developed for the diagnosis of diseases based on the knowledge given by doctors in the system. A computer Program Capable of performing at a human- expert level in a narrow problem domain area is known as called an expert system [5]

II. DIAGNOSIS OF HIV

The diagnosis of HIV is based on the presence of certain signs and symptoms. This research presents a novel method for online diagnosis of HIV disease. The expert system gives some symptoms from which the user needs to select symptoms. Based on the selection of symptoms, the user is again asked some questions. According to the answer selection, the fuzzy expert system diagnosis diseases based on its Knowledge, add catalyst factor (if any), do ranking and gives the result in a fuzzy form. A fuzzy expert system deals with uncertainty and vague terms; it is generously accepted in a different sphere of life [6].

The objective of this research is to develop an Adaptive Neuro-Fuzzy Expert System for diagnosing HIV.

III. RELATED WORKS

A. Brief History of Artificial Intelligence

The history of Artificial Intelligence (AI) began in antiquity with myth, stories, and rumours of artificial beings endowed with intelligence or consciousness by master artisans; as [7] writes, AI began with "an ancient wish to forge the gods." The seed of modern AI was planted by classical philosophers who attempted to describe the process of human thinking as the mechanical manipulation of symbols. Although the computer provided the technology necessary for AI, it was not until the early 1950s that the link between human intelligence and machines was really observed, Norbert Wiener was one of the first Americans to make observations on the principles of feedback theory. The most familiar example of feedback theory is thermostat: it controls the temperature of an environment of the house, comparing it to the desired temperature and responding by turning the heat up and down. What was so important about his research into feedback loops was that Norbert Wiener theorized that all intelligent behavior was the result of feedback mechanisms. Mechanisms that could possibly be stimulated by machines. This influenced much of early development of AI [8].

B. Review of Expert System

The expert system is a type of computer application program that makes decisions or solves problems in a particular field, such as finance or medicine, by using knowledge and analytical rules defined by experts in the field. Human expert solves problems by using a combination of factual knowledge and reasoning ability. In an expert system, these two essentials are contained in two separate but related components, a knowledge base, and an inference engine provide the reasoning ability that enables the expert system to form conclusions [9].

The Major Components of Expert Systems are;

The User Interface: - The user interface is the means of communication between a user and the expert systems problem-solving processes. A good expert system is not very useful unless it has an effective interface. It has to be able to accept the queries or instructions in a form that the user enters and translate them into working instructions for the rest of the system. It also has to be able to translate the answers, produced by the system, into a form that the user can understand.

Knowledge Base: - The knowledge base stores all the facts and rules about a particular problem domain. It makes these available to the inference engine in a form that it can use. The facts may be in the form of background information built into the system or facts that are input by the user during a consultation. The rules include both the production rules that apply to the domain of the expert system and the heuristics and rules-of-thumb that are provided by the domain expert in order to make the system find solutions more efficiently by taking shortcuts.

The Shell or Inference Engine: - The inference engine is the program that locates the appropriate knowledge in the knowledge base, and infers new knowledge by applying logical processing and problem-solving strategies. The inference engine can be considered the brain of the system. It is responsible for the "reasoning" of the system. In the proposed expert system, the inference engine extracts keywords from input by the user and processes them to check the validity of the question asked. The system is rule-based and thus implements inferencing by utilizing the IF-THEN rule to draw conclusions as to which answer is to be retrieved for a relevant query or question [10]. Some Expert Systems in Healthcare are presented in [11], [12] and [13].

C. Fuzzy Inference System

The fuzzy inference system is the process of formulating the mapping from a given input to an output. The logic in the system is built on the experience of people who understand the system to be modelled in natural language. The statement of if-then (or rules) is the main mechanism in the fuzzy inference system. This fuzzy inference system makes the system natural and beneficial to model a complex humanistic in the loop system. [14] Showed that a fuzzy inference system is capable of approximating any real continuous function to arbitrary accuracy, and this is a basis from which decisions can be made, or patterns discerned.

The main components are a fuzzification interface, a fuzzy rule base (knowledge base), an inference engine (decision-making logic), and a defuzzification interface. The input variables are fuzzified whereby the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule antecedent. Fuzzy *if-then* rules and fuzzy reasoning are the backbones of fuzzy expert systems, which are the most important modeling tools based on fuzzy set theory. The fuzzy rule base is characterized in the form of *if-then* rules in which the antecedents and consequents involve linguistic variables. The collection of these fuzzy rules forms the rule base for the fuzzy logic system. Using suitable inference procedure, the truth value for the antecedent of each rule is computed and applied to the consequent part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Again, by using suitable composition procedure, all the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Finally, defuzzification is applied to convert the fuzzy output set to a crisp output. The basic fuzzy inference system can take either fuzzy inputs or crisp inputs, but the outputs it produces are always fuzzy sets. The defuzzification task extracts the crisp output that best represents the fuzzy set. With crisp inputs and outputs, a fuzzy inference system implements a nonlinear mapping from its input space to output space through a number of fuzzy *if-then* rules [15].

D. Adaptation of Fuzzy Inference Systems

Expert knowledge is often the main source to design the fuzzy expert systems. Parameters and components that need to be adapted for controlling a process. According to the performance measure of the problem environment, the membership functions, rule bases, and the inference mechanism are to be adapted [8].

Neural network learning, self-organizing maps, and clustering methods could be used to generate rules. Gradient descent and its variants could be applied to fine-tune the parameters of parameterized input/output membership functions and fuzzy operators [8].

The task of Adaptive fuzzy inference systems is to develop a fuzzy expert system to forecast the reactive power (*P*) at time $t+1$ by knowing the load current (*I*) and voltage (*V*) at time *t*. The experiment system consists of two stages: developing the fuzzy expert system, and performance evaluation using the test data. The model has two in–out variables (*V* and *I*) and one output variable (*P*). Training and testing data sets were extracted randomly from the master dataset. This is shown in Fig.1

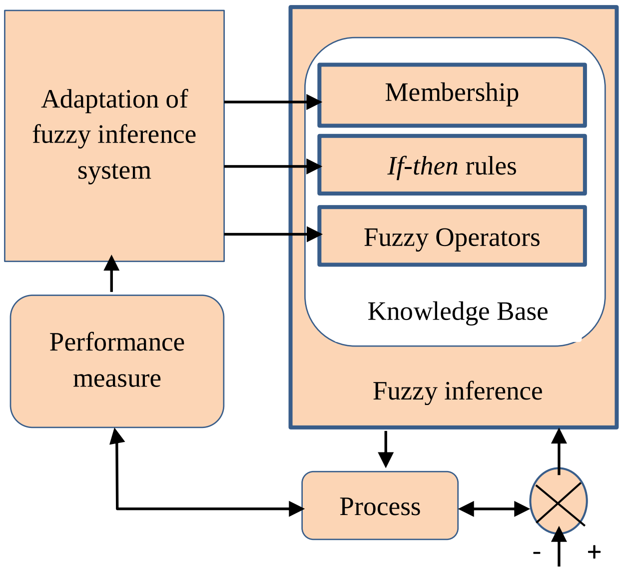

Figure 1. Adaptation of fuzzy inference systems

IV. METHODOLOGY

Data for this study and information from HIV consultants were collected from University Teaching Hospital (UCH), Ibadan, Nigeria. A set of parameters used for diagnosis (13 basic and major parameters) are presented in Table 1.

TABLE 1 Symptoms Parameter of HIV

SYMTOM CODES	SYMPTOMS OF HIV (HUMAN IMMUNODEFICIENCY VIRUS)
P01	Headache
P02	Chronic Cough
P03	Diarrhea
P04	Swollen gland
P05	Lack of appetite
P06	Loss of appetite
P07	Weight loss
P08	Frequent fever
P09	Frequent yeast infection
P10	Skin rashes
P11	Pelvic/ abdominal cramps
P12	Sores on certain parts of the body
P13	Short-term memory loss

The fuzzy expert Software used for the diagnosis is MATLAB. There are five primary GUI Tools for building, editing, and observing fuzzy inference system in the toolbox namely; Fuzzy Inference System (FIS) Editor, Membership Function Editor, Rule Editor, Rule Viewer, Surface Viewer.

A. Fuzzy Expert System HIV Diagnosis

The most important application of fuzzy system (fuzzy logic) is in uncertain issues. When a problem has dynamic behavior, fuzzy logic is a suitable tool that deals with this problem. The first step of fuzzy expert system designing is the determination of input and output variables. In this design, there are 13 input variables and 1 output variable. After which the membership functions (MF) of all variables were designed. These membership functions determine the membership of objects to fuzzy sets. A description of the input variables with their membership functions are as follows:

***P01. Headache*:** This input variable supports 3 symptom types (Migraine, Cluster, and Tension-type). We have defined a value in this system for each symptom type that we use these values for system testing. Each symptom type is a fuzzy set. In this field, fuzzy sets do not have overlap and sets define in form of crisp because the patient has just one symptom type on time. This is shown in Fig. 2

INPUT FIELD	RANGE	FUZZY SET
Headache	>2 3-7 8>	Migraine Cluster Tension Type

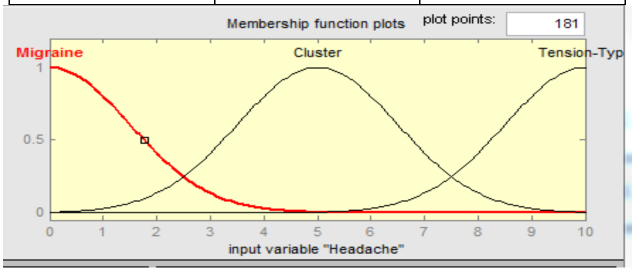

Figure 2. Membership Function of Headache

***P02. Chronic Cough*:** Different values of Chronic Cough change the result easily. In this field, we use Chronic Cough. This input variable has divided into 4 fuzzy sets. Fuzzy sets are "Dry", "Croup", "Whooping" and "Wet". Membership functions, sets are trapezoidal. We have defined fuzzy membership expressions for Chronic Cough input field. This is shown in Fig. 3

INPUT FIELD	RANGE	FUZZY SET
Chronic Cough	0-3 1-7 5-10 7-10	Dry Wet Whooping Croup

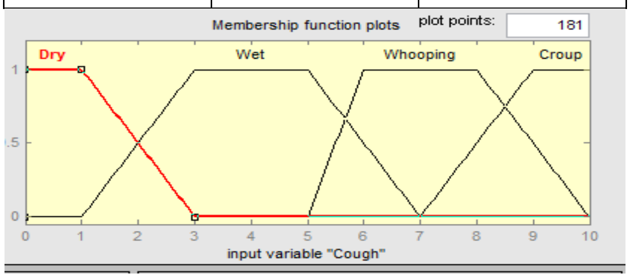

Figure 3. Membership Function of Cough

***P03. Diarrhea*:** Diarrhea has a salient effect on the result and can change it easily. For this input field, Diarrhea field has 2 fuzzy sets (Acute and Chronic). These fuzzy sets have been shown in Table 2. Membership function sets are trapezoidal. This is shown in Fig. 4

INPUT FIELD	RANGE	FUZZY SET
	<3	Acute
Diarrhea	3-10	Chronic

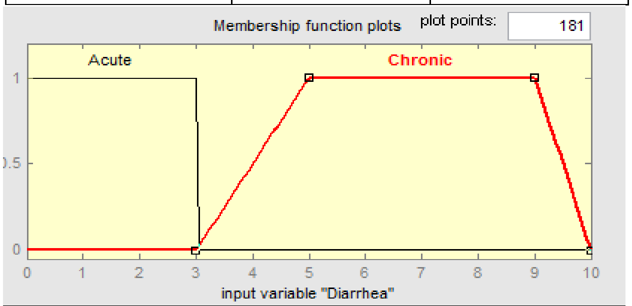

Figure 4. Membership Function of Diarrhea

***P04. Swollen Gland*:** Swollen Gland field is one of the most important factors in this system that changes the result. This input field has 4 fuzzy set. In this system, we have ("Armpit", "Others", "Neck" and "Groin"). The membership function of this fuzzy set is triangular. This is shown in Fig. 5

INPUT FIELD	RANGE	FUZZY SET
	0-1	Armpit
	1-6	Others
Swollen Gland	<3-7	Neck
	5-10	Groin

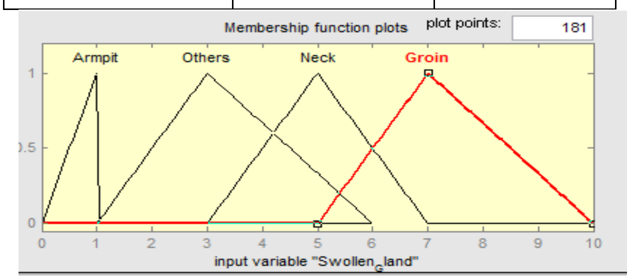

Figure 5. Membership Function of Swollen Gland

P05. Lack of appetite: In this field, we have 2 fuzzy sets (True or False). Membership functions of fuzzy sets are Gaussian "RANGE" column, we have defined a value for each fuzzy set in left side of each interval and we use just these values for system testing. This is shown in Fig. 6

INPUT FIELD	RANGE	FUZZY SET
Lack of appetite	<5-5.9	True
	<9	False

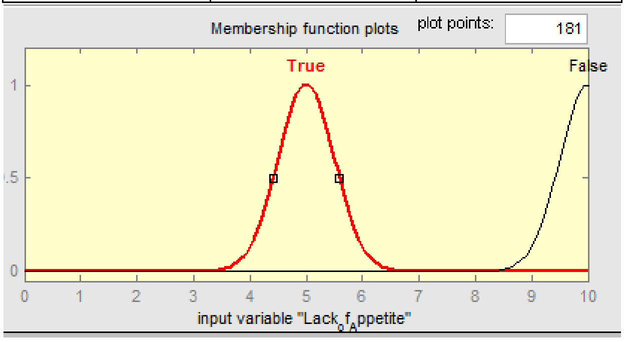

Figure 6. Membership Function of Lack of Appetite

***P06. Loss of appetite*:** This input field has just 2 values (0, 1) and one fuzzy set (true). If doctor determines exercise test for patient, value 1 will enter in system, otherwise, value 0 will enter in it. This is shown in Fig. 7

INPUT FIELD	RANGE	FUZZY SET
Loss of appetite	<7	True
	0-10	False

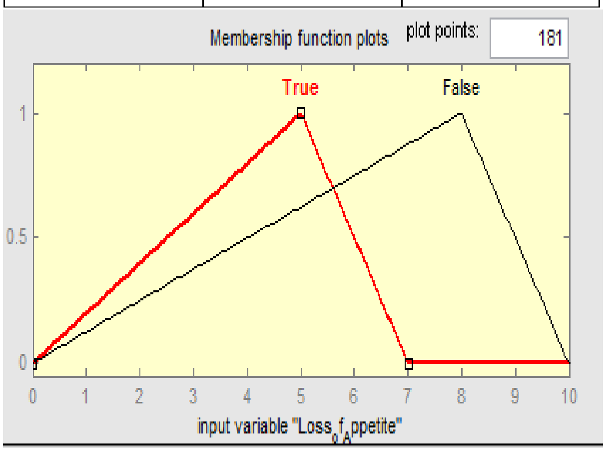

Figure 7. Membership Function of Loss of Appetite

***P07. Weight loss*:** This input field has just 2 values (0, 1) also and one fuzzy set (true). If doctor determines exercise test for patient, value 1 will enter in system, otherwise, value 0 will enter in it. This is shown in Fig. 8

INPUT FIELD	RANGE	FUZZY SET
Weight loss	0-5 1-8	True False

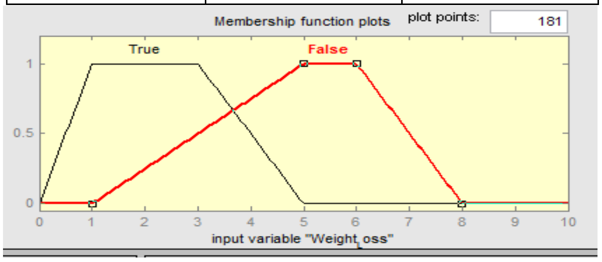

Figure 8. Membership Function of Weight Loss

***P08. Frequent fever*:** This input field has 4 fuzzy sets (Typhoid, Malaria, FUO and Others). Membership functions of "Typhoid" and "Malaria" fuzzy sets are trapezoidal and membership function of "FUO" and "Others" fuzzy set is triangular. This is shown in Fig. 9

INPUT FIELD	RANGE	FUZZY SET
Frequent fever	1.4 - 4.8 1.4 - 8 5 > >10	Typhoid Malaria FUO Others

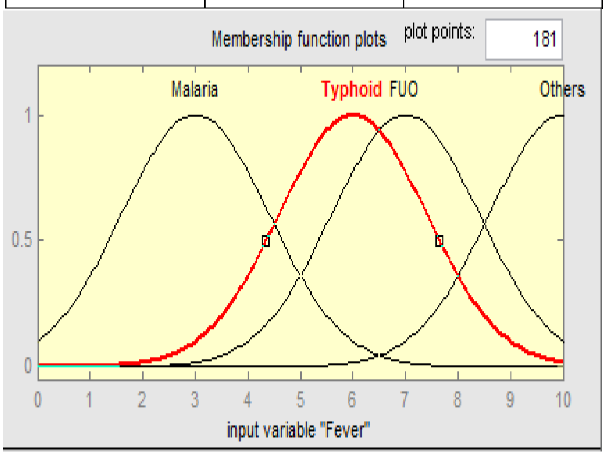

Figure 9. Membership Function of Fever

***P09. Frequent yeast infection*:** This input field consists 4 fuzzy sets: Oral, Others Vagina and Male. For each fuzzy set we have defined a value that we use them for system testing. This is shown in Fig. 10

INPUT FIELD	RANGE	FUZZY SET
Frequent yeast infection	0-3 0-4 3-7 7-10	Oral Others Vaginal Male

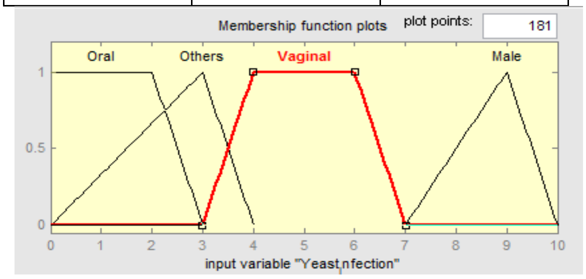

Figure 10. Membership Function of Yeast Infection

***P10. Skin rashes*:** This input field just has 2 values (0, 1) and sets (True or False). Value 0 means that patient does not have, the value 1 means that patient is have. This is shown in Fig. 11

INPUT FIELD	RANGE	FUZZY SET
Skin rashes	<10 5-10	True False

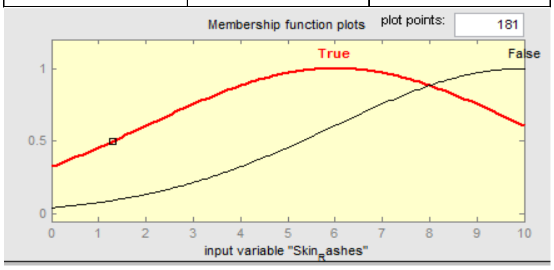

Figure 11. Membership Function of Skin Rashes

***P11. Pelvic/ abdominal cramps*:** Also this input field just has 2 values (0, 1) and sets (True or False). Value 0 means that patient does not have, the value 1 means that patient is have. This is shown in Fig. 12

INPUT FIELD	RANGE	FUZZY

		SET
Pelvic/ abdominal cramps	2-10 9 >	True False

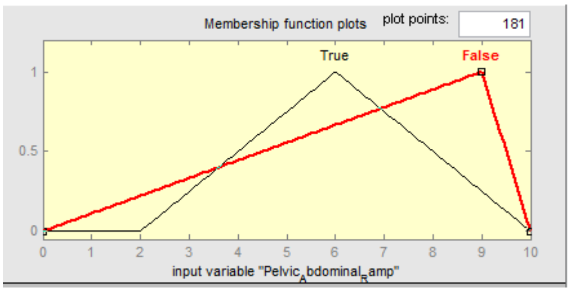

Figure 12. Membership Function of Pelvic Abdominal Ramp

P12. Sores on certain parts of the body: This input field divides to 3 fuzzy sets (Mouth, Throat, and Others). Membership functions of "Mouth and Throat" are trapezoidal and membership functions of "Others" is triangular. This is shown in Fig. 13

INPUT FIELD	RANGE	FUZZY SET
Sores on certain parts of the body	0-5 <10 5-10	Mouth Throat Others

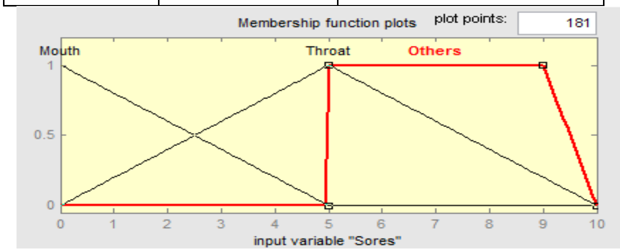

Figure 13. Membership Function of Sore

P13. Short-term memory loss: This input field has just 2 values (0, 1) and one fuzzy set (true). If doctor determines exercise test for patient, value 1 will enter in system, otherwise, value 0 will enter in it. This is shown in Fig. 14

INPUT FIELD	RANGE	FUZZY SET
Short-term memory loss	0-7 1-9	True False

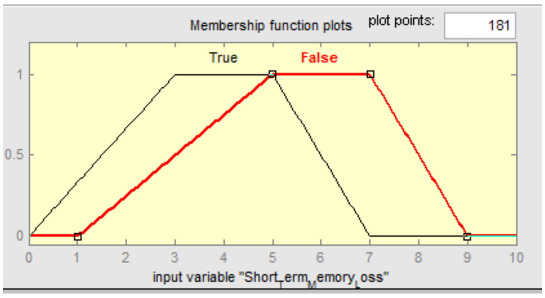

Figure 13. Membership Function of Short-term Memory Loss

B. Output Variable

The "goal" field refers to the presence of HIV disease in the patient. It is an integer value from 0 (no presence) to 3. By increasing the integer value, HIV disease risk increases in the patient. In this system, we have considered a different output variable, which divides into 3 fuzzy sets (Not HIV Infected, Might be HIV Infected and HIV Infected). Table 8 shows these fuzzy sets with their ranges. Membership functions of "Not HIV Infected", "Might be HIV Infected" and "HIV Infected" fuzzy sets are triangular. This is shown in Fig. 14

INPUT FIELD	RANGE	FUZZY SET
Result	0-10 10-20 20-30	Not HIV Infected Might be HIV Infected HIV Infected

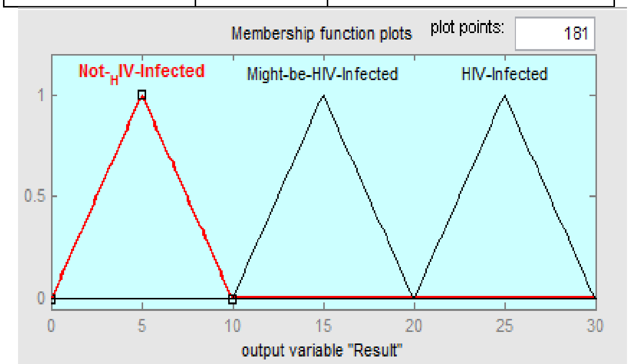

Figure 14. Membership Function of Output Variable Result

V. EVALUATION OF THE SYSTEM

We have tested the developed system with corresponding values for each field and the graphical result is shown in Fig. 15. The designed system uses inference mechanism Sugeno approach. In this system, we don't have any logical combination of inputs with AND/OR because antecedent part of all rules has one section. We have defined a validity degree (k) for each rule as shown. This is shown in Fig. 16 to Fig. 27. The flow diagram of the system is in Fig. 28

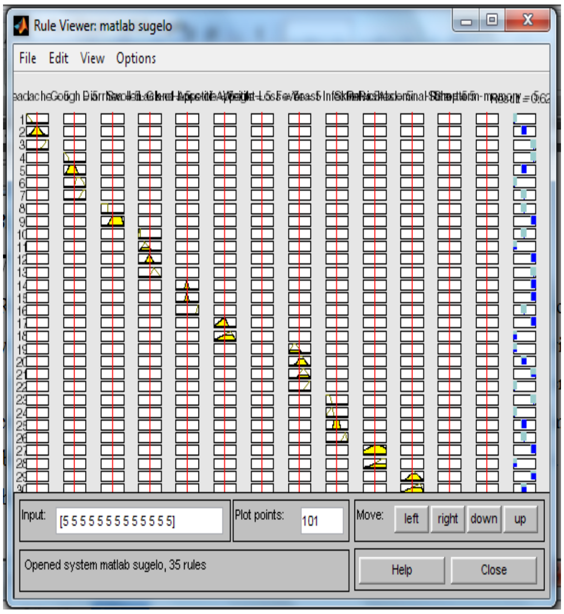

Figure 15. Flow diagram Rule Base

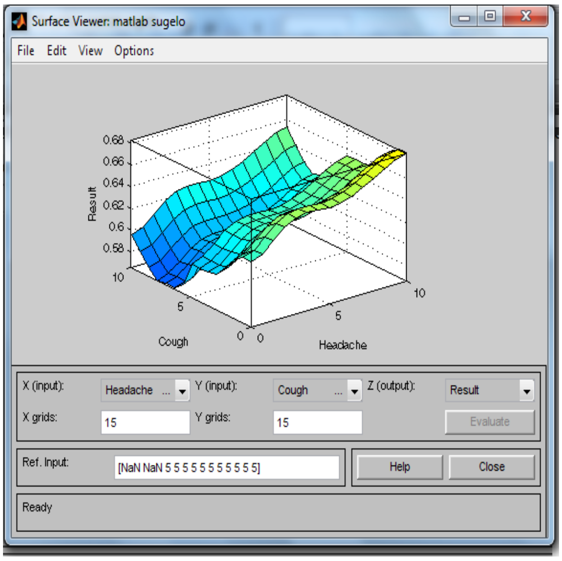

Figure 16. Surface Viewer and Simulation for cough and headache

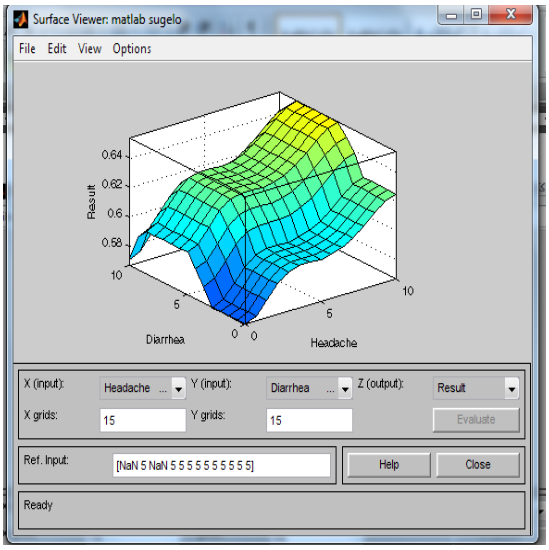

Figure 17. Surface Viewer and Simulation of cough and headache

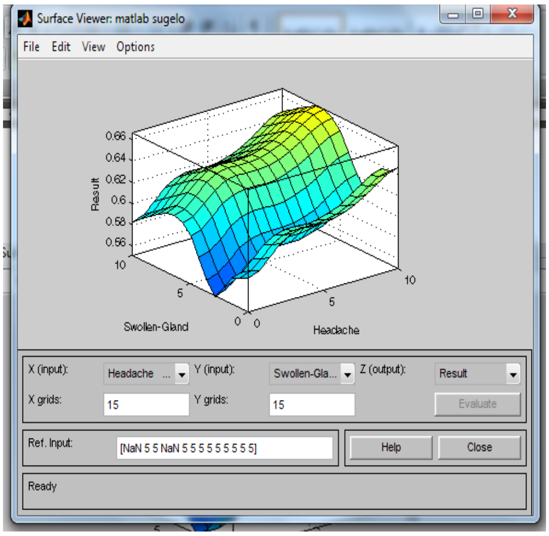

Figure 18. Surface Viewer and Simulation of Swollen Gland and headache

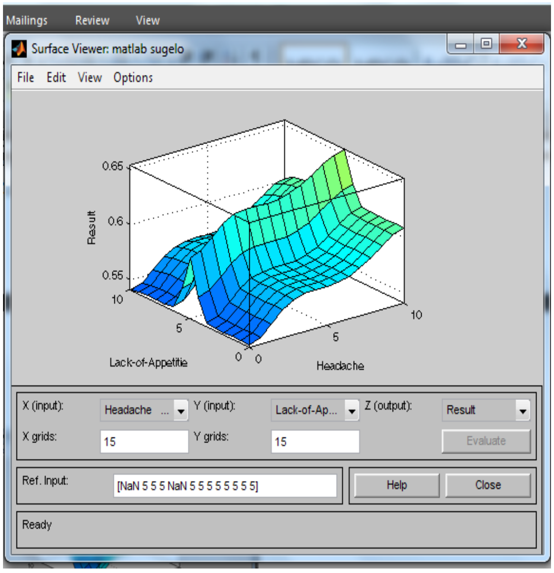

Figure 19. Surface Viewer and Simulation for Lack of Appetite and headache

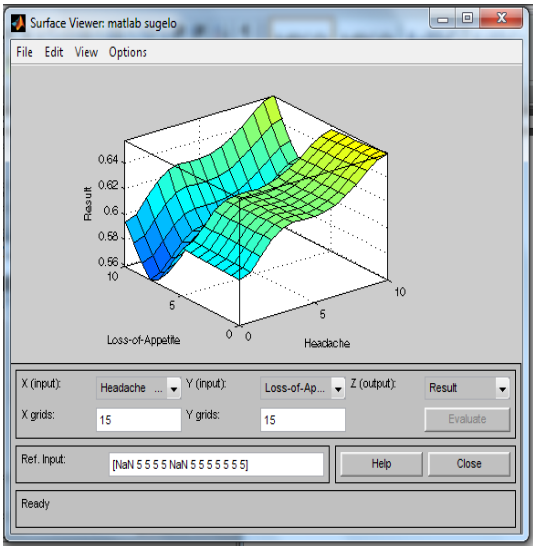

Figure 20. Surface Viewer and Simulation of Loss of Appetite and headache

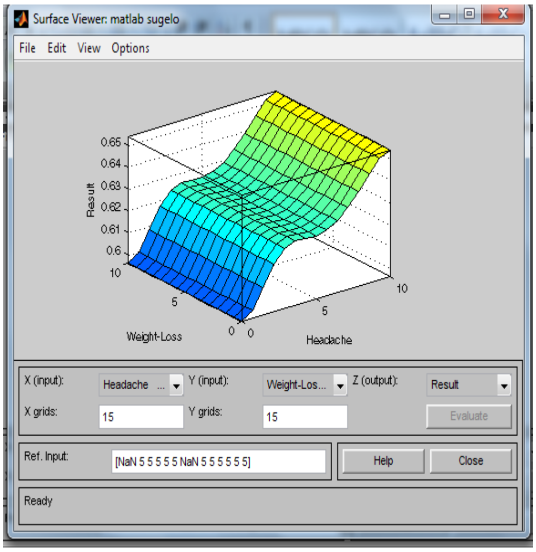

Figure 21. Surface Viewer and Simulation of Weight Loss and headache

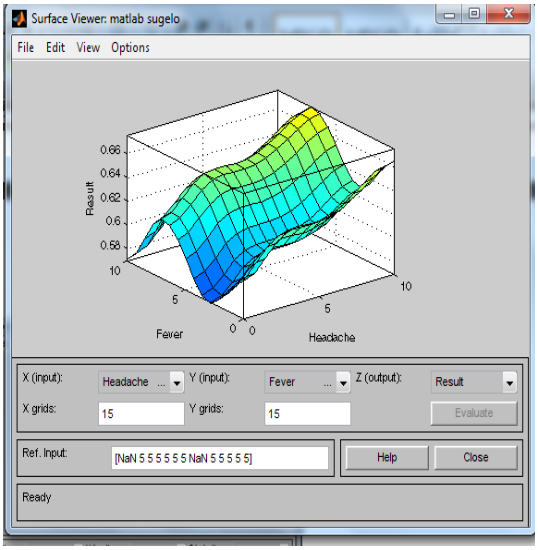

Figure 22. Surface Viewer and Simulation of fever and headache

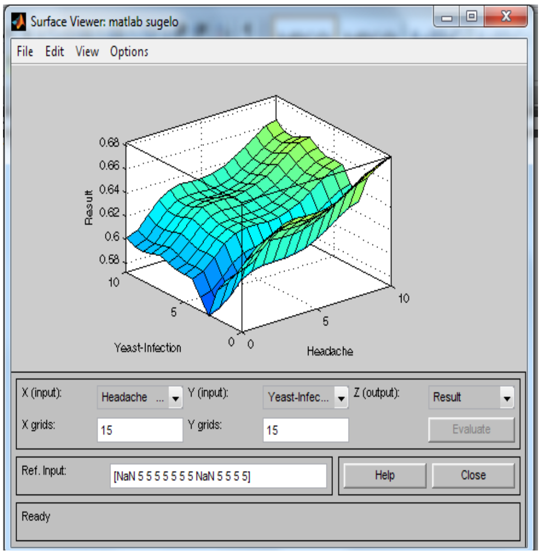

Figure 23. Surface Viewer and Simulation of Yeast Infection and headache

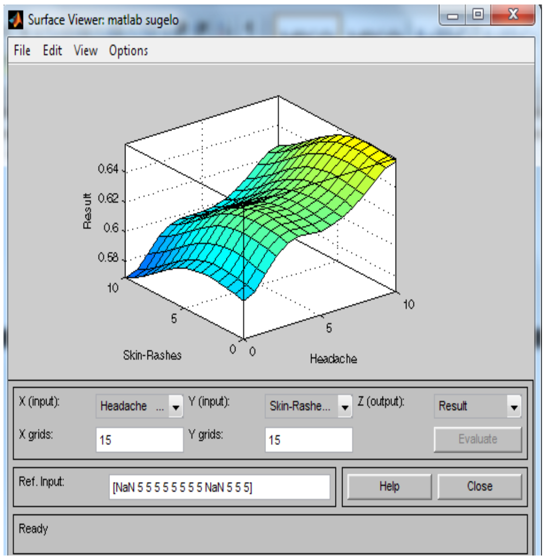

Figure 24. Surface Viewer and Simulation of Skin Rashes and headache

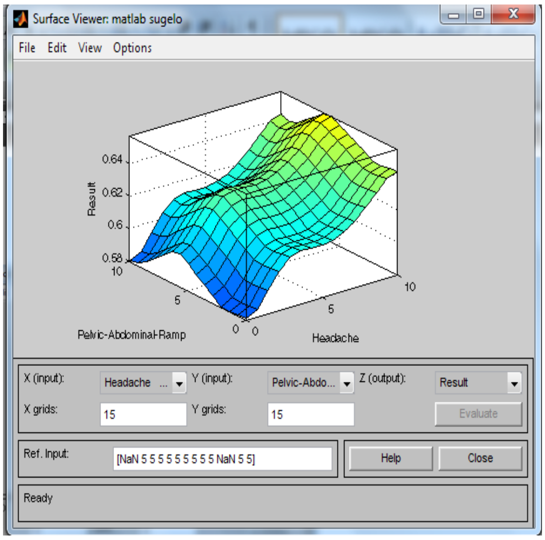

Figure 25. Surface Viewer and Simulation of Pelvic Abdominal Ramp and headache

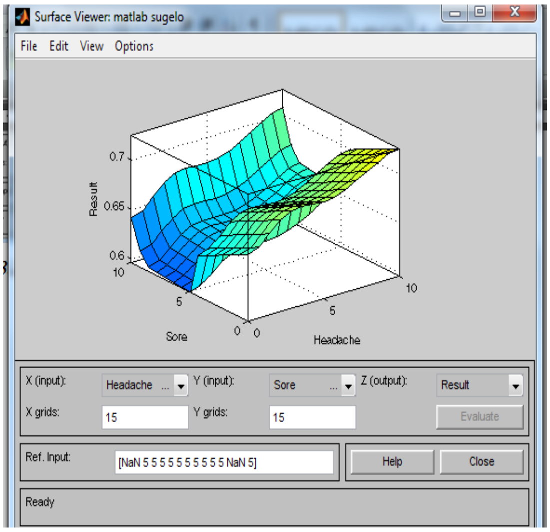

Figure 26. Surface Viewer and Simulation of Sore and headache

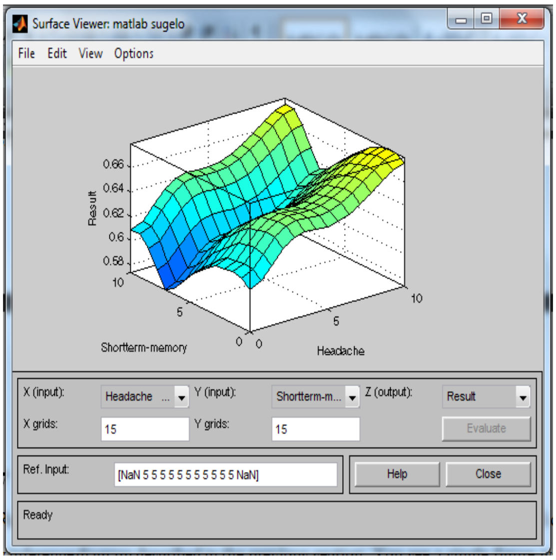

Figure 27. Surface Viewer and Simulation of Short term Memory and headache.

VI. CONCLUSION

The need to design a system that would assist doctors in medical diagnosis has become imperative and hence cannot be overemphasized and in this study, an Adaptive Neuro-Fuzzy Expert System for Diagnosing HIV has been presented. This study presents an Adaptive Neuro diagnostic fuzzy logic system to help in the diagnosis of HIV using a set of symptoms and demonstrates the practical application of ICT (Information and Communication Technology) in the domain of diagnostic pattern appraisal by determining the extent of membership of individual symptoms. This advanced system which uses a set of logic data set

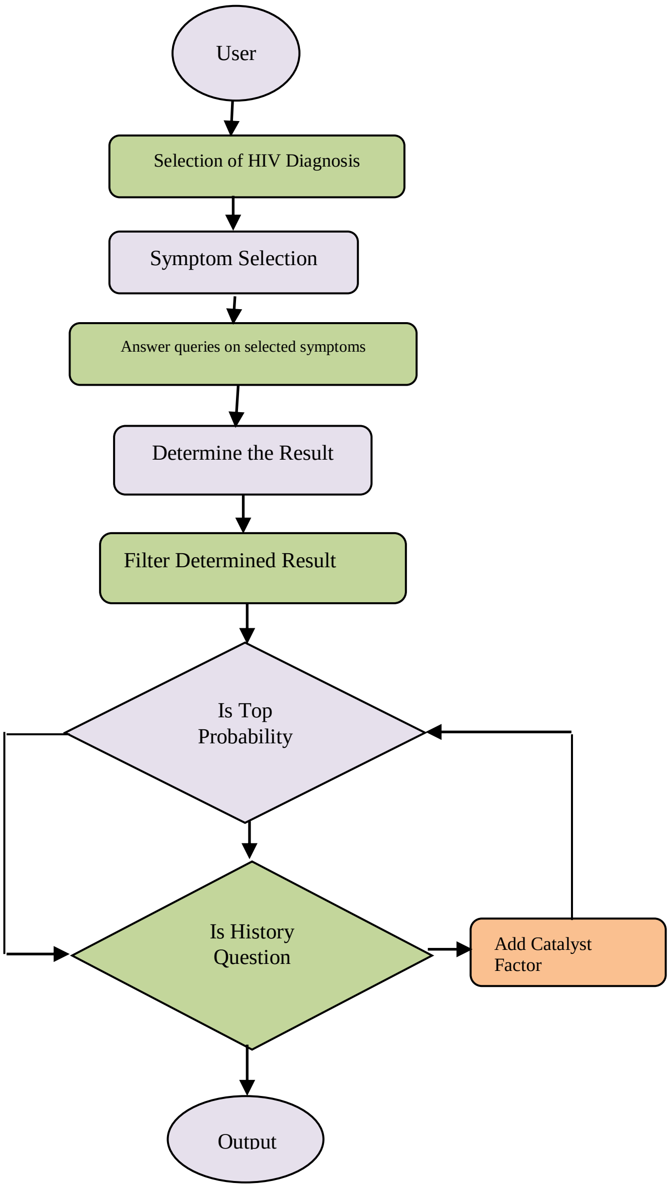

Figure 28. The flow diagram of the system

is more precise than the traditional system. The classification, verification, and matching of symptoms to the three groups of logic were necessary, especially in some complex scenarios. The Adaptive Neuro-fuzzy logic system has been tested and appears to be a more natural and intelligent way of classification and matching of symptoms to HIV.

IV. REFERENCES

1. Christian Nordqvist (2018). Explaining HIV and AIDS.

https://www.medicalnewstoday.com/articles/17131.php
2. WHO (2018). HIV/AIDS.
3. http://www.who.int/gho/hiv/en/
4. UNAIDS 2018 Fact sheet - Latest statistics on the status of the AIDS epidemic. http://www.unaids.org/en/resources/fact-sheet
5. Access Campaign (2010). The Ten Consequences of AIDS Treatment Delayed, Deferred, or Denied.
6. https://www.msfaccess.org/sites/default/files/MSF_assets/HIV_AIDS/Docs/AIDS_report_10consequences_ENG_2011.pdf
7. M Negnevitsky, (2005) "Artificial intelligence: A guide to intelligent systems", Addison Wesley Longman.
8. Shi, Y. and Eberhart, R. and Chen, Y., (1999) "Implementation of evolutionary fuzzy systems", IEEE Transactions on Fuzzy Systems, Vol. 7, No. 2, pp. 109 - 119
9. Pamela McCorduck (2004). Machines Who Think: A Personal Inquiry into the History and Prospects of Artificial Intelligence. AK Peters Ltd .ISBN:1568812051
10. Abraham, A. (2001) Neuro-Fuzzy Systems: State-of-the-Art Modeling Techniques, Connectionist Models of Neurons, Learning Processes, and Artificial Intelligence, in Lecture Notes in Computer Science, Vol. 2084, (eds. Mira., Jose and Prieto., Alberto) Springer Verlag, Germany. pp. 269 - 276.
11. Microsoft Encarta (2018). Microsoft Encarta - latest version 2018 free download
12. https://microsoft_encarta.en.downloadastro.com
13. Donald, W.A. (1986) A Guide to Expert Systems, Addison- Wesley, Boston, MA. horvitz@microsoft.com http://research.microsoft.com/~horvitz/ with eric horvitz 2006
14. Wilcox, AB (July 2012). "Gallagher KD, Boden-Albala B, Bakken SR.". Med Care. doi:10.1097/MLR.0b013e318259c1e7. Retrieved 12 May 2017.
15. Simon Kendal, Malcolm Creen (2007). An Introduction to Knowledge Engineering. Authors, Edition, illustrated. Publisher, Springer Science & Business Media, 2007. ISBN, 1846286670.
16. Amosa Babalola, Hameed Aderemi, Kawonise Kayode, Ekuewa Jacob, (2017). Fuzzy Logic means for Intelligent Diagnosis of Obstetrics Fistula Disease. International Journal of Electrical, Electronics and Computers (ISSN: 2456-2319).2(6), pp. 01-06
17. Wang, L.X. and Mendel, J.M. (1992) Generating Fuzzy Rules by Learning from Examples. IEEE Transactions on Systems, Man, and Cybernetics, 22, pp. 1414-1427.
18. http://dx.doi.org/10.1109/21.199466
19. DrIng. Habil. B. Möller. Uncertainty in Engineering, Fuzziness, 2005.
20. URL:http://www.uncertainty-in-engineering.net/uncertainty_models/fuzziness.