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A Novel IOT Based Smart Wheelchair Design for Cerebral Palsy Patients

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ABSTRACT

Several patients face Cerebral Palsy. Such debilitating diseases impede motor control and make it difficult for them to operate traditional electric wheelchairs. Existing models of smart wheelchairs accommodate these issues to a certain extent but fail to deliver a solution for patients to use the wheelchairs completely autonomously. This paper proposes a novel model for a cost-effective smart wheelchair that takes simple gestures as input for movement, along with several quality-of-life and assistive modules such as vitals monitoring and voice memo support for patients suffering from memory loss, along with obstacle detection to ensure complete safety of the patient regardless of the terrain. The paper discusses the various modules present in the wheelchair, elaborates upon the algorithm used for input detection and calculation, and finally, the implementation of each module. Lastly, the paper enlists comparisons between existing smart wheelchair models and the proposed model and lists out its strengths, weaknesses and states its findings from the proposed system's results.

Keywords : Cerebral palsy, Smart wheelchair, Gesture control, MicroBit, Node MCU, Internet of Things, Vitals monitoring system, Voice memo, Robotics, Sensor network

I. INTRODUCTION

The World Health Organization (WHO) estimates that almost 10% of the global population suffers from one or more forms of disability. In the case of India, this figure is close to 3.8% of the country's population. Nearly 15-20% of the total physical disabilities in children are caused by Cerebral Palsy (CP). In India alone, CP occurs in around 3 of every 1000 live births. However, the expected figure could be way higher given the fact that India is still a developing nation. The feeling of loss of autonomy that a person with disabilities experiences on a day-to-day basis is something that the rest of us often take for granted. A Cerebral Palsy patient is subject to many complications like restricted muscle movements and frequent loss of memory. People with Cerebral Palsy may have uncontrollable muscle spasms, rigid muscles, and occasionally, tremors. People with severe Cerebral Palsy have trouble swallowing, breathing, eating, controlling their bladder and bowel movements, and face digestive and dental disruptions. Recently, significant efforts have been made, as documented in [2] and [7], to solve any difficulties between human and PC-based systems by making collaborations (which previously relied on information devices such as consoles and mic) as natural as possible with motion controls. Signal acknowledgment is useful for processing data from people that aren't transmitted by speech or type. Joystick, EEG, Image Processing are some of the various methods that have been used to solve the issues faced by these patients. This paper attempts to alleviate the conditions faced by these patients through the proposed smart wheelchair model, which aims to provide these patients with some degree of autonomy in a cost-effective manner. The proposed system aims to alleviate the ordeals faced by these patients. The proposed smart wheelchair has state-of-the-art sensors built into it to ease movement and track health on the go. It has a built-in gesture sensor that can recognize hand gestures and move the wheelchair accordingly with obstacle avoidance. Due to limited muscle movement and an occasional presence of learning disability, the proposed system relies on a simple and intuitive gesture-controlled system that requires minimum effort and provides the patient with a greater degree of control over their movement. This is accompanied by a voice memo system that makes it possible to keep track of information that the patient might potentially forget. Additionally, a vitals monitoring system is employed within the proposed model to keep track of patients' vitals and send alerts to designated personnel in case of an anomaly. The vitals monitoring and voice memo modules are implemented within the companion Android application for the wheelchair.

II. RELATED WORK

The traditional wheelchair needs to be pushed, but that isn't required anymore with the technological advancements. The invention of the electric wheelchair provides several options for moving the chair. The typical electric wheelchair uses finger-operated buttons that might become difficult for such individuals to use because of the various involuntary movements, as indicated in [1]. So, to overcome this problem, a joystick was employed. It is usually used in combination with an accelerometer. The joystick provides a simple method to move the wheelchair with no training required, as shown in [2]. Although a joystick is susceptible to the involuntary movements a Cerebral Palsy might have, various methods were employed to improve the user experience. [1] introduces some experimental changes made in the design such that the whole hand is gripping the joystick with a strong grip. It allows the person to rest his hand in the proximal transverse arch to find an efficient and comfortable position. Moreover, there is a middle layer that absorbs shocks in case of some involuntary movements. [3] takes a different approach. It proposes to tackle the involuntary movements using an adaptive involuntary attenuation filter. Synthetic velocity is taken as a parameter for the filter that tells how strong the involuntary movement is. The movement is attenuated accordingly. Its real-time application is a bit impractical because correction is time-consuming. With the advancement of smartphones, a mobile interface can replace joysticks[4,5]. The mobile interface can track the location of the patient for any medical emergencies. [6] Proposes eye gaze as navigation which is a new navigation method. There are usually three modes of eye gaze navigation. These can be tested by creating a VR environment. The methods dwell on buttons placed on an overlay display for direction, looking at a particular point in the direction where one wants to move, and waypoint navigation. The experiments concluded that the waypoint method of navigation is the most comfortable one out of the three. A hands-free approach of using a brain control interface has been a new addition to the existing methods. It uses EEG (Electroencephalography), a non-invasive activity that uses signals from the brain to help move the wheelchair. The EEG signal is encoded into the direction that the patient wishes to traverse in. The headset used to encode the brain signals is light, and this use of technology will help in the independent lifestyle of physically challenged patients, as done in [7,15]. This method may cause unnecessary commands. To solve this problem, there can be multiple methods used in conjunction to improve the accuracy. One such method is to use the combination of BCI and eye gaze tracking system, as an input, for controlling the electric wheelchair. The system receives EEG data and processes it using appropriate functions. Apart from this, the system looks for changes in eye gaze, takes that as an input, and combines the two results to perform the appropriate function. The combined command is then shown in a graphic user interface to let the person know what is happening. The cursor must be kept at the specific command for the time duration to move the wheelchair. There is a thread running every 20 milliseconds that checks for the current command. The fusion of BCI and eye glaze helps in reducing unnecessary commands and resolving the 'Midas touch' problem. It is still not a safe enough option for use, according to [8]. Another limitation is difficulty in operation for an inexperienced user, which is indicated in [9]. Giving voice commands using the smartphone is another possibility. As shown in papers [9,10], the user gives commands on the mobile app, and then the data is sent to the wheelchair using Bluetooth. This may give rise to concerns regarding latency because of data transfer and voice modeling, but with a better implementation, it can be very intuitive. "Adremo Head/Foot System" model proposes a simple mechanism, where the feet pedals are used to determine the acceleration of the wheelchair, and the head movement determines the direction in which the wheelchair is to traverse. These inputs are then synchronized for a smooth experience. To monitor the various movements and create a personal feel for a specific individual, 5 IMU sensors are placed on the limbs and head of the person, allowing appropriate changes. This has a better response to sudden strong involuntary actions, according to [11]. The method that the proposed system will be using involves hand gestures. The proposed model implements it using MicroBits. Other implementations use microcontrollers like Arduino UNO and sensors like MPU6050, as suggested by models in papers [2, 12, 13]. There are various implementations for hand gestures, like placing a sensor on hand that looks into the navigation, as proposed in [16]. IMG sensor is also used. EMU is a sensor placed on the hand of the user, as shown in [19]. This requires the sensor to be on hand at all times. The implementation in [22] takes a step forward in the wireless direction by removing wired connections in the sensor and microcontroller. One feature of every electric wheelchair should be obstacle detection and collision prevention. This makes the wheelchair safer in case of sudden strong involuntary motion or any hardware failure. There are various methods to implement object avoidance. It could be done by various algorithms such as YOLOv3(You Only Look Once), as displayed in [14,15]. This is used for object detection. Then to estimate the depth of the object, the model [14] proposes using Intel RealSense. In the end, using a sorting algorithm, the objects are tracked. There is a huge dataset being used in this project. It involves objects as small as doorknobs for training the model. Monodepth is used for calculating the distances. Another method uses IR sensors to automatically stop the wheelchair when there is an object near the wheelchair. This has been used in [10]. IR sensors can be replaced by ultrasonic sensors as well, which is used in [18,20]. According to [9], various sensors can be used to monitor a person's vitals. The health vitals are Oxyhemoglobin saturation (SpO2), sweat rate, heart rate, glucose content in the user's blood.

An alert system is a mechanism that allows people other than the user to know specific details about a user when the values cross a certain threshold. For instance, in paper [25], a person's location can be sent via SMS in a confined region as and when required. Vital monitoring on a wheelchair can be a lifesaving feature as it asserts the condition of the patient. The importance of monitoring is implied in [21]. The pressure-measuring sensors are located in strategic spots to offer a smooth and seamless experience, like a chair rest, chair seat, and footrest, as done in [23]. There are other sensors to measure temperature and humidity(sweat) from the cushion of the wheelchair, like in [17]. Other sensors that can be used include the LiDAR RGB camera, as proposed in [26]. Existing high-end technologies can create obstacle-avoidance models like point clouds, for which we use laser 3D modeling, as shown in [24]. [27] proposes a cost-effective and simple design for a smart electric wheelchair. It is equipped with onboard sensors for obstacle detection. It also features an Android smartphone repurposed for GPS navigation in real-time for the wheelchair user.IMUs that are placed on the patient's body. Logging of sensor values helps to keep track of the movement, and all the values are logged. To fill this research gap, further developments can synchronize/ calibrate the difference in waves obtained from patients with a healthy person, and find a way to trigger the movement better for patients, by shifting waves either ahead or behind the timeline.[30] Some systems have used socially assistive robots that assist the motor limitations in a child at an early age.[28] Another system proposes a solution featuring an exoskeleton of a 3 DOF Robotic Arm that has 3 joints: shoulder abduction, shoulder flexion, and elbow. These joints are connected to force detecting resistors to provide uniformity in movement by making use of feedback. The movement in [29] is triggered based on these force resistors, and each exoskeleton is tailored to the patient it is designed for.

III. PROPOSED MODEL

The electronic components and sensors used in the proposed system are mentioned as follows:

2 MicroBit microcontrollers, 2 Node MCU modules, Grove Shield Gesture Sensor, 4 HCSR04 Ultrasonic Sensors, 1 EC:0567 PulseRate Sensor, 1 TMP36 Temperature Sensor, 12V 220Ah Battery, 2 Ebike MY1016Z3 24V 350W Gear DC Motors, 2 Dual Channel DC Motor Drivers.

Each module of the smart wheelchair, its respective configuration, and the sensors required are described below. The proposed model's design, along with the Android companion app, has been evaluated using Nielsen's 10 heuristics for User Interface Design, broad rules of thumb to ensure easy-to-use interfaces for different types of users.

A. Voice memos

Voice memos allow the users to record and replay information at will, reducing the burden on the user's memory. Saving the voice memo is made possible through the means of a companion Android application. The same app displays real-time health vitals.

B. Microcontrollers

The microcontrollers are primarily used for input recognition and computation in the context of smart wheelchairs. In the proposed system, a decision was made to opt for the BBC MicroBit, an open-source ARM-based embedded system designed by the BBC in the United Kingdom, over the Arduino and the Raspberry Pi systems, which have been adopted by most of the existing models. The grove module installed inside the MicroBit helps retrieve a gesture as an input from the user, which is then displayed on a hexadecimal display on the MicroBit itself. Upon receiving the input gesture, a number, unique to each gesture, is assigned and passed via a radio channel onto another MicroBit, connected to the actuating motors and motor driver. Then, the number is interpreted by the receiving MicroBit, and a unique action is suggested. The motors then make the wheels move accordingly. The user will be able to move the wheelchair left, right, forward, or stop. The Ultrasonic Sensors, situated on all 4 sides of the wheelchair, detect obstacles in real-time and prevent collisions.

C. Battery

The battery used in the proposed system is a pair of 220 Ah - ILTT26060 units, connected in series to decrease the overall expenditure on the battery and increase the operating time of the wheelchair on a single charge. It has a 220 Ah capacity and a voltage of 12V. It is a lead-acid battery, which has a long backup power.

D. Hand gesture

The gesture is used as an input to assign and transmit values via the radio channel to the receiving MicroBit. The receiving MicroBit then recognizes the value and suggests a movement so that the wheels are activated. For example, the gesture Up assigns 1 and transmits it via the radio channel to the receiving MicroBit. The receiving MicroBit knows that 1 suggests a forward movement, so both the wheels are given a high power signal, and the wheelchair moves forward. Similarly, Left assigns 4, Down assigns 3, and Right assigns 2. For a pivot turn, only one wheel is activated, and hence a turn is made possible.

E. Motors

The wheel movement is made possible using 2 Ebike 24V 350W Gear DC Motors. The calculations for the torque, power, current, and angular velocity requirements have been done based on the expected load (user and the structure of the wheelchair, assumed to be 100 kilograms), maximum incline at which the wheelchair may ascend (assumed to be up to 20 degrees), expected velocity of the chair (0.7 m/s), desired acceleration (0.1 m/s^2) and desired operating time (12 hrs).

F. Motor drivers

SmartElex 30D is a dual channel motor driver rated for up to 30 amperes of continuous current supply. It has the capability of withstanding peak currents as high as 85 amperes (2s) per channel. This is used to regulate the amount of current to be transmitted to the motors. The voltage rating and current requirements of the motors aided in this decision of choosing the motor driver.

G. Vitals monitoring

A person's vital signs are important indicators of their health at any given time. The two main vital signs recorded by the proposed system are pulse rate and body temperature. The application that the system is using displays real-time health vitals. Every time the user's vitals threshold is breached, an alert is sent to the respective emergency contact from the companion Android application.

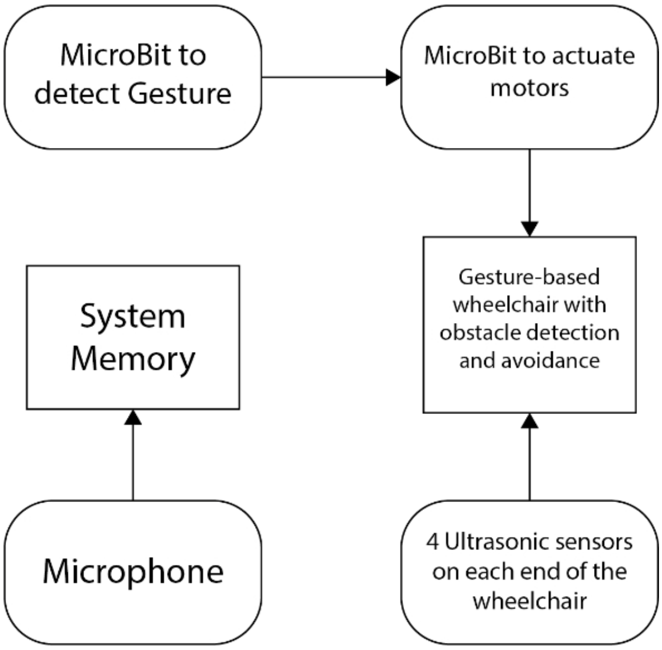

Figure 1. The flow of control of the onboard microphone, input gesture sensor, and ultrasonic sensors, and their interactions with the user and the environment

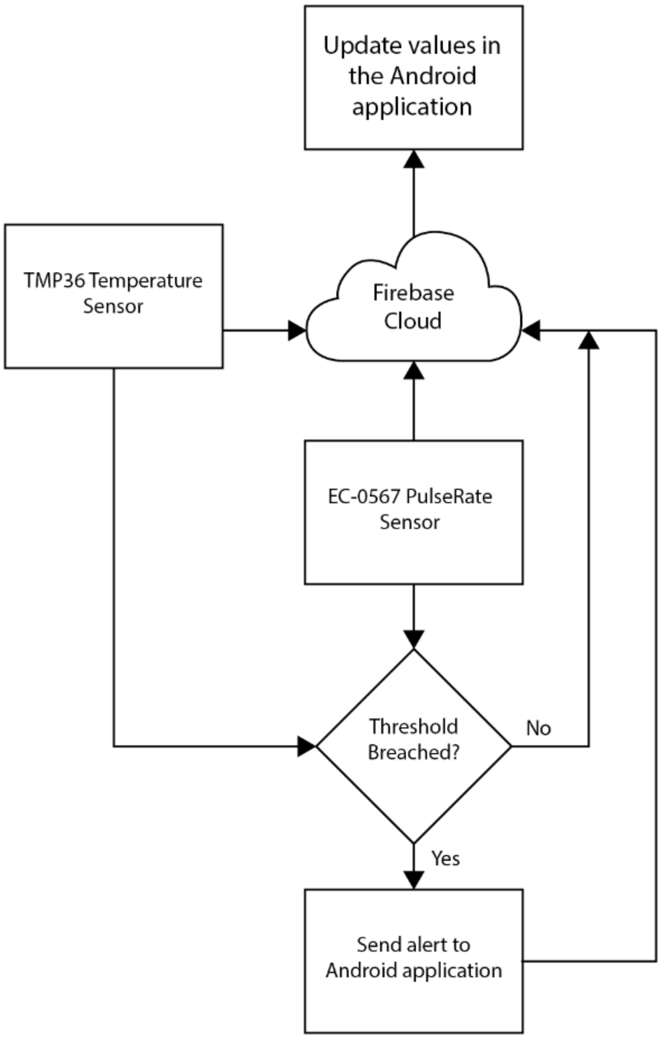

Figure 2. Flow of data within the system

Algorithm

1) Setting up the radio channel: For radio connection, a particular number to the connection is assigned at random. Then this line of code is input into both MicroBits, one of which parses the gesture recognition, and the other actuates the motors. Radio.setGroup(n).

2) Parsing the gesture input received from the user: We then process the accepted gesture input and encode it as the desired movement of the wheelchair in that particular direction. Then the command to trigger movement of the wheelchair in a path appropriate to the gesture is transmitted over the radio channel. For example,

- Input: Right Gesture // different value for different gesture
- Initialize: x=2
- Output: String R is displayed on the MicroBit
- Process: Transmit x over the radio channel to the receiving MicroBit

The essence of this step is to map a gesture to its corresponding number and transmit it to the receiving MicroBit so that the receiving MicroBit knows what action it's supposed to perform based on the gesture. In this example, the output displayed on MicroBit's 5*5 display is R. This is because the given gesture is right. The initialized integer x(=2) is transmitted over the radio channel to the receiving MicroBit using the line radio.sendNumber(x).

3) Activating the actuators: Now, configure the powering of the motors using the digital PINs based on the input number received from the transmitting MicroBit.

- Input: x from the transmitting MicroBit
- Output: Powering the Digital Pins connected to the motors based on the value of x, Displaying a directional arrow in case of movements right, left, and forward or displaying an icon whenever the down gesture is given to halt the Wheelchair.

The value of x corresponds to a movement. For example, x=2 implies a right movement. So, P1 has been assigned as 1 (HIGH), while the rest of the pins are still 0 (LOW). The pins P1 and P11, when high, move both the right and left wheels clockwise, respectively, hence, moving the wheelchair forward. The pins P13 and P14, when high, move both the right and left wheel anticlockwise, respectively, hence, moving the wheelchair in a reverse motion. The pins are set as 0 whenever the input gesture is down and whenever any obstacle is detected so that the wheelchair is brought to a halt. When a single pin is set to 0, it signifies that the movement is restricted to one wheel. So, this is done to make the chair turn in either direction based on the input received from the first MicroBit that took the gesture as an input. Similarly, for each input gesture, an x value is produced and transferred over the channel so that the receiving MicroBit can accordingly power the required pins to run the motors.

4) Obstacle Avoidance: Install 4 ultrasonic sensors on the left, front, back, and right of the wheelchair. This is done to detect obstacles and prevent collisions automatically. Whenever the proximity threshold gets breached, the down gesture function is called, x is assigned as 3, sent over the radio channel, and the wheelchair stops.

input is then displayed on a 5*5 LED Dot Matrix in the form of a directional arrow.

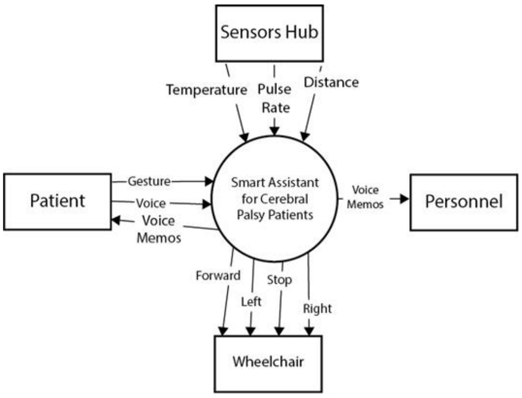

Figure 3. A block diagram depicting the flow of data

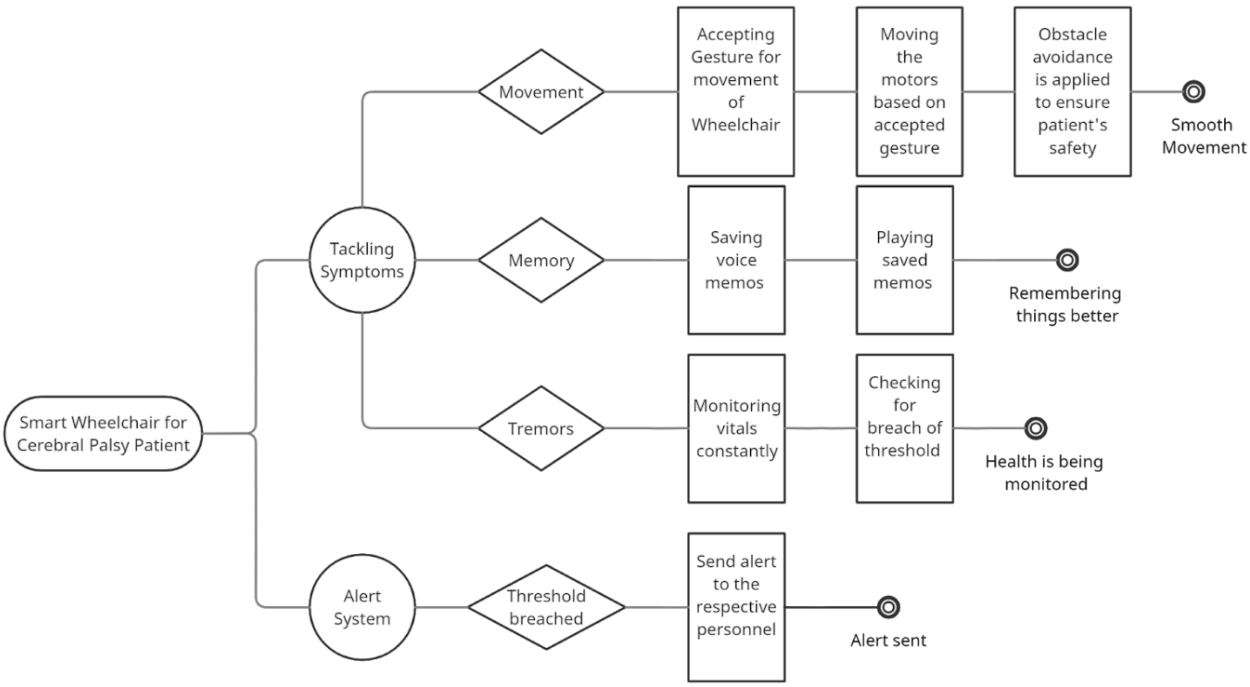

Figure 4. A block diagram depicting the various modules of the wheelchair

IV. IMPLEMENTATION

The wheelchair works on a power supply that powers up the motors and the microcontrollers involved in the system. The proposed system comprises two MicroBits. One accepts and processes the user's hand gesture as input, and the second actuates the motors to move the wheelchair in the desired direction. The processed

V. RESULTS AND DISCUSSION

In this section, various hardware components of the proposed model, and four other models from [7, 10, 11, 27], are compared and tabulated in Table 1. This is followed by a comparative study of various microcontrollers used by the referred models, along with an evaluation of their strengths and weaknesses.

Finally, a comparison study tabulating the various modules implemented in each model is performed, proving that the proposed model accommodates almost all the modules that are partially implemented by the other models when factors like the cost-effectiveness of the model as a whole are considered.

A. Comparing microcontrollers used in the contemporary model with the proposed model

The proposed model was developed after identifying the BBC MicroBit as the ideal choice for the solution. This is because MicroBit provided a suite of benefits most suited to the proposed model. It has greater processing power than an Arduino Uno while being cheaper than a Raspberry Pi. Table 2 summarizes and compares the technical specifications of the Arduino Uno, BBC MicroBit, and Raspberry Pi 3.

Figure 5. Logging the recorded values from vitals sensors on Firebase

TABLE I

Comparing microcontroller specifications

Category	The Proposed Model	Keerthi Kumar M et al.[7]	AKM Bahalul Haque et al. [10]	Dakhilallah et al. [27]	Sarnali Basak et al. [11]
Input Transmitter	MicroBit	Arduino Uno	Arduino Nano	Arduino Uno	Raspberry Pi 3
Input Method	Hand Gesture	EEG (Brain-Computer Interface)	Hand Gesture, Voice recognition	Joystick	Hand Gesture
Input Sensor	Grove Shield for BBC micro:bit v2.0	Neurosky Headset	MPU6050 Accelerometer	Joystick, smartphone	Skywriter HAT
Input Receiver	MicroBit (separate)	Arduino Uno (doubles as transmitter and receiver)	Arduino Mega 2560	Arduino Uno (doubles as transmitter and receiver)	Arduino Mega
Programming Software	JavaScript	Matlab R2018b, Arduino IDE (C++)	Arduino IDE (C++)	Arduino IDE (C++)	Python, Arduino IDE (C++)

Obstacle Detection Sensors	4x HCSR04 Ultrasonic Sensors	None Specified	IR LED along with Sharp GP2YOA21 YK0F Position Sensing Device (PSD)	1x HCSR04 Ultrasonic Sensor	Not specified
Power	12V Battery 220 Ah - ILTT26060	12V Battery	12V Battery	Unspecified	12V Battery
Wireless Protocol	Bluetooth, Radio	Bluetooth (Neurosky proprietary)	Bluetooth	WIFI (only when using a smartphone)	Bluetooth, GSM (For emergency text feature)
Vital Monitoring sensors	EC-0567 Pulse Rate Sensor, TMP36 Temperature Sensor	No vitals monitored	No vitals monitored	No vitals monitored	No vitals monitored
Motor Driver	Dual Channel DC Motor Driver	L293D motor driver	BTS7960 Motor Driver	DROK 16A Dual Channel H Bridge Motor Driver	BTS7960 (IBT-2) motor driver
Voice memo support	Yes (Collar Mic)	No	No	No	No

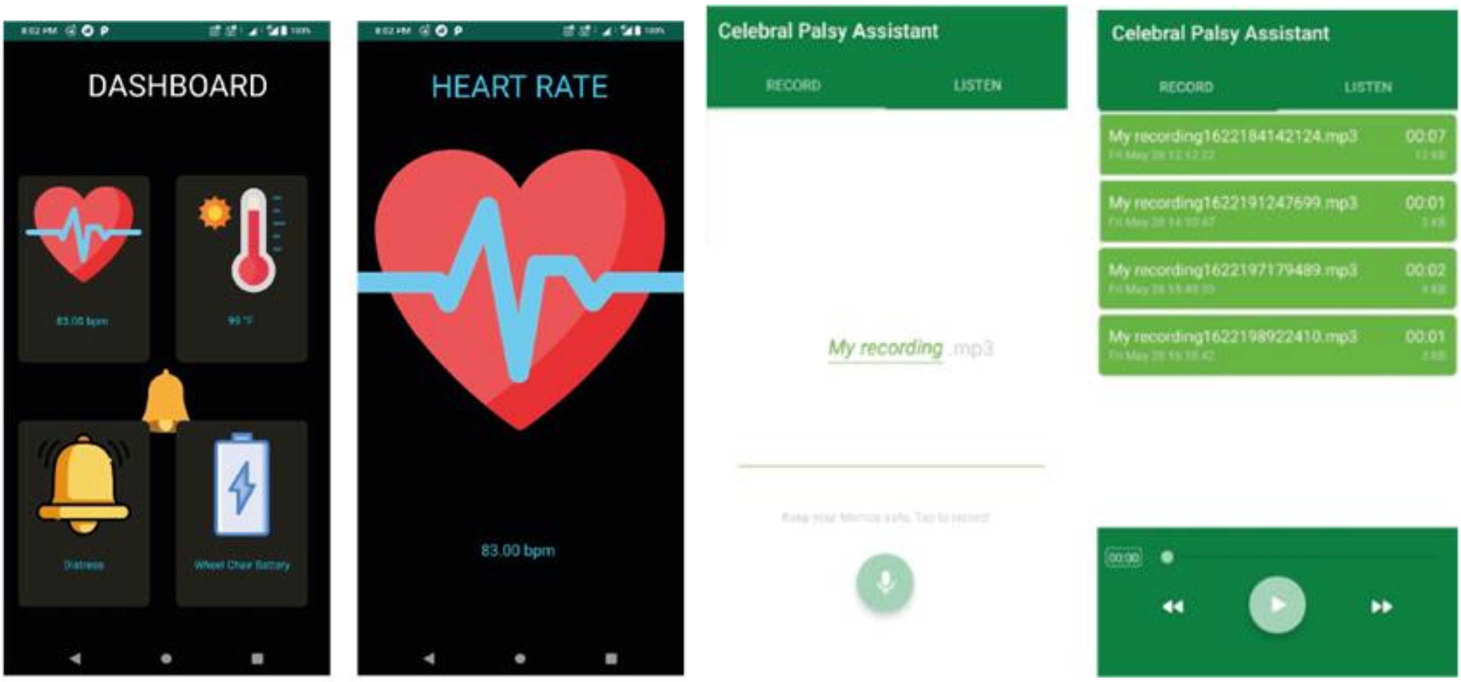

Figure 6. Views of the companion Android application

TABLE II

COMPARING MICROCONTROLLER SPECIFICATIONS

Metrics	BBC MicroBit	Arduino Uno	Raspberry Pi 3
CPU	nRF51822	ATmega328P	BCM2837
Processor	32-bit ARM Cortex M0	8-Bit AVR	64-Bit ARM Cortex A53
RAM	16KB	2KB	1 GB
Flash ROM	256KB	32KB	External Via microSD
Clock Speed	16MHz	16MHz	1200MHz
LEDs	5x5 LED Dot Matrix	1 (PIN 13)	None
GPIO	19	13	40
Buttons	2 Programmable	None	None
Accelerometer	Built-In	None	None
Digital Compass	Built-In	None	None
Bluetooth	Built-In	None	Built-In
Wi-Fi	None	None	Built-In + Ethernet
Power	USB or Battery Case	USB or AC Power	AC Power
Programming Language	Blockly, Python, C++	C Based	Debian-Based OS

B. Comparing modules implemented in contemporary models with the proposed model

Table 3 comprises the results of a survey conducted to find the modules implemented. As evident, the proposed model encompasses all modules implemented either in part of not at all in contemporary smart wheelchair systems.

C. Comparing communication protocols used by contemporary models

Table 4 details the communication protocols and technologies used by the contemporary models, including the proposed model. It is inferred that Bluetooth Low Energy (BLE) is the most widely adopted and the most efficient communication protocol used in smart wheelchair models. Results affirm that the proposed model is the most comprehensive model of all those studied. The velocity is configured such that no jerks be experienced. Several tests were developed and conducted to gauge the efficacy of each conceptualized component of the proposed model.

TABLE III

Comparing modules present in each model

Models	Gesture input	Vitals	Obstacle avoidance	Memos	Alerts
Proposed Model	✓	✓	✓	✓	✓
Jingsheng Tang et al. [15]			✓		
Samuel Oliver et al. [16]	✓				

Yu-Sheng Yang et al. [17]		√			
Sudipta Chatterjee et al. [18]			√		
Kundu AS et al. [19]	√				
Hayder Fadhil et al. [20]			√		
K. Sakthivel et al. [21]		√			
Fahd N. Al-Wesabi et al. [22]	√				
Cátia Tavares et al. [23]		√			√
Díaz-Vilariño L et al. [24]			√		
P. Upender et al. [25]	√				√

TABLE IV

Comparison between communication protocols used by contemporary models

Models	**Hardware used**		**Network protocol**	**Communication technology**			
	Microcontroller used	**Other modules**		**Type**	**Frequency**	**Throughput**	**Latency**
Proposed System	BBC MicroBit v2	NodeMCU	MQTT	Bluetooth 5.1 with Bluetooth Low Energy (BLE)	2.4GHz	0.27-1.37 Mbit/s	6 ms
Y. Ogata et al.[1]	Arduino Uno	USB 2.0 (via CP2102 bridge controller)	N/A	USB 2.0	N/A	480 Mbps	N/A
K. Rahimunnisa et al.[2]	Arduino Uno	HC-06 Bluetooth module	Not specified	Bluetooth Low Energy (LE)	2.4GHz	0.27-1.37 Mbit/s	6 ms
Motoyu Katsumura et al.[3]	Arduino Nano	RF Transmitter	None	Radio Frequency (RF) transmission	433.92MHz	Not Specified	6 ms
E. N. S Alenzi et al.[5]	Arduino Uno	Not Specified	WiFi	Bluetooth	Not Specified	Not Specified	Not Specified
Keerthi Kumar M et al.[7]	Arduino Nano	HC-06 Bluetooth module	Not specified	Bluetooth Low Energy (LE)	2.4GHz	0.27-1.37 Mbit/s	6 ms

Yu-Sheng Yang et al.[17]	Arduino Mega 256 R3	Bluetooth (BT) module	Not Specified	Bluetooth	2.4GHz	0.27-1.37 Mbit/s	6 ms
Kundu AS et al. [19]	Arduino Uno	ZigBee Transceiver	Not Specified	ZigBee	2.4GHz	250Kb/s	>4 ms
Hayder Fadhil et al. [20]	Arduino Mega	HC-06 Bluetooth module	Not Specified	Bluetooth 5.1 with Bluetooth Low Energy(BLE)	2.4GHz	0.27-1.37 Mbit/s	6 ms

Models	**Proposed System**	Y. Ogata et al. [1]	K. Rahimunnisa et al. [2]	Motoyu Katsumura et al. [3]	E. N. S Alenzi et al. [5]	Keerthi Kumar M et al. [7]	Yu-Sheng Yang et al. [17]	Kundu AS et al. [19]	Hayder Fadhil et al. [20]
Data Rate	125 kbit/s, 500 kbit/s, 1 Mbit/s, 2 Mbit/s	480 Mbps	125 kbit/s, 500 kbit/s, 1 Mbit/s, 2 Mbit/s	10Kbps	Not Specified	125 kbit/s, 500 kbit/s, 1 Mbit/s, 2 Mbit/s	1–3 Mbit/s	20/40/250 kbps	125 kbit/s, 500 kbit/s, 1 Mbit/s,

VI. CONCLUSION

In this paper, a novel smart wheelchair design has been proposed for Cerebral Palsy patients and other debilitating diseases patients. The modules are elaborated upon, along with their configuration and interconnectedness with other modules present. Through various comparison studies with existing models for smart wheelchairs, this paper can confidently say that the proposed model is a cost-effective and exhaustive solution for patients, developed using easily procurable components.

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