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# Enhancing Independence: Innovating an IoT-Integrated Wheelchair for Mobility and Health Monitoring in People with Different Abilities: A Prototype

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ABSTRACT

*Wheelchair is an essential tool for people with disabilities, enabling them to move around independently and participate fully in society. They come in different types, such as manual wheelchairs, power wheelchairs, sports wheelchairs, and pediatric wheelchairs among others. Certain types of disabilities such as Monoplegia, Hemiplegia, Paraplegia, and Quadriplegia pose difficulties in using conventional power wheelchairs. To overcome these hurdles and provide ease to differently-abled individuals, an Advance Monitoring and Assistive Wheelchair (AMAW) is proposed in this work. The Prototype includes a voice-controlled system for controlling the movement of a wheelchair, an IoT-based real-time health monitoring system to monitor the vitals of the patient remotely, a fall detection system for detecting falls, a tracking system for position and location, and an alarm system to alert caretaker in case of a fall. The real-time embedded monitoring system allows the monitoring of the user's vital signs like temperature, pulse rate and oxygen saturation and the assistive part allows the wheelchair to move around electronically either through voice or through mobile application. With the assistance of various sensors, the data can easily be monitored remotely by the caretaker at regular intervals of the time. The data display on the LCD fitted onto the wheelchair and in the designed mobile application. Furthermore, the whereabouts of the user are sent via the alert system that notifies the caretaker through GSM in case of changes in parameters and if the user has lost the balance. The vitals through the sensors on the prototype has undergone testing on number of individuals with precise outcomes. In comparison to typical joystick-controlled wheelchairs, this project excels in several aspects, such as its ability to stop or turn using voice commands and avoid collisions with people, furniture, fixed objects, and walls. The user friendly AMAW prototype with real-time monitoring, assistance and alert system may serve as a cost-effective solution in maintaining and providing an independent quality life to differently-abled individuals.*

KEYWORDS

Voice controlled wheelchair, IoT based Health monitoring, fall detection, Alert system, GPS, GSM.

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## INTRODUCTION

Presently, 15% of the world's population is disabled and approximately 10% of people with disabilities require wheelchairs [1]. The increasing demand for wheelchairs is due to old age, accidents and due to non-communicable diseases [2] resulting in lifelong disability such as Monoplegia, Hemiplegia, Paraplegia, and Quadriplegia. Spinal cord injuries (SCI) is among the major cause of disability leading to wheelchair use as the primary mode of transportation for individuals with SCI [3]. Individuals with disabilities may choose to use different types of wheelchairs based on their individual needs that fits them well and satisfies their unique needs in order to ensure successful mobility. While manually controlled wheelchairs can be difficult to operate and require assistance from others, electrically controlled wheelchairs are available to reduce the need for manual pushing and provide a joystick for control [4],[5],[6]. Users with motor system complications in their limbs are unable to freely control these wheelchairs and hence there is an overwhelming need for smart wheelchair[7]. Technology and services in the healthcare industry are developing swiftly and researchers are nowadays working hard on smart wheelchair-controlling systems for those who cannot use MW or EW [8].

In recent years, there has been a remarkable surge in research and innovation at the intersection of smart wheelchairs, assistive technologies, and healthcare, driven by the rapid advancements in the Internet of Things (IoT) technology. This convergence has paved the way for transformative solutions to enhance the lives of individuals with disabilities and the elderly. Notable examples include the first autonomous wheelchair by Madarasz et al [9]., which utilised sonars for corridor navigation and employed a topological-based language for navigation. Levine's NavChair [10] offered shared control decisions with users and featured capabilities like doorway passing, wall following, and automatic obstacle avoidance. Tin Man I and Tin Man-II [11] introduced multiple modes of operation, such as obstacle avoidance, wall following, and backup functions. The cyber-physical wheelchair has cloud-based speech control, introducing a novel approach to complex cyber-physical systems that relies on cloud APIs for speech recognition and allows disabled individuals to navigate the wheelchair using speech commands [12]. Another part introduces a smart wheelchair controlled by eye blinks, incorporating advanced image processing and Raspberry Pi technology [13]. The wheelchair's movements are wirelessly transmitted, offering seamless eye-controlled navigation and an obstacle recognition system. Moreover, a camera-based system that detects eye movements, processed through MATLAB and Arduino to control the wheelchair's motor driver, enables eye-controlled navigation and obstacle detection using ultrasonic sensors, aimed at enhancing user independence and performance [14]. Lastly, an intelligent robotic arm and wheelchair operated by an innovative EOG-based HMI, allows individuals with severe spinal cord injuries to control both the wheelchair and robotic arm [15].

Advanced Monitoring and Assistive Wheelchair has various advantages over other smart wheelchairs. This voice-controlled wheelchair prototype provides greater convenience and autonomy to individuals with disabilities, especially those with upper and lower limb impairments by using their voice to move in specific directions. This eliminates the need for manual controls and assistance from others, giving the user a greater sense of independence and control over their mobility. Patients relying on wheelchairs may require full-time monitoring subject to the nature of their disability and health condition, which can make it challenging to move around independently and carry out daily activities without assistance [16]. With the global population ageing and an increase in health-related issues, remote patient monitoring is a revolutionary idea with numerous advantages [17]. The monitoring system, if integrated into the wheelchair may enable continuous tracking of vital signs such as heart rate, temperature, and oxygen saturation. This information is crucial for assessing the well-being of the user and detecting any potential health issues or emergencies. By monitoring these vitals in real-time, the smart wheelchair can alert the caretaker in case of abnormal readings or critical situations, allowing for timely intervention and medical assistance.

After careful consideration of the challenges highlighted in the preceding discussion, the Advanced Monitoring and Assistive Wheelchair prototype is proposed that aims to address the challenges faced by individuals with disabilities and improve their quality of life. The prototype also provides assistance by monitoring the user’s vital signs remotely and whereabouts in case of a fall using GPS and GSM technology. The use of Global Positioning System (GPS) and Global System for Mobile Communication (GSM) technologies can assist in providing the precise location of the smart wheelchair user. To avoid facing a higher risk of accidents that can lead to severe injuries or even death, these patients must be closely monitored and provided with appropriate safety measures [18].

The wheelchair also exhibits improved navigational skills, halting and turning with voice commands and avoiding collisions with things and people. A larger populace can access it more easily because of the affordable solution. Overall, the project's qualities combine to make it a highly beneficial and practical option for people with physical disabilities who use wheelchairs in a variety of contexts.

## METHODOLOGY

Wheelchairs are the main way of transportation for people with particular diseases, which leads to mobility impairment or related issues. Advance Monitoring and Assistive Wheelchair (AMAW) is a carefully designed wheelchair, which helps in improving the autonomy of differently-abled people, with both upper and lower limb disabilities by controlling movement with their voice and satisfying their unique needs in order to ensure comfort and successful mobility.

The proposed prototype consists of following major elements as shown in Figure 1:

- Real-time health monitoring using IoT
- Fall detection using an accelerometer
- Tracking location
- Voice-controlled system
- Mobile applications for patients and caretakers.

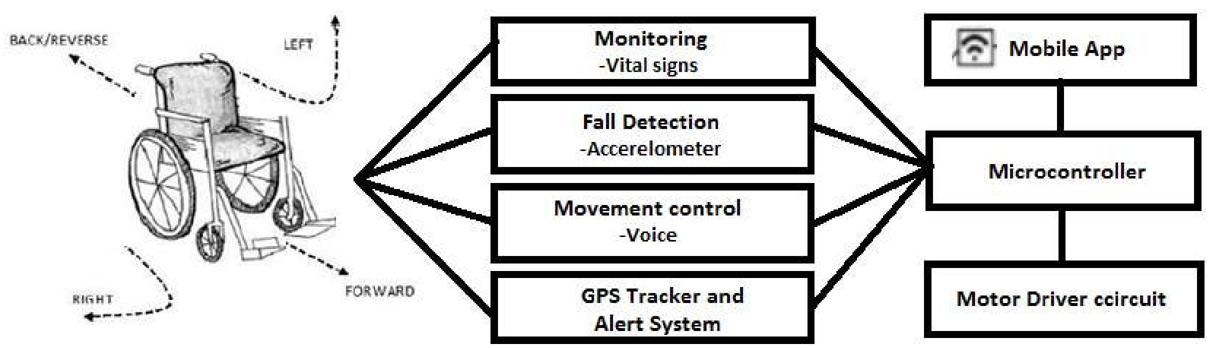


Figure 1 Block diagram of the proposed Advanced Monitoring and Assistive Wheelchair prototype showing its major elements.

### Real-time health monitoring, fall detection and location tracking using IoT

Real-time health monitoring, fall detection and tracking using IoT in Advanced Monitoring and Assistive Wheelchair (AMAW) involve the use of devices connected to the internet, referred to as IoT devices, to continuously collect and transmit data about a person's health and related information. This data includes heart rate, temperature, oxygen saturation, patient’s location and if the person has fallen or not. The section is divided into 3 groups:

**1. Real-time health monitoring using IoT:**

Health monitoring involves the use of sensors such as a pulse oximeter (MAX30100) to determine heartbeat along with the oxygen saturation and temperature sensor (DS18B20) to monitor the user's body temperature. The MAX30100 is a sensor solution with integrated pulse oximetry and heart rate monitoring shown in Figure 2. It can detect pulse oximetry and heart rate signals by using its two LEDs, photo detector, optimized optics, and analog signal processing with low noise. The MAX30100 sensor's photodiode is made to measure the change in light intensity. This photodiode measures the intensity of the light that is absorbed by the blood and the finger before sending the signal to the analog to digital converter and providing the output data. The DS18B20 is a digital temperature sensor that uses Maxim's exclusive 1-Wire bus protocol which is used for creating a bus communication system based on a single control signal shown in Figure 3. The DS18B20 is a versatile and reliable temperature sensor that is widely used due to its accuracy, small size and low cost.


Figure 2 MAX30100 Heart Rate Oxygen Pulse Sensor for determining heatbeat along with oxygen saturation.

Figure 3 DS18B20 Digital Sensor used for determining temperature.

**2. Fall detection using an accelerometer:**

A six-axis accelerometer and gyroscope sensor (MPU6050) is deployed to determine the patient's physical state[19,20] and the object's orientation along with other motion-related parameters such as angular velocity and acceleration. The MPU6050 is a compact MEMS (Micro-Electro-Mechanical system) sensor module that simplifies complex processing and computation tasks, while also transmitting sensor data to other MCUs through I2C serial communication shown in Figure 4. It features a three-axis accelerometer, a three-axis gyroscope, a temperature sensor, and a Digital Motion Processor (DMP), all contained in a small 4x4x0.9mm package. The module considers the x, y, and z channels simultaneously.

The results are shown on the OLED display and all these parameters are enabled over the IOT platform of Thing Speak by Wi-Fi and Bluetooth module (ESP32). The information can easily be accessed by the caregiver and/or healthcare professionals through designed health monitoring App[21]. Figure 5 shows the work flow of the fall detection system. As the system turns on, the fall detection system continuously calculates the angular velocity and acceleration of the AMAW and compares the results with the referenced values. If it observes any changes between the reference and current value, an interrupt in initialized and alert message is sent to the care-taker.


Figure 4 MPU6050 Accelerometer to calculate the angular velocity and accelation of wheelchair.

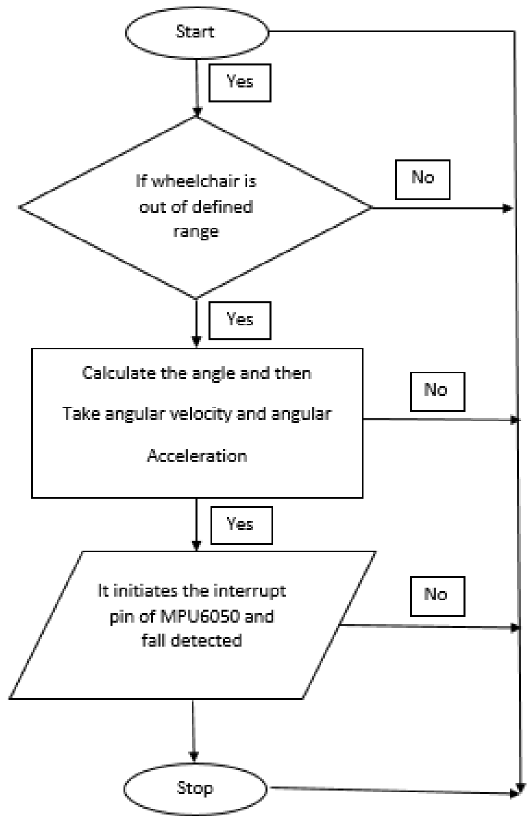


Figure 5 Flowchart showing the working of fall detection system and generating an interrupt.

**3. Tracking Location and Alert system**

GSM (SIM800L) and GPS Modules (NEO6MV2) are interfaced with Wi-Fi and Bluetooth modules for the latitude and longitude coordinates to determine the geographic location of the user. In case of fall and abnormal vitals, a notification message to the registered contact number is sent via GSM [22] is sent to alert the caregiver.The SIM800L GSM Module is shown in Figure 6. Any microcontroller with the SIM800L GSM module from Simcom may connect to the mobile network to make and receive phone calls, send and receive text messages, and connect to the internet using GPRS, TCP, or IP.

Figure 7 SIM800L GSM Module connected with mobile network to send alert messages.

Figure 7 NEO-6MV2 GPS Module to determine the geographic location of the user.

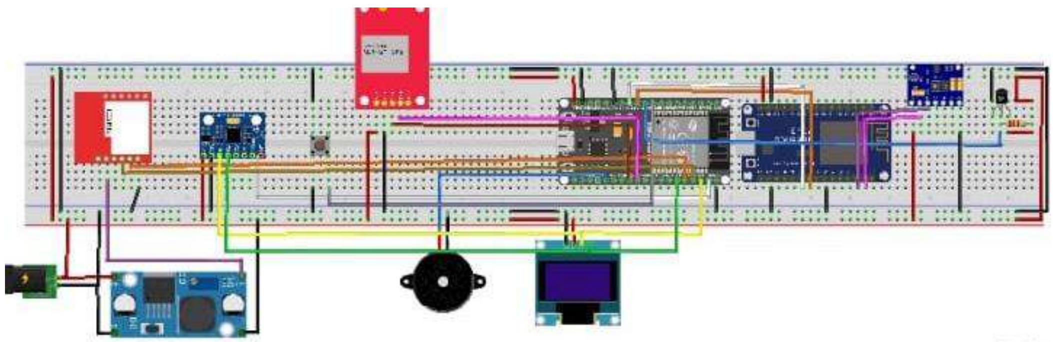

Figure 6 Circuitory of Real-time health monitoring, fall detection and alert system

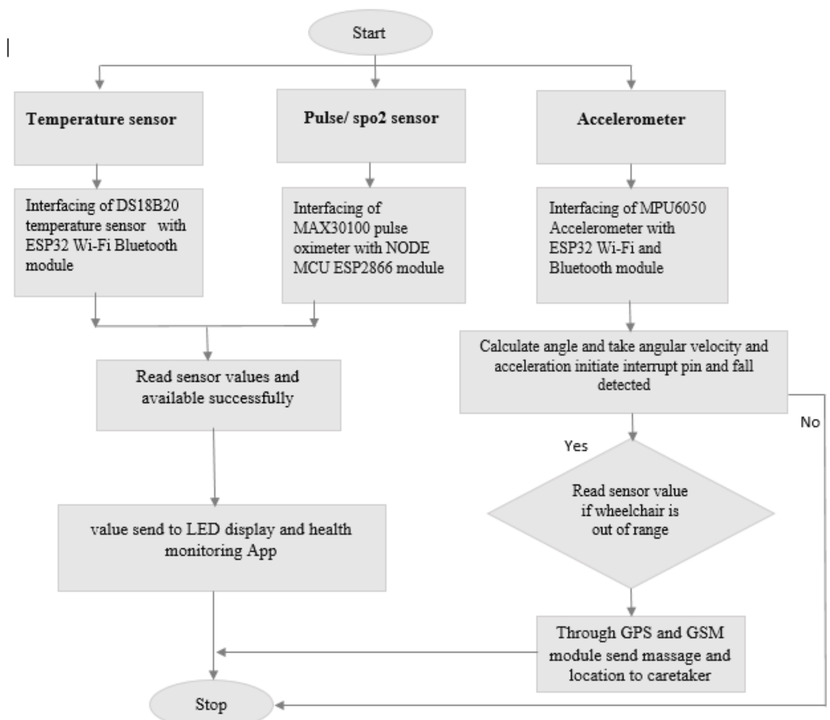


Figure 9 Block diagram showing the working of all the sensors collecting data and generating alert system

A GPS (Global Positioning System) module called the NEO-6MV2 is utilised for navigation shown in Figure7. The module only verifies its position on the planet and outputs data, including its longitude and latitude. It belongs to a group of independent GPS receivers that use the powerful u-blox 6 positioning engine.

The Figure 8 below shows the circuitry of real-time monitoring, fall detection and tracking system using IoT.

The circuit diagram shows the connects of all the sensors with the microcontrollers. Figure 9 shows the brief summary of working of all the sensors connected with microcontrollers and how alert messages are generated.

**Voice control**

Speech recognition technology is utilized to understand and respond to the given commands of the user which is processed by the microcontroller and the signal is sent to the L293D motor driver IC to control the movement of the wheelchair, as shown in Figure 10. A voice-control app is designed using MIT App Inventor [23] enabling users to control their movement using voice commands and button inputs. Voice control App supports both Bluetooth and Wi-Fi communication options.

A notable integration that improves user comfort and mobility is the voice control recognition system. This method makes it possible for users to control the wheelchair's motions and features with just their voice, improving accessibility for those with different physical capabilities. The Google vocal Recognition system's vocal instructions are intercepted by the mobile app's Bluetooth module, which serves as a bridge between the user's voice commands and the wheelchair's control mechanisms.

Google Voice Recognition technology transforms spoken words into text when the user issues voice commands using the mobile app, and the Bluetooth connection then sends the text to the wheelchair. The wheelchair can move in the correct directions, turn, stop, and carry out other predetermined activities thanks to the onboard system's processing of these commands and translation of them into matching actions.

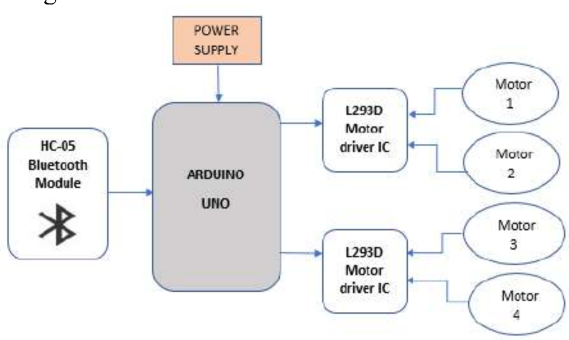


Figure 10 Block diagram of the voice control section of the proposed wheelchair prototype.

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**HC-05 Bluetooth Module**

The HC-05-Bluetooth module is made specifically for clear wireless serial communication shown in Figure 11. It is a simple module for Bluetooth Serial Port Protocol. It is used in either the master or slave configuration.

Figure 11: HC-05 Bluetooth Module for connecting mobile app with the system.

**L293D Motor Driver Shield**

The L293D motor driver shield is a popular motor driver board used to control DC motors and stepper motors in various robotic and automation projects shown in Figure 12 .

Figure 12: L293D Motor Driver to control movement of DC motors used in prototype.

The Figure 13 shows the interfacing of HC-05 Bluetooth module, L292D Motor driver shield and DC motors with the Arduino UNO to control movement of the wheelchair.

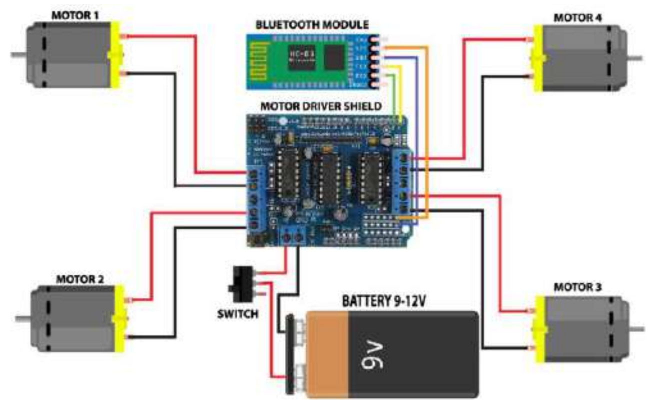


Figure 13: Circuitry of the Voice Controlled System

**RESULTS AND DISCUSSION**

The designed AMAW Prototype is shown in Figure 14 and incorporates sensors for vital signs monitoring a fall detection system, and a voice recognition system through which wheelchair moves.

Figure 14: The designed prototype of AMAW

The heart rate, pulse rate and temperature data are displayed on an LCD as shown in Figure 15 as well as this data is sent to caretaker on health monitoring app as shown in Figure 16. In case of any change in vital parameters, it is tracked, and considered by a doctor [24]. Various tests are conducted on the designed modules, as discussed in the previous section, including the compliance tests of the vital signs, fall detection and speech recognition in both noisy and silent environments.

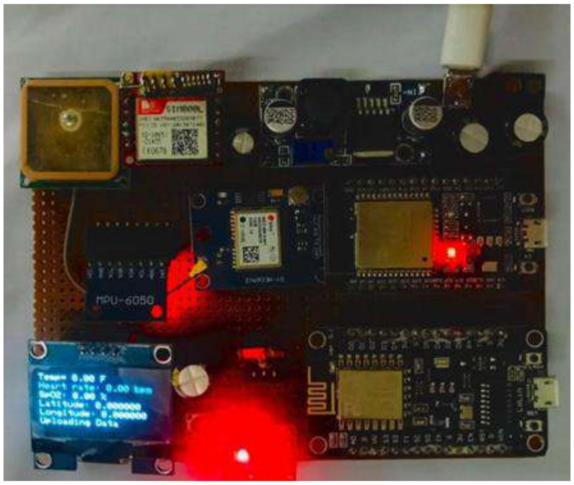

Figure 15: The Results of the heart rate, pulse rate and temperature data are shown on the OLED.

**Compliance Test of Health monitoring and Fall Detection Acquisition Module**

For the health monitoring of the user, the vital signs including body temperature, oxygen saturation, and heart rate of randomly selected twenty-five individuals are measured using the designed monitoring system. Three measurements of each vital parameter such as oxygen saturation, heart rate and temperature is measured and the average is calculated for each subject's vitals. The average values of each subject for the body temperature, oxygen saturation and the heart rate are found to be 96.029°F ,93.34% and 73.36, respectively Concluded that there is ±1 accuracy in the pulse oximeter and ±2 accuracy in the temperature sensor the reason of this ±1 and ±2 accuracy is that as this is a prototype and there was limited testing conducted on a small sample size. Additionally, there might be slight variations in manufacturing processes, calibration errors, or environmental factors that can affect the accuracy of the measurements. These inaccuracies are expected to be minimized in the final production version through further refinement and calibration processes.

We have developed simulated scenarios to test the performance of an AMAW for compliance with fall detection criteria. These scenarios include the wheelchair being in use while being given a rapid shock to represent a fall. The outcomes are then shown on the App and LCD, and the results with location is relayed to the carer via GSM [25,26]. We have concluded that the accelerometer performs satisfactorily based on the findings of the fall detection. When the wheelchair is used on uneven ground, we have seen some accuracy variation.

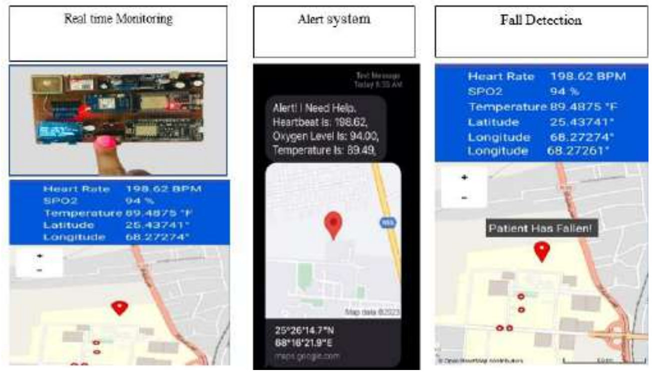


Figure 16: Results of Real time monitoring, fall detection and Alert system of AMAW.

The findings of this study provide evidence that the body temperature and vital signs monitoring system is capable of accurately measuring the vitals and it also allows for remote monitoring and data sharing with their caretaker.

**Compliance Test of Speech Recognition Module**

To evaluate the accuracy of the prototype, random volunteers were selected to participate in testing and each volunteer uses 15 voice commands to control the wheelchair. To assess the performance of the speech recognition system for the wheelchair, the keyword recognition rate was calculated by dividing the number of recognized commands by the number of total spoken commands in silent and noisy enviroment and the results are recorded as shown in Table 1 and Table 2.

Table 1: Results of the speech recognition system performance in silent environment.

| **Volunteers** | **commands spoken** | **commands followed** | **Accuracy** |
|---|---|---|---|
| **1** | 15 | 15 | 100% |
| **2** | 15 | 15 | 100% |
| **3** | 15 | 14 | 93.33% |
| **4** | 15 | 15 | 100% |
| **5** | 15 | 14 | 93.33% |
| **6** | 15 | 15 | 100% |
| **7** | 15 | 14 | 93.33% |
| **8** | 15 | 15 | 100% |
| **9** | 15 | 15 | 100% |
| **10** | 15 | 15 | 100% |

Table 2: Results of the speech recognition system performance in noisy environment.

| Volunteers | commands spoken | commands followed | Accuracy |
|---|---|---|---|
| **1** | 15 | 13 | 86.67% |
| **2** | 15 | 14 | 93.33% |
| **3** | 15 | 11 | 73.33% |
| **4** | 15 | 14 | 93.33% |
| **5** | 15 | 12 | 80% |
| **6** | 15 | 13 | 86.67% |
| **7** | 15 | 11 | 73.33% |
| **8** | 15 | 12 | 80% |
| **9** | 15 | 10 | 66.66% |
| **10** | 15 | 13 | 86.67% |

The voice control scores are calculated for both silent and noisy environments and the average values are found to be 97.99% and 81.99% respectively. The results indicate that the speech recognition system performs fairly well in both silent and noisy situations, with an overall accuracy rate of approximately 80% or higher.

In the silent situation, the system achieved an average recognition rate of 97.99%, indicating a high level of accuracy in understanding and interpreting the spoken commands. This suggests that the system is highly proficient at recognizing speech in optimal, noise-free conditions.

In the noisy situation, the average recognition rate dropped to 81.99%. While this is lower than the performance in the silent situation, it still suggests that the system is able to function reasonably well in the presence of background noise. An accuracy rate of 81.99% indicates that the system successfully recognized and interpreted the majority of the commands, despite the added challenge of noise.

Overall, the results suggest that the speech recognition system is capable of providing reliable performance, even in less ideal, noisy environments. However, there is room for improvement, as the accuracy drops when noise is present. This insight can help guide further refinements to the system, such as developing better noise cancellation algorithms or incorporating advanced techniques to enhance performance in noisy conditions.

## ETHICS AND PRIVACY

The numerous and crucial ethical ramifications of using this cutting-edge wheelchair must be considered. Even though the technology provides unmatched advantages in terms of autonomy, safety, and comfort, it also raises questions regarding user privacy and data security. The collection of location and health information for remote monitoring and navigation may give rise to concerns regarding ownership, permission, and possible abuse. It is crucial to implement strong cybersecurity safeguards and clear data usage guidelines. A careful balance between user empowerment and over-reliance is also required when implementing autonomous features to preserve individual agency and reduce hazards. To avoid a technological gap that puts some sections of the population behind, it is also necessary to address the price and accessibility of such technologies. To avoid technology obsolescence, regular maintenance, upgrades, and user education.

## CONCLUSION

The Advance Monitoring and Assistive Wheelchair (AMAW) is designed to provide independence to people with physical disabilities like monoplegia, hemiplegia, paraplegia, quadriplegia etc. It includes an IoT-based health monitoring system, a fall detection system, position and location tracking, an alerting system, and a voice-controlled system. The real-time monitoring system embedded in the wheelchair monitors the patient's vitals i.e. temperature, pulse rate, and oxygen saturation with the assistance of various sensors and provides data to the caretaker. The fall detection system alerts the caregiver if the patient falls off the wheelchair, and the intended caretaker can locate the patient's location using a mobile app. The directional movements of the wheelchair can be selected by using the voice commands specified. It is successfully built and tested for accuracy on the number of people and the cost of this AMAW prototype has been kept low. The project outperforms ordinary joystick-controlled wheelchairs in many ways including the ability to be stopped or turned with voice commands, preventing collisions with people, furniture, fixed objects, and walls.

The size of AMAW prototype is 10-inch width and 12-inch height but the size of the standard wheelchair one needed for user can vary depending on various factors, including the intended use, the individual's body measurements, and specific requirements. However, there are generally accepted standard dimensions for wheelchairs. Here are some common measurements The standard seat width of a wheelchair typically ranges from 16 to 20 inches Seat, the standard seat depth usually falls between 16 to 18 inches, the standard backrest height is typically around 16 to 18 inches, the standard armrest height is usually between 8 to 10 inches and The overall width of a standard wheelchair ranges from 24 to 30 inches.

## FUTURE RECOMMENDATION

Here are some future recommendations to enhance the wheelchair's capabilities and user experience:

The project demonstrates the viability of voice control for smart wheelchairs using Arduino-based hardware, but there is potential for further advancement through machine learning techniques.

Future work could investigate alternative control mechanisms such as gesture-based control, brain-computer interfaces, or eye-tracking. Additionally, incorporating more health monitoring parameters and environmental sensors can enhance the functionality and user experience of the smart wheelchair system.

Utilize a smart seat cushion with pressure sensors to track the user's position, give feedback, and encourage better posture to avoid pressure sores. In accordance with the user's choices and requirements, it may also provide customized comfort modifications.

Adapt your system to the environment by installing sensors that can measure things like temperature, humidity, and air quality. The wheelchair might then give the user feedback or alarms in real-time to guarantee their comfort and safety in various settings.

## CREDIT AUTHOR STATEMENT

**Zuhra Bano:** Writing- Original draft preparation, Data curation, **Farwa Qureshi :** Conceptualization, Methodology, Software **Moomal Ansari**: Visualization, Investigation. **Sarmad Shams**: Supervision.**: Nimra Imdad**: Software, Validation.: **Fahad Shamim : ** Writing- Reviewing and Editing

## COMPLIANCE WITH ETHICAL STANDARDS

It is declared that all authors don’t have any conflict of interest. Furthermore, informed consent was obtained from all individual participants included in the study.

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