Android-Based Smart Wheelchair with Joystick, Gesture, and Voice Control: A Low-Cost Solution

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***Abstract*— People with motor disabilities are hoping to become more self-sufficient by using an electric wheelchair with standard joystick control. However, when these patients have upper-extremity disabilities, such as tetraplegia, a problem emerges. Voice control, chin control, eye blinking, and sip-and-puff have been used, but each has its own set of benefits and drawbacks. Furthermore, some methods are preferable to others in certain conditions. In this work, a mechanism for a low-cost wheelchair that integrates numerous control methods is proposed. The same wheelchair will have joystick, gesture, and voice control mechanisms, and the option to choose which one to use will be given to the user. As the controller for this entire system, a simple Android application will be employed. It will help the individual with a disability be more autonomous, as the method that suits them better can be decided at any particular time. Additionally, the addition of a distance sensor for the detection of objects on the back of the wheelchair and an LED light module around the wheelchair to illuminate the darkness and facilitate a safe ride for the user is also proposed.**

Keywords—*mobility, wheelchair, android, Arduino, Bluetooth, sensors*

I. Introduction

Motor impairments limit a person's movement. Electric wheelchairs can help these individuals become more autonomous, improve their overall well-being, and reduce dependency. Mobility devices like wheelchairs can enhance the participation of people with disabilities [1].

The earliest evidence of wheeled furniture dates back to ancient China and Greece. In the sixth century, China used the first wheeled seats to transport people with disabilities, while in the sixteenth century, King Phillip II received a complex chair with armrests and leg rests [2]. Stephan Farffler, a 22-year-old paraplegic watchmaker, developed the first self-propelling chair on a three-wheel chassis in 1655. The first lightweight, steel, foldable, portable wheelchair was created in 1933 by mechanical engineers Harry C. Jennings, Sr. and Herbert Everest using their "X-brace" design [3]. In 1953, Canadian inventor George Klein and his team developed the first motorized wheelchair, the "Klein Drive Chair," utilizing a distinctive set of technologies that are still utilized in electric wheelchairs today [4].

According to the WHO (World Health Organization), there are more than 65 million individuals worldwide who require wheelchairs due to mobility problems (WHO, 2018). Many families struggle to afford even a basic powered wheelchair, which can cost anywhere from several thousand dollars to tens of thousands. As a result, there is a pressing demand for reasonably priced automated wheelchairs, which can significantly enhance independence and quality of life for those with mobility impairments. The traditional electric wheelchair moves faster when you push one way, like a gas pedal [2]. Higher motor disability patients often can't control their hands. Traditional electric wheelchairs require additional joystick control, making them complicated and bulky. There are plenty of controllers available. Chin, voice, tilt, eye-blink, and sip-and-puff controls are examples. But voice control may not work in noisy areas. After a few moves, tilt control fatigues the neck, making it impossible to use. From this perspective, it was suggested to integrate multiple control options at once, allowing the user to activate one at a time. Finding the right hardware and software for such a system is the hardest part.

II. Literature Survey

A low-cost smart wheelchair system was proposed by C. F. Lung et al. (2018) designed for people with severe physical disabilities [5]. The proposed system uses a range of sensors to enable autonomous obstacle detection and avoidance, a joystick for manual control, and a tablet interface for remote control and real-time monitoring. It is low-cost, making it accessible to people in developing countries. A. El-Moghazy et al. (2017) [6] presented the design and fabrication of a low-cost electric wheelchair that is intended to provide mobility assistance for disabled people. Low-cost safety features, such as anti-tip wheels and a seat harness, are to ensure the user's protection. A joystick can be used to control it. C. F. Lung et al. (2017) [7] designed and developed a low-cost smart wheelchair system for disabled people. The suggested system includes a manual controller, speech recognition for verbal instructions, and camera-based gesture recognition for non-verbal commands. It also integrates ultrasonic obstacle detection and avoidance capabilities to increase accessibility for users of varying physical abilities. Multi-controlled wheelchair for upper extremities disability is presented by A. B. Satpe et al. (2018) [8]. It is a novel design of a wheelchair that can be controlled using joystick, speech recognition, and head movements to accommodate individuals with upper extremity disabilities. C. F. Riman (2018) [9] proposed an Android phone-controlled wheelchair that uses voice, gesture, and touch screen input for navigation. They developed an Android application to control a wheelchair using voice commands, gesture recognition, and touch screen control, with obstacle detection and avoidance capabilities. A wheelchair control system using hand movement and voice with obstacle avoidance was presented by S.U. Khadilkar and N. Wagdarikar (2015) [10]. It is a low-cost smart wheelchair system that is controlled using hand gestures and voice commands. The system incorporates obstacle detection and avoidance, making it safe to use in various environments. It uses a glove with flex sensors to capture hand gestures and a microphone to get voice commands.

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Prior to deployment, it is necessary to consider the aforementioned pending concerns. Control systems can be prohibitively expensive and difficult to access. Another concern is equipment availability and cost. Ambient light can affect face recognition. A voice-operated wheelchair is useless for a non-communicator, while a touch-operated wheelchair is useless for hand amputees. The aforementioned concepts don't address speed control or darkness visibility. All of the preceding designs are poor in user-friendliness and service feedback.

This study proposes a more practical, cost-effective, and user-friendly wheelchair for a wider range of patients. The hardware and software of this system include security mechanisms to protect against potential attacks and hardware faults.

III. Proposed Methodology

3.1 Features of the System

Our proposed system offers numerous features, i.e.,

A. Using the mobile application developed for the project, the user can control the wheelchair using an in-app joystick, gestures, or voice commands.

B. Users can control the direction as well as the speed of the car from the application.

C. Informs the user about how far away the wheelchair is from any nearby backward object and notifies the user with a caution signal on the mobile application.

D. Establishes a secure connection between the wheelchair and the controller, including software security, to prevent potential security threats.

3.2 Basic Working Principle

The system can be divided into two main units.

A. Car or Wheelchair Unit

B. Mobile Application

The basic principle of the system is illustrated in Fig. 1, where the main interface of the system is shown. The mobile application provides the controller framework for the user to control the wheelchair. This application provides a joystick, gesture, and voice controller. Mobile applications and wheelchair units are connected via Bluetooth. The application sends byte-string commands to the Bluetooth module connected to the wheelchair unit, and the wheelchair responds to these commands accordingly by moving forward, backward, right, or left.

In addition, an accelerometer is used to monitor the change in speed of the wheelchair, making it safer. Also, the ultrasonic sensor connected to the wheelchair continually monitors the car's rear for any obstacles. The wheelchair unit sends distance data to the mobile application to alert users of adjacent backward objects.

3.3 Wheelchair Controls

The proposed design employs three types of controls.

A. Joystick Control: For individuals with lower motor disabilities, joystick control is preferred. The joystick facilitates precise and uncomplicated control of the wheelchair.

B. Gesture Control: The gesture control module is recommended for individuals who may have limited mobility or use of their hands and arms. Individuals with restricted movement or use of their hands and arms should use the gesture control module. It enables individuals to control the wheelchair with simple hand or body movements rather than complex motor abilities. Individuals with motor coordination issues, such as cerebral palsy, may benefit from gesture control as well.

C. Voice Control: The voice control module is recommended in particular for those who have both upper and lower motor impairments. Individuals with various disabilities, such as those with restricted mobility or visual impairments who may have difficulties controlling the wheelchair manually, may gain benefit from it.

However, the user may shift the control according to his preference, comfort zone, or what his doctor recommends.

3.4 Security

Security facilities in this wheelchair model include

A. Kill Button

A hardware pushbutton is connected to the battery that powers the whole wheelchair unit. It can cut off the power in the event of any unexpected or unusual behaviour by the controls.

B. Unique Wheelchair ID

A unique ID is provided for each wheelchair unit. Only a person who is familiar with the UID can operate a wheelchair. This should ensure a secure connection between the controller and wheelchair. Fig. 2(a) shows the first interface to connect the wheelchair Bluetooth module with the one of the Android device of the user. The particular ID for the wheelchair must be selected, as highlighted in the color yellow.

C. Mobile Application Security

An AppLocker is implemented for the mobile application. Only the actual user of the wheelchair, who knows the pin, can open and run the software application. Fig. 2(b) shows the interface of the mobile application, where there is a box to enter the pin number and a keyboard for typing the pin.

IV. Design & Implementation

4.1 Required Apparatus

The apparatus required for system development includes both hardware and software components.

A. Hardware

The general hardware part of the system is developed using the components listed in Table I.

B. Software

The software components of the system consist of

1. Arduino IDE
2. MIT App Inventor

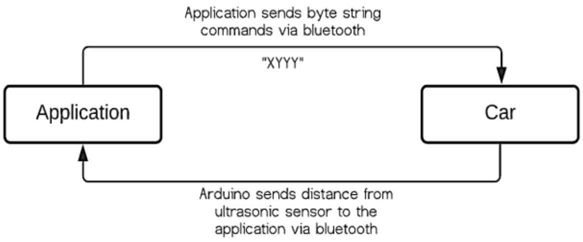
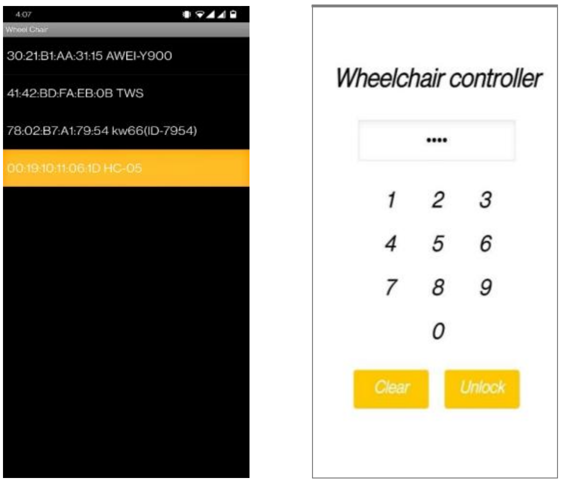


Fig. 1. Basic working principle of the system



(a) (b)

Fig. 2. Connection with the Bluetooth module (a) and app-locker for the mobile controller application (b)

Open-source software known as the Arduino IDE has been used here to program Arduino boards. MIT App Inventor has been used to design the mobile application for Android.

4.2 Block Diagram

This block diagram in Fig. 3 showcases the functioning of the proposed wheelchair system. The system is designed to allow for simple and flexible control via a mobile application on an Android phone, which sends instructions to the wheelchair's microcontroller via Bluetooth wireless connection. A battery source, motor drivers, and various sensors all work together to operate the microcontroller. The microprocessor receives inputs, operates the wheelchair using a joystick, voice, or speech, and sends data to the Android app. The wheelchair also incorporates an accelerometer for speed control, a sensor for obstacle detection, a light module for illumination, and a kill button for emergency disconnection from mobile control, ensuring user safety.

4.3 State Diagram

Fig. 4 illustrates the functional state diagram of this system. Incorrect information closes the application. The mobile device looks for the wheelchair Bluetooth controller's Bluetooth network when Bluetooth is on. Bluetooth controllers connect to networks when found. The user selects voice input and movement direction. The wheelchair's engine drives it to its goal. The system remains off until the user opens the program, then it turns idle. Bluetooth turns the system on, connects to the mobile's Bluetooth network, and propels the wheelchair in the desired direction. If the user refuses to move, the program closes and the system resets.

TABLE I. LIST OF REQUIRED HARDWARE COMPONENTS

Name	Quantity
Arduino UNO	1
L298N Motor Driver	1
DG01D-A130 Gear Motor	2
Bluetooth Module HC-05	1
HC-SR04 Ultrasonic Sensor	1
3.7V BRC 18650 6800mAh Li-ion Battery	3
Motor Wheel	2
Rotating Wheel	1
Wheelchair Frame	1
Connecting Wires	As required

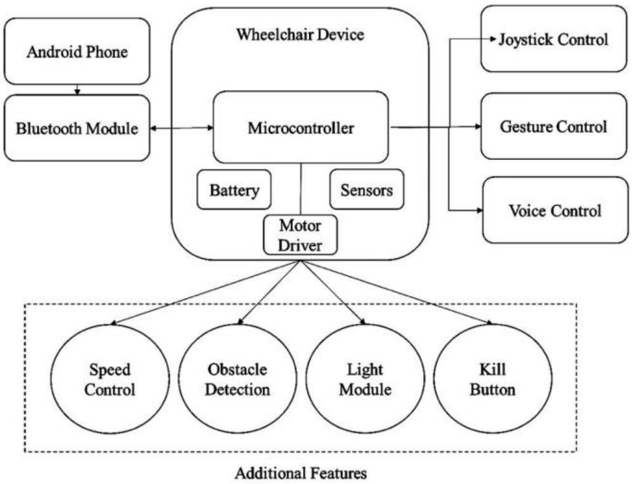


Fig. 3. Functional Block Diagram of Wheelchair Unit

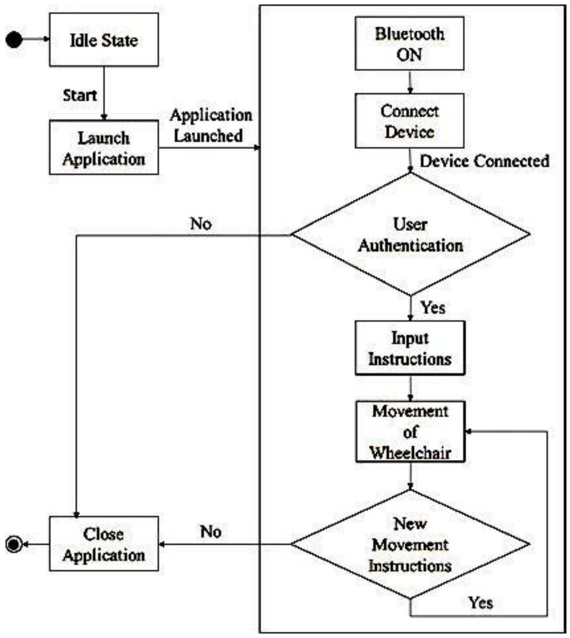


Fig. 4. State Diagram

4.3 Implementation

A. Wheelchair Controls

1. Joystick: A virtual joystick controller has been implemented in the mobile application. This is operated through the touch screen of the mobile phone. The interface of the joystick for the mobile application is shown in Fig. 5. The direction command is detected using the rotation angle of the joystick knob, and the further the knob is from the center, the greater the speed of the wheelchair.

2. Gesture: Gesture control is implemented using a mobile phone's in-built accelerometer sensor. The interface of the gesture control for the mobile application is shown in Fig. 6. It shows the control of the wheelchair using the gesture, where the red knob will show us the direction of where the wheelchair is going. An accelerometer can detect orientation relative to gravity as well as translational motion. The tilt of the phone was detected in order to track down the direction command. For example, if the phone is tilted forward, then the direction command will be forward. And the higher the tilt of the phone, the higher the speed of the wheelchair. The tilt of the phone is detected using transitional acceleration in the X-axes and Y-axes. Fig. 7(a) presents the layout of the gesture module on the mobile application screen.

3. Voice: From the voice input of the user, the algorithm checks for trigger words like 'forward', 'backward', 'right', and "left," and the number of seconds the wheelchair will move in that triggered direction. For example, if the voice input is 'go forward for 2 seconds," then the wheelchair will move forward for 2 seconds. Again, if the voice input is 'go forward," then the wheelchair will move forward for a predetermined amount of time set on the app settings. Voice commands can also be triggered by shaking the phone. Fig. 7(b) shows the voice control module where Google Assistant has been used as a platform for the recognition of speech.

B. Wheelchair Control Commands

Each time the user inputs a move command through the application, either by joystick, gesture, or voice controls, a command signal is sent from the mobile application to the Bluetooth module of the wheelchair. A command is of the form "XYYY", where 'X' indicates direction command and 'YYY' is the motor speed command (from 0 to 100) for joystick or gesture, and a timer in seconds for voice control system. Table II visualizes how different digits are fixed as notation for commands in different directions.

For example, '1063' means direction is forward and motor speed is 63; '7008' is a voice command, which means the wheelchair will move backwards for 7 seconds. "0000" means stop.

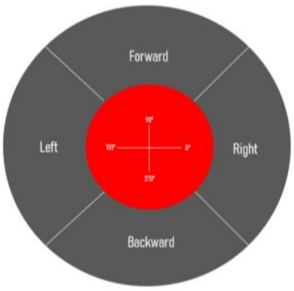


Fig. 5. Joystick layout

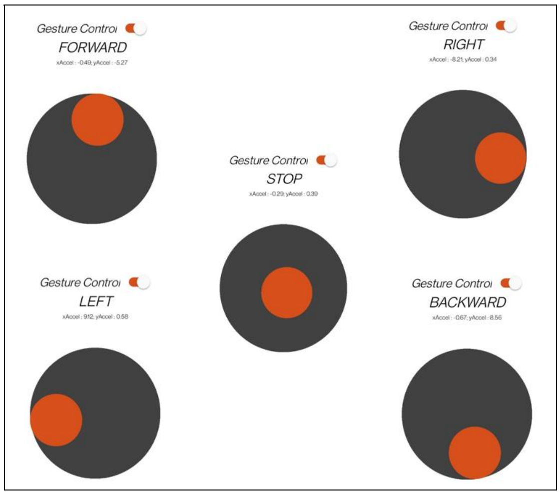
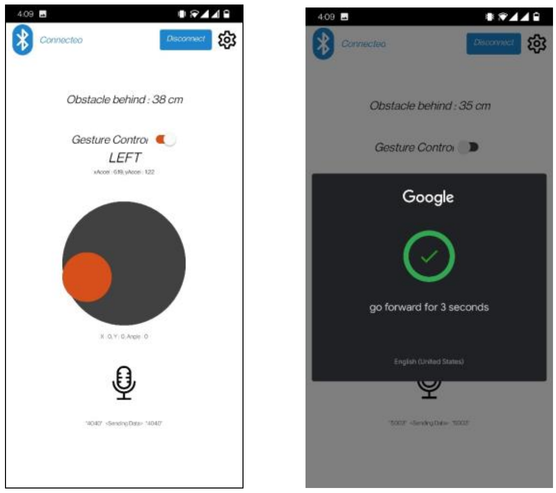


Fig. 6. Gesture Control Using In-built Phone Accelerometer



(a) (b)

Fig. 7. Gesture control module (a) and voice control module (b)

C. Sending Backward Object Distance from the Wheelchair Unit

Distance is measured using an ultrasonic sensor. The basic principle of ultrasonic distance measurement is based on ECHO. When sound waves are transmitted in the environment, they are returned back to their origin as ECHO after striking the obstacle. Using this duration of sending and detection of the ECHO signal, Arduino measures the distance using the following formula:

$$\text{Distance} = (\text{Duration} \times \text{Speed of sound})/2 \qquad (1)$$

The distance was measured in centimeter every 250 milliseconds (4 times every second) and sent into the mobile application via Bluetooth in order to inform the user.

V. RESULTS & DISCUSSIONS

5.1 Results

The hardware system has been developed as a prototype for a wheelchair. The final look can be seen in Fig. 8. which is a prototype of the proposed and developed wheelchair system. It has been successfully operated with the built-in Android application shown in Fig. 9(a).

TABLE II. CONTROL COMMANDS NOTATION

For Joystick / Accelerometer		For Voice commands	
1	Forward	5	Forward
2	Right	6	Right
3	Backward	7	Backward
4	Left	8	Left

Fig. 9(a) depicts the main user interface of the software application once the Bluetooth connection has been established, as stated in Fig. 2(a). On the homepage, three control modules are presented, and the user can switch control actions as needed by simply clicking on the respective icons. Fig. 9(b) shows the special distance alert feature that is named "Caution!" This mechanism was previously discussed in Section 3.2. Fig. 10 shows another interface of the Android application, which is the settings menu, where features like pins, time fixation, gesture sensitivities, etc. are provided to edit or modify by the user.

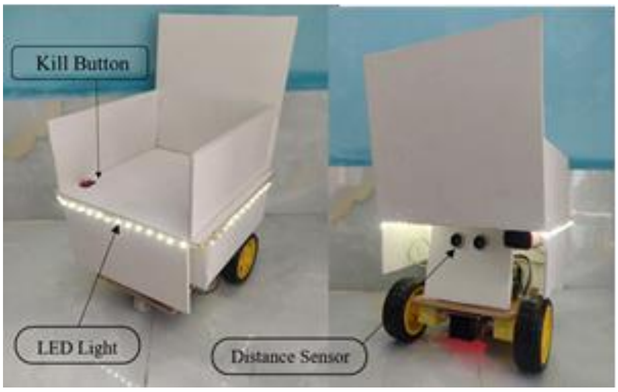
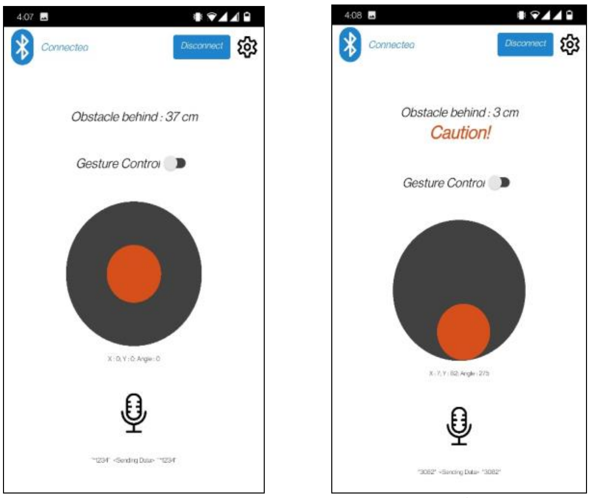


Fig. 8. Final Prototype Demonstration



(a) (b)

Fig. 9. Homepage of the mobile application (a) and collision alert for objects behind (b)

Fig. 10. All Application Settings

To check the effectiveness of this prototype, average latency and success rates have been calculated based on 40 trials. Table denotes the average latency and success rate for each control method of the wheelchair. According to the data, the joystick control module has the lowest latency of 5 ms, indicating near-instantaneous user input. It also executes all instructions successfully, with a 100% success rate. The gesture control module lags an average of 30 ms. 97.50% of motions are recognized and executed. Voice control module instructions are 1000 ms slower. Despite the delay, it performs 87.50% of voice-based commands.

The bar chart in Fig. 11 compares our wheelchair model to the wheelchair models reviewed in Section II, denoted from S1 to S6. These devices support several extremities, have multiple control modules, and prioritize device safety. But few of them lacs Android control, and application security. Some has the fewest controls and solo extremity support. Our model outperforms high- and low-featured versions. It has several control modules, extremity support, and device safety, Android control, and application security. It also adds features to improve the user experience. For a well-rounded, feature-rich wheelchair, this model delivers value without sacrificing quality.

5.2 Discussions

The major goal was to build a low-cost joystick, hand gesture, and voice-controlled wireless wheelchair for disabled or elderly people who depend on others or struggle to get around. An automated wheelchair has been designed

TABLE III. LATENCY AND SUCCESS RATE (40 TRIALS)

Control Module	Average Latency (ms)	Success Rate
Joystick	5	100%
Gesture	30	97.50%
Voice	1000	87.50%

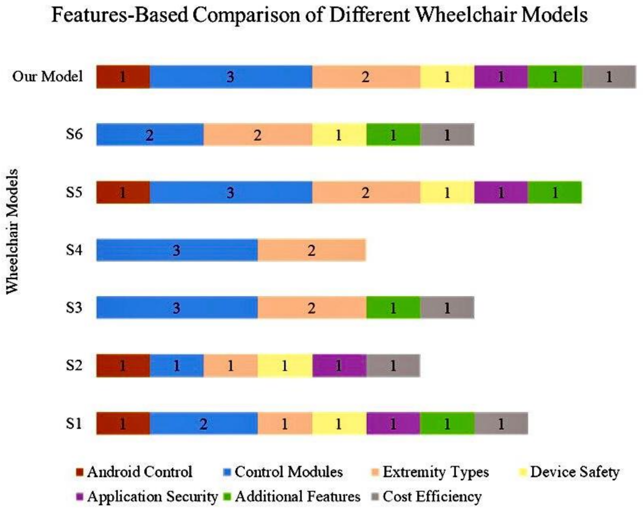


Fig. 11. Feature-based comparison of different wheelchair models

with a corresponding Android application controller that achieves the purpose. The software application would be free. This system outperforms the most common available devices due to the addition of speed control, a light module, three types of security mechanisms (a kill button, a unique ID, and an application lock), and obstacle detection. Furthermore, the equipment employed here is affordable and readily available, saving both money and time and making the device simpler, more suitable, and more compact.

VI. APPLICATION AREA

These advances may help to avoid falls, accidents, additional disability, premature mortality, and reduce healthcare costs. For institutions like airports and hospitals, having the ability to change manual wheelchairs into electric ones is crucial. The conversion process is simplified when our technological module is added to a standard wheelchair. This ensures that those in need, regardless of their physical abilities, can take advantage of our system's benefits.

VII. CONCLUSIONS

Automated wheelchairs will help disabled people gain mobility, stay healthy, and fully participate in communal life. People with disabilities might struggle to access all parts of their lives due to even the smallest step. Autonomous wheelchairs improve independence and socialization, but they don't cure them.

This approach will let people with impairments participate and reduce care-giver’s time and physical hardship when given through a supportive service. This will increase health, quality of life, education, and employment. They may also avoid falls, accidents, disability, and early death. It will reduce health-care costs, economic vulnerability, and productivity while improving life.

VIII. FUTURE SCOPE

This project can be developed in the following ways in the future:

- Increasing the Bluetooth range of the wheelchair
- Implementing obstacle detection and avoidance for all the sides.
- Using GPS for location tracking and contact ones in case of emergency.
- Healthcare features can be introduced in the future including pulse sensors and heart beat sensors that may provide accurate measurements for the disabled's health.
- Using artificial intelligence (AI) for achieving.

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