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Smart Wheel Bot: An IoT-Driven Obstacle Avoidance System for Wheelchairs

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ABSTRACT

Like many other sectors, the medical field in India is not widely known for its automation. Even in contemporary society, people with physical disabilities often rely on a caregiver for movement assistance. However, caregivers may be busy attending to other responsibilities and obligations, which can leave patients feeling stuck and dependent. To solve this problem, we designed an autonomous wheelchair which further enhances safety and facilitates greater independence in mobility. The Smart Mobility Bot is an economical autonomous wheelchair with decently priced features. It is controlled by DC motors and employs ultrasonic sensors for detecting obstacles.

Keywords: *Omnidirectional Mobility, Obstacle Avoidance, Autonomous Navigation*

1. INTRODUCTION

Mobility is one of the most critical aspects of daily life, yet for individuals with physical disabilities, it often comes with significant challenges. Traditional wheelchairs, while helpful, require a great deal of manual labor and motivation, which invariably places limitations on a person's autonomy and independence. As now automation and Embedded systems are evolving, we are integrated both these technologies but easier, safer, and more autonomous. This project Smart Mobility Bot, an automatic wheelchair that is controlled by Wi-Fi and is designed to help the user freely move around the surroundings. The system integrates basic units such as DC motors, ultrasonic sensors, and a NodeMCU (ESP8266) module to provide wireless control and automatic identification of obstacles. The wheelchair can be controlled using a cell phone, laptop or any device without effort.

This project aims to reduce the dependency of people with mobility challenges through effective automation while improving their quality of life by focusing on cost, ease of use, and real time control with limited latency.

1.1 Distribution of Disability Types in India (NFHS-5, 2019–2021):

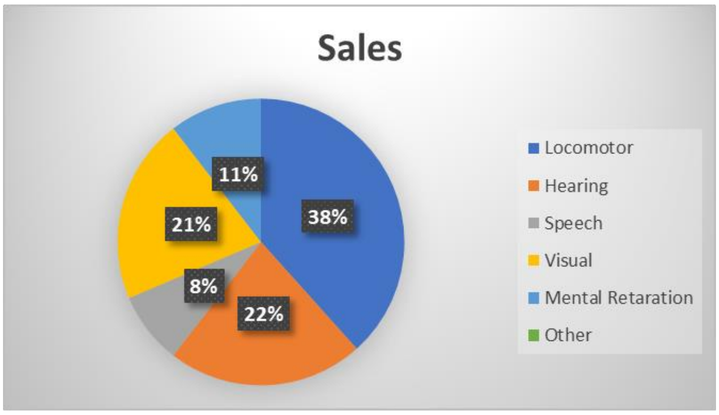

Fig 1.1. the pie chart showing the Distribution of Disability Types in India based on data from the NFHS-5 (2019–2021)

Source:
NFHS-5 (2019–21) data via Ministry of Health and Family Welfare. https://www.frontiersin.org/articles/10.3389/fpubh.2023.1036499/full

2. LITERATURE REVIEW

M. Xiong et al.., (2019) [1] conducts the study a hybrid EEG/EMG method with semi-autonomous navigation, improving user flexibility and affordability. In line with developments in accessible assistive robotics, their work uses sensor fusion and inexpensive hardware to close gaps in the real world.
Hartman et al. (2018**)** [2] In order to move smoothly and prevent collisions, this study combines sensors, quick computers, and obstacle detection to create a smarter wheelchair. By striking a balance between power, speed, and safety, the design enhances medical mobility and is useful for daily use.
Derasari et al., (2022) [3] This study demonstrates the incorporation of Bluetooth Low Energy (BLE) glove-based wireless control for electric wheelchair operation. It also emphasizes the automatic obstacle detection and avoidance capabilities of ultrasonic sensors. With assistive technologies, these features are meant to increase user independence, mobility, and safety.
E. Sola-Thomas et al.., (2021) [4] shows the development of a smart wheelchair equipped with LIDAR, stereo depth camera, and a Jetson processor for autonomous indoor navigation. The system supports both joystick and hands-free app-based control, enhancing user independence. It is designed as an open-source, cost-effective solution for individuals with limited mobility.
Rabbani et al.., (2024) [5] highlights the need for robotic and automated solutions and demonstrates that increasing hospital bed mobility calls for more than just structural adjustments. To improve maneuverability, it highlights different wheel systems such as omni wheels and swerve drives. The study suggests using robotics to lessen caregiver stress and boost productivity in healthcare settings, taking inspiration from automation in other sectors.
Alshraideh et al.., (2014) [6] shows the development of a Robotic Intelligent Wheelchair System (RIWS). The system helps users get to hospital destinations on their own by using autonomous navigation and obstacle avoidance. Its efficacy and dependability in scheduled patient transport were validated by experimental results.
D. A. Bell (2002) [7] The NavChair system was developed by to assist people with multiple disabilities who are unable to use standard wheelchairs. For real-time obstacle detection and navigation in a powered wheelchair, the project used the Vector Field Histogram (VFH) technique. Although more improvement in obstacle response is required, the maneuverability results from the trials were encouraging.
Study by L. Kitagawa et al., (2001) [8] demonstrates a semi-autonomous control approach for omnidirectional wheelchairs that integrates collision avoidance without overriding user input. The system enhances safety by resisting joystick movement toward obstacles, ensuring user control and comfort.
Study by J. B. Fernando et al.., (2012) [9] presents a collision avoidance path planning algorithm tailored for hospital robots, considering the movement characteristics of different disabled individuals. The robot adapts its path based on the user's mobility model, enhancing safety and ease of movement in shared spaces.
Study by M. Nitulescu et al.., (2018) [10] focuses on the kinematic and dynamic modeling of a three-wheeled medical wheelchair, emphasizing smooth navigation across linear and curvilinear paths. Two driving strategies—direction-based and speed-based—are proposed to enhance trajectory tracking without sudden variations.
Study by N. Farheen et al.., (2022) [11] explores the use of machine learning and deep learning techniques to enhance obstacle detection and navigation in commercial non-autonomous wheelchairs. The research integrates depth image classification using TensorFlow Lite on compact platforms like Raspberry Pi and simulates path planning in MATLAB.
Study by Antonio Sgorbissa et al.., (2011) [12] shows that the Roaming Trails approach enables robots to safely navigate dynamic environments by integrating planning with local obstacle avoidance. It ensures deadlock-free movement through controlled path deviation
Study by R. Bostelman et al.., (2007) [13] presents the HLPR Chair, a multifunctional mobility aid designed to assist wheelchair users with tasks like transferring to beds or accessing high surfaces. The chair incorporates autonomous planning and control features to enhance independence and reduce caregiver strain.
Study by U. Masud et al.., (2024) [14] shows that a vision-based autonomous wheelchair can empower fully handicapped individuals by enabling movement through eye-tracking control. The system uses a camera to follow eye orientation and integrates obstacle-detecting sensors, enhancing mobility and independence.

3. METHODOLOGY

3.1 Design Objective and Planning

The project began with defining the need for affordable autonomous mobility in hospitals. Due to high costs associated with advanced sensors and AI-based systems, a simplified prototype was planned. The objective was to demonstrate core functionalities—directional movement, obstacle detection, and wireless control—using cost-effective hardware.

3.2 Hardware Architecture

The wheelchair was equipped with essential components for mobility and control:

i. Arduino Uno: Serves as the primary controller for sensor input and motor output.
ii. Ultrasonic Sensors (HC-SR04): Positioned at the front and sides for obstacle detection.
iii. DC Motors and L298N Driver: Provide forward, backward, and turning motion.
iv. Bluetooth Module (HC-05): Enables wireless control through a mobile app.
v. 12V Battery: Powers the motors and electronics for untethered movement.

These components were mounted securely on a modified manual wheelchair frame.

3.3 Software Integration

The Arduino was programmed using the Arduino IDE to handle inputs from the Bluetooth module and ultrasonic sensors. It responds to directional commands and performs basic obstacle avoidance by stopping or changing direction when an object is detected within a predefined range.

- The mobile application, built using MIT App Inventor, allows users to control the wheelchair via Bluetooth. The interface includes buttons for all movement directions and an emergency stop, transmitting single-character commands to the microcontroller.

3.4 Testing in Simulated Environment

The prototype was tested in a custom-built indoor setup simulating hospital corridors and patient rooms. Key testing parameters included:

i. Obstacle avoidance accuracy
ii. Delay in command execution
iii. Maneuverability in narrow paths

Observations were recorded to assess performance, identify limitations, and refine control logic.

3.5 Future Scalability

Although the current system is semi-autonomous, its modular design supports future upgrades, such as:

i. LIDAR and Camera Integration for vision-based mapping
ii. Raspberry Pi/NVIDIA Jetson for high-level processing
iii. SLAM and IMU modules for real-time autonomous navigation

This flexible architecture ensures that the system can be scaled up when advanced components become affordable or funding becomes available.

4. CALCULATION

4.1 Obstacle Detection - Ultrasonic Sensor

The ultrasonic sensor measures distance using the time-of-flight principle.

$$\textbf{Distance (cm)} = \frac{\text{Time Taken } (\mu s) \times \text{Speed of Sound } (cm/\mu s)}{2}$$

Given the speed of sound in air is approximately 0.0343cm/µs at 20∘C. For a measured time of 500µs (travel to object and back), the distance is:

$$\textbf{Distance (cm)} = \frac{500\mu s \times 0.0343 cm/\mu s}{2} = 8.58 \text{ sec}$$

A critical threshold (e.g., 30cm) is set in the code for initiating avoidance maneuvers.

4.2 Power Drive - DC Motors

Total Operating Current: The sum of operating currents for all four DC motors determines the load on the power source. Assuming an average operating current of 0.3A per motor:

Total Motor Operating Current=0.3A/motor×4motors=1.2A

Motor drivers must be rated to handle the motors peak stall currents, which are significantly higher than operating currents.

Wheelchair Speed (Theoretical):

The linear speed depends on motor RPM and wheel diameter.

Wheel Circumference=π×Wheel Diameter

$$\text{Linear Speed } (cm/s) = \frac{\text{Motor RPM} \times \text{Wheel Circumference } (cm)}{60}$$

For example, if a 10cm diameter wheel (31.4cm circumference) and 60RPM motor:

$$\text{Linear Speed} = \frac{60RPM \times 31.4cm}{60} = 31.4 \text{ cm/s}$$

4.3 Power Source - Battery

The battery life estimation is crucial for sustained operation.

Total System Current Draw:

This is the sum of current consumed by all components:

Total Current=Motor Current+ESP8266 Current+Ultrasonic Sensor Current+Motor Driver Current+Other Components Current

Estimated Operating Current (Example):

- Motors: 1.2A
- ESP8266 (NodeMCU): 0.08A (average)
- Ultrasonic Sensor (1 unit): 0.02A
- Motor Drivers (2 units): 0.08A (quiescent)

Total Estimated Current ≈1.2+0.08+0.02+0.08=1.38A

5. PROTOTYPE MODEL:

A prototype was developed of 1: 5 scale Model Prototype for the Smart Mobility Bot, a small and useful demonstration of an autonomous wheelchair system prototype has been created.

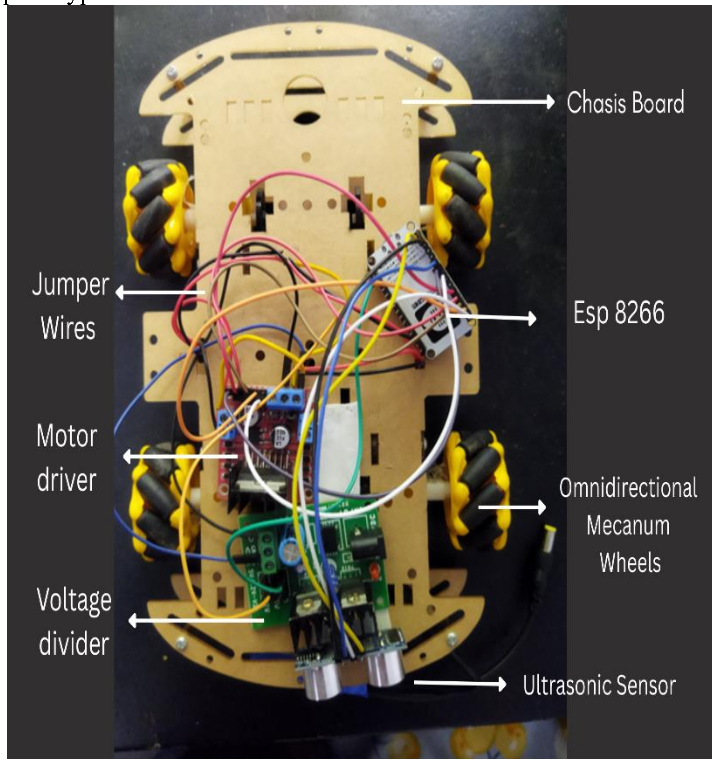

Fig 2.1 Prototype model for the smart bot

The system, which has four Mecanum wheels and a small chassis, enables unrestricted movement in all directions. DC motors are controlled by a motor driver circuit gives the movement. The ESP8266 (NodeMCU) microcontroller, which controls the Wi-Fi connections and carries out the commands sent by the interface, is the central component of the system. The control panel has simple directional buttons for forward, backward, left, and right as well as stopping. It uses a local IP address, such as 192.168.103.202. At the front of the chassis is a sensor that uses ultrasonic waves for obstacles detection. This sensor continuously monitors the distance to nearby objects and ensures the bot stops or changes direction when an obstacle is detected. A battery pack attached to the board powers the system, removing the need for external power sources. The wiring is arranged to minimize interference during movement, and every component is firmly fastened to the frame. This prototype is a workable foundation for developing into a full-sized autonomous wheelchair since it successfully illustrates essential features like remote control, autonomous sensing, and real-time response.

6. RESULT AND DISCUSSION

The table summarizes the stopping distance behaviour of the robot across various surfaces, speeds, and obstacle materials using an ultrasonic sensor.

From the results:

Test No.	Condition	Speed Level	Obstacle Material	Sensor Reading (cm)	Actual Distance (cm)	Stopping Distance (cm)	Remark
1	Tile Floor	Low	Cardboard	20	20	5	Accurate stop
2	Carpet	Medium	Plastic	25	23	7	Slight overshoot
3	Concrete	High	Metal	30	28	10	Late response
4	Wooden Surface	Low	Glass	15	14	6	Sensor slightly off
5	Rough Concrete	Medium	Plastic	22	21	8	Stable detection

The robot exhibited precise stopping on smooth surfaces such as wood and tile
Stopping distance was higher on bumpy or soft roads such as carpet and concrete.
Increased speeds resulted in increased stopping distances, emphasizing response delay.
Ultrasonic sensor was quite accurate overall, but material of obstacles influenced readings slightly

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5. CONCLUSION

The Smart Wheelchair System project successfully designed a strong conceptual foundation for an evolution mobility aid that control with autonomous obstacle detection. With the integration of direction inputs through Bluetooth Low Energy (BLE) and ultrasonic sensors for real-time environmental scanning, the system suggests a dual-control system. This facilitates seamless manual control as well as actively avoiding collision through active combination of user input with necessary safety features using advanced sensor integration and embedded system processing. This meets the urgent need to increase user independence, especially for those with severe physical impairments, by substantially reducing the necessity for external aid in indoor settings. The model illustrates an obvious path towards empowering users with increased autonomy, dignity, and safety while moving about their environments. The blending of various technologies seeks to offer an all solution that truly enhances the quality of life for the users. In the future, the project's subsequent important step is the physical construction and intense testing of a working prototype. mounting all sensors and the microcontroller on a wheelchair platform and performing thorough performance tests.

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