# Voice Controlled Wheelchair with Home Automation

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## ABSTRACT
This research presents a novel voice-controlled wheelchair system that integrates with home automation technologies to enhance mobility and independence for individuals with disabilities. Through a multidisciplinary approach, this project addresses the limitations of existing assistive devices by leveraging state-of-the-art voice recognition and machine learning techniques. The primary objectives of this study were twofold: first, to develop a highly accurate and reliable voice controlled wheelchair system capable of interpreting user commands with precision. Second, to seamlessly integrate this system with home automation devices, enabling users to control their living environments through natural voice commands. The research methodology combines hardware design, software development, and machine learning algorithms. The results of this project demonstrate significant advancements in assistive technology, offering a comprehensive solution that empowers users with increased independence and an improved quality of life. The integration of voice control and home automation features represents an approach that holds broader implications for the fields of assistive technology and healthcare.

## Keywords
Voice-controlled wheelchair, Speech recognition, ESP32, CNN, Home automation, Obstacle detection

## 1. INTRODUCTION
The intersection of technology and healthcare has witnessed remarkable advancements in recent years, particularly in the field of assistive devices aimed at improving the quality of life for individuals with disabilities. Among these innovations, the development of voice-controlled wheelchairs represents a promising approach to enhancing user mobility and autonomy.

According to the World Health Organization (WHO), over 2.5 billion individuals worldwide live with some form of disability [1], and mobility impairment is a significant challenge faced by more than 80 million people globally. However, only 5%-35% (depending on the country) of these mobility-challenged individuals have access to a wheelchair. The current wheelchair market is dominated by two primary types: manual and power (joystick-based) wheelchairs. Manual wheelchair users often encounter physical strain due to the manual propulsion required, while joystick-based wheelchairs pose challenges with precise control, particularly in tight spaces [2]. Moreover, individuals with limited dexterity or cognitive impairments, notably the elderly, find operating both manual and joystick controls challenging, diminishing their independence and the usability of wheelchairs [3].

In response to this pressing need, the current research project seeks to harness the power of voice recognition technology to create an intuitive and efficient solution for individuals with mobility limitations, especially elderly people. The focus of this work extends beyond mere transportation, aiming to provide seamless control over home automation systems, thereby enhancing the overall quality of life for users.

The significance of this project lies in its potential to redefine the mobility assistance paradigm by prioritizing user autonomy, convenience, and safety. By seamlessly integrating the voice controlled wheelchair system with home automation devices, the proposed solution empowers users to navigate their living spaces with ease while exerting control over various household appliances and systems.

This research endeavors to develop a highly accurate and reliable voice-controlled wheelchair system capable of interpreting user commands with precision and efficiency. Moreover, it seeks to seamlessly integrate this system with home automation devices to provide elderly users with comprehensive control over their environment. With the ultimate goal of empowering these elderly individuals to live with increased independence and an enhanced quality of life.

## 2. LITERATURE REVIEW
In recent years, there has been a notable surge in the development of assistive technologies aimed at enhancing the mobility and autonomy of individuals with disabilities, particularly those with mobility impairments. Technological advancements coupled with user-centered design approaches have fueled innovation in this field, leading to a diverse array of assistive solutions tailored to meet the specific needs and preferences of users. This literature review aims to explore and synthesize existing research endeavors in this domain to elucidate the current state of the art, identify gaps, and pave the way for further advancements.

Dalsaniya and Gawali (2016), in their work on "Smartphone based wheelchair navigation and home automation for the disabled" [4], have showcased the feasibility of utilizing smartphones as control interfaces for wheelchair navigation and integrating home automation functionalities, thereby enabling users to maneuver through their environment with ease and control various household devices using a unified platform. However, a notable gap in their approach lies in the reliance of individuals on mobile phones for voice command input, which may pose challenges for users in consistently providing commands through a connected mobile device.

Subsequent studies have explored diverse approaches to voice controlled wheelchair systems. Mane et al. (2023) presented a voice-controlled wheelchair solution at the 2nd International Conference on Vision Towards Emerging Trends in Communication and Networking Technologies (ViTECoN) [5], demonstrating the potential of voice commands in facilitating intuitive wheelchair control. However, a limitation in their approach, similar to the first paper, is the dependency on mobile devices for voice command input, which may present usability challenges for users and be restricted to wheelchair control.

Krishna et al. (2021) proposed a system combining voice control with joystick-based navigation [6], offering users flexibility in choosing their preferred control modality based on their abilities and preferences. While this approach addresses some user preferences, it also relies on voice recognition modules v3, which support a limited (maximum of eight) number of commands [7], restricting the full potential of controlling smart devices within the home environment.

Joly, Pradeep, and Kavitha (2023) contributed to this body of research with their work on "Intelligent voice-controlled wheelchairs for disabled people" [8], emphasizing the importance of intelligence and adaptability in wheelchair systems to cater to diverse user needs and environmental challenges. Despite the intelligent features, their reliance on voice recognition modules v3 with limited command capacity presents a notable gap in the system's ability to control a wide array of smart devices effectively.

Abdullah et al. (2021) presented a "Smart wheelchair with voice control" [9], integrating voice control capabilities through an Arduino voice control app. However, similar to previous approaches, this method may pose challenges in providing seamless and comprehensive control over smart devices due to limitations in the number of supported commands and dependence on mobile devices.

Furthermore, advancements in voice recognition technologies have been pivotal in enhancing the performance and reliability of voice-controlled systems. Patel, Gupta, and Gajjar (2023) showcased the implementation of real-time voice recognition using Tiny ML on Arduino Nano 33 BLE [10], demonstrating the feasibility of deploying lightweight machine learning models on resource-constrained platforms for efficient and responsive control.

Moreover, researchers have explored the application of various machine learning algorithms, such as convolutional neural networks (CNNs) and support vector machines (SVMs), for voice control in wheelchair systems. Sharifuddin, Nordin, and Ali (2020) conducted a comparative study on CNNs and SVMs for voice control [11], highlighting the importance of algorithm selection in optimizing system performance and user experience.

In addition to wheelchair control, the integration of home automation functionalities further enhances the utility and accessibility of these systems. Prasad et al. (2021) demonstrated the feasibility of voice-controlled home automation [12], laying the groundwork for seamless integration with wheelchair control systems to provide users with comprehensive control over their environment.

In light of these findings, a key research gap emerges in the need for voice-controlled wheelchair systems with robust voice recognition capabilities that can support a wide range of commands for effective home automation integration and do not have to rely on mobile devices for giving commands. This research focuses on addressing these gaps by exploring advanced voice recognition technologies and sensors and integrating them seamlessly into wheelchair control systems to enhance the user experience and accessibility.

## 3. METHODOLOGY

The methodology section begins by identifying the central problem statement, highlighting the difficulties encountered by individuals with mobility impairments, particularly the elderly, in effectively managing traditional wheelchairs and household devices. These challenges include limited motor skills, coordination issues, and the need for integration with home automation systems. By acknowledging these barriers, the methodology sets the groundwork for the systematic development and assessment of a voice-controlled wheelchair system designed to cater to the specific needs and constraints of the target user group.

### 3.1 Model Development

#### *3.1.1 Data Collection*

The Speech Commands Dataset from TensorFlow datasets is used to create a model for wake word detection. This dataset contains over 100,000 audio files of 36 different spoken English words and background noise [13]. It offers a diverse range of audio samples, which helps in training and evaluating machine learning models for wake word detection, IoT, and robotics applications [14].

#### *3.1.2 Preprocessing*

The raw audio waveforms from the dataset are transformed into spectrograms to facilitate model training. Spectrograms provide a visual representation of audio frequencies over time, resembling images, which are more amenable to processing by neural networks. The preprocessing pipeline includes normalization, random audio segment shifting, and the addition of background noise samples to improve model performance.

The wake word "Marvin" was selected from the Speech Commands Dataset due to its uniqueness and distinctiveness among the available options. The dataset comprises numbers from “0” to “9” and common words such as "Yes", "No", "Up", "Down", "Left", "Right", "On", "Off", "Stop", "Go", "Forward", "Backward", and others. Among these, "Marvin" stood out as a unique and less commonly used word, making it an ideal choice for wake word detection.

#### *3.1.3 Selection of Model Architecture*

A convolutional neural network (CNN) architecture is chosen for the wake word detection model due to its effectiveness in analyzing image (spectrogram) data. The CNN comprises convolution layers, max-pooling layers, densely connected layers for feature extraction, and softmax for classification.

#### *3.1.4 Training Process*

The model is trained using TensorFlow's high-level APIs, with training, validation, and test datasets used to evaluate performance [15]. Training is performed with data shuffled and batched for efficient processing. Hyperparameters such as learning rate, batch size, and optimizer settings are tuned to optimize model accuracy and convergence. Additionally, ambient background noise recordings are incorporated to augment the dataset and enhance the model's robustness.

#### *3.1.5 Model Evaluation*

After training, the model's performance is evaluated on separate validation and test datasets to assess its ability to detect the wake word "Marvin" accurately. Metrics such as accuracy, precision, recall, and F1 score are computed to quantify model performance.

#### *3.1.6 TensorFlow Lite Conversion*

Once the wake word detection model is trained, it is converted to TensorFlow Lite (a lightweight version optimized for deployment on embedded devices) format for deployment on the ESP32. The conversion process involves passing the trained model through the TFLiteConverter, along with sample input data, to accurately quantize the model. Subsequently, a command-line tool generates C code from the converted model, enabling seamless integration into the project's embedded systems. TensorFlow Lite enables efficient execution of machine learning models on devices like the ESP32, Arduino Nano 33 BLE Sense, Sparkfun Edge, etc., ensuring optimal performance and minimal memory usage.

## 3.2 Hardware Setup

The hardware components selected for the project, including the ESP32 development board, INMP441 microphone, L298 motor driver, DC motors, ultrasonic sensor, and LED indicators, were carefully chosen based on criteria such as compatibility, performance, and cost-effectiveness.

For this system, two ESP32s are configured as a master and a slave; both are connected to the same WiFi [16]. The master ESP32 serves as the central processing unit, facilitating communication between various components of the system and connected APIs via WiFi. It communicates with the slave by using the HTTP protocol through the WiFi by using the MAC address. The slave ESP32 is connected to all the smart devices and controls them according to the commands from the master ESP32.

The INMP441 microphone module captures voice commands from users, while the L298 motor driver translates digital control signals into precise motor movements, enabling the wheelchair to navigate effectively. Ultrasonic sensors mounted on the wheelchair detect obstacles in the surrounding environment, providing crucial data for obstacle avoidance. LED indicators integrated into the wheelchair offer visual feedback on operational status, enhancing user awareness and safety during operation.

## 3.3 Software Development

The project's software infrastructure is built upon several key components. Google Colab handles data preprocessing, feature extraction, and model training, while PlatformIO IDE is utilized for firmware development on the ESP32 microcontroller. Wit.AI Natural Language Understanding (NLU) enhances the system's interaction through voice command recognition.

Google Colab is integral to various tasks, such as data preprocessing, feature extraction, model training, and evaluation. Python scripts execute within Colab to process audio data, generate spectrograms, and train the wake word detection model.

Within the PlatformIO IDE, C/C++ code is written to manage voice input from an I2S-based microphone. This code converts voice input into spectrograms and utilizes the trained model to detect wake words. Additionally, programs are implemented for sampling voice commands, buffering them, and uploading them to the Wit API via WiFi using the HTTP protocol.

Wit.AI's NLU processes spoken commands captured by the INMP441 microphone, converting them into text format and detecting user intent. This API recognizes spoken words and phrases, returning textual representations, which are then forwarded to the ESP32 microcontroller for interpretation and execution.

The text commands received from the Wit API contain user spoken text and detected intents in JSON format. A program is implemented to process this JSON response, extracting the intent and executing the associated action, whether controlling the wheelchair or other devices.

For safety features, code related to object detection using ultrasonic sensors and indicator lights is also implemented.

## 3.4 Integration and Testing

Integration of Hardware and Software: The hardware components, encompassing the microcontroller, microphone, motor driver, sensors, and LEDs, are seamlessly integrated with the software stack developed in PlatformIO IDE.

Functional Testing: The voice-controlled wheelchair system undergoes comprehensive testing and evaluation to measure its performance, accuracy, and reliability. Different test scenarios are executed to assess wake word detection, voice command recognition, wheelchair movement control, obstacle detection, and integration with home automation.

Model Evaluation: Performance metrics like accuracy, precision, recall, and F1 score are computed to measure the model's effectiveness and pinpoint areas for refining the wake word detection mode.

## 3.5 Flow Chart

The flowchart (see Figure 1) outlines the sequential steps involved in the operation of the voice-controlled wheelchair system. It begins with the activation of the system, followed by the detection of the wake word "Marvin" using the INMP441 microphone and ESP32 board. Upon wake word detection, the system captures and processes voice commands using the Wit.AI Speech-to-Text API. The recognized commands are then interpreted and executed to control the movement of the wheelchair via the L298 motor driver and DC motors. Additionally, ultrasonic sensors are employed for obstacle detection, ensuring safe navigation. LED indicators provide visual feedback on the wheelchair's status and actions.

The flowchart for the project outlines the sequential steps involved in the operation of the voice-controlled wheelchair system, including integrating hardware components, software modules, and user interactions. The flowchart provides a visual representation of the system's functionality and the flow of data and commands throughout the process.

### *3.5.1 Initialization and Setup*

The process begins with the initialization and setup phase, where the hardware components, including the ESP32 development board, INMP441 microphone, L298 motor driver, DC motors, ultrasonic sensor, and LED indicators, are initialized and configured for operation. The software modules, such as the wake word detection model, speech-to-text conversion module, and home automation integration, are also loaded and initialized during this phase.

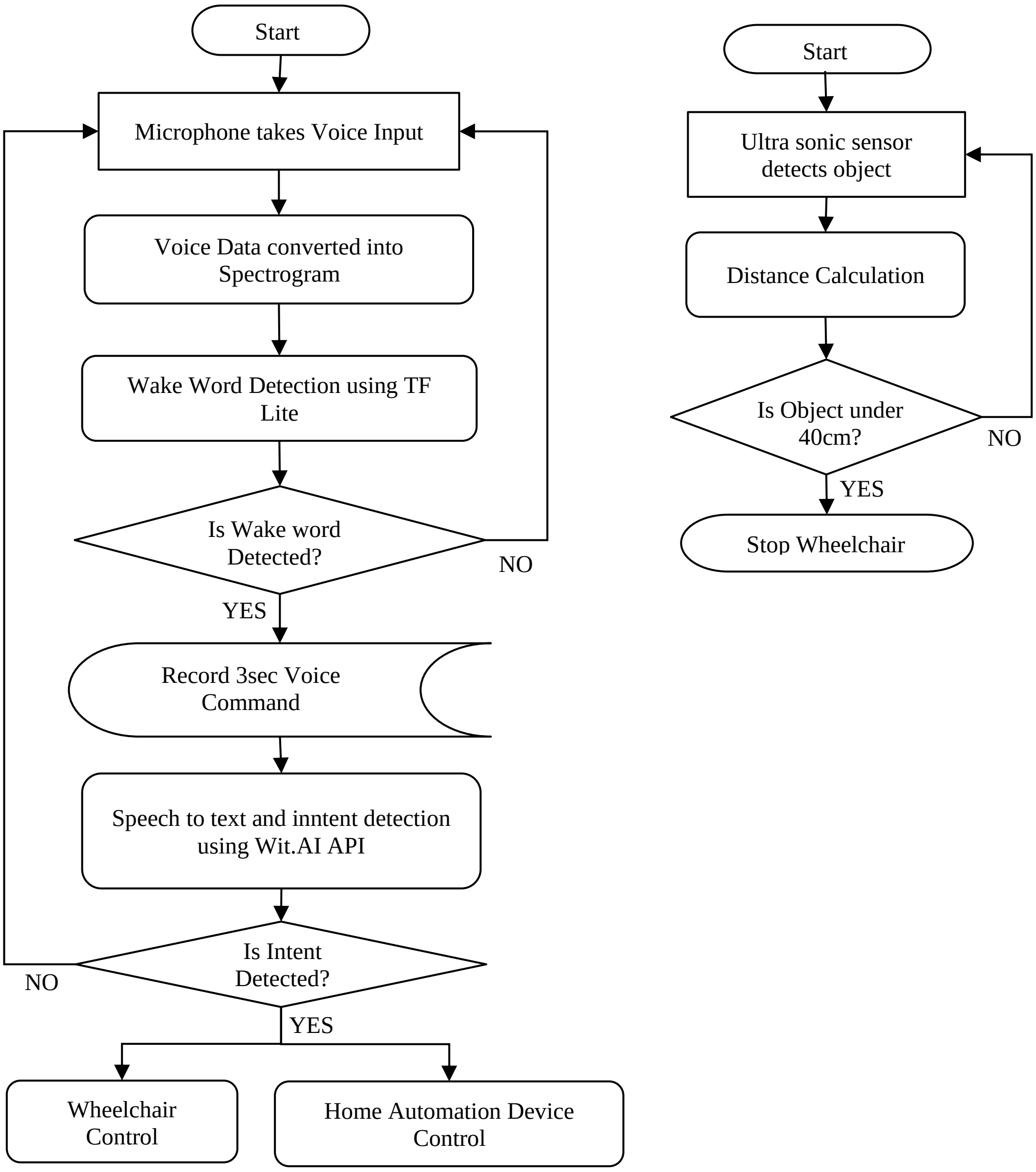


**Fig 1: Flow Chart**

### 3.5.2 *Wake Word Detection*

Upon initialization, the system enters the wake word detection phase, where the INMP441 microphone captures audio input from the user. The audio samples are continuously monitored, and the wake word detection model implemented on master ESP32 analyzes the incoming audio stream by converting the incoming audio into a spectrogram to detect the specified wake word, "Marvin." If the wake word is detected with a high level of confidence, the system proceeds to the next phase.

### 3.5.3 *Speech-to-Text Conversion and Intent Detection*

Once the wake word "Marvin" is detected, the system waits for three seconds to record the command from the user and then initiates the speech-to-text conversion process using the Wit.AI API. The audio input containing the user's spoken commands is converted into text format, allowing the system to interpret and process the user's instructions accurately. The converted text commands are then parsed and analyzed to determine the intent of the user [15]. Based on the user's intent, control of the device or wheelchair's task is processed.

### 3.5.4 *Wheelchair Control*

If the user intends to control the wheelchair, then the system generates control signals to maneuver the wheelchair according to the command. Commands such as "Forward," "Backward," "Left," "Right," and "Stop" are processed to control the movement of the wheelchair's DC motors through the L298 motor driver. The master ESP32 adjusts the motor speed and direction based on the received commands, enabling the wheelchair to navigate its surroundings as per the user's instructions.

### 3.5.5 *Smart Device Control*

Based on the intent, if the user wants to control the devices, the system processes the command to detect the device. Commands related to home automation, such as "Turn on lights," "Close the door," or "Turn on the fan," are interpreted and executed by the master ESP32, and the control signal is sent to the slave ESP32, which controls the home automation devices. The master ESP32 communicates with the slave via WiFi using a MAC address. The slave ESP32 controls the smart devices based on the commands from the master.

#### *3.5.6 Obstacle Detection*
Simultaneously, the system utilizes the ultrasonic sensor to detect obstacles in the wheelchair's path. The ultrasonic sensor emits ultrasonic pulses and measures the time it takes for the pulses to reflect off nearby objects. If an obstacle is detected within a predefined range, the system will stop the wheelchair.

#### *3.5.7 Loop and Iteration*
The entire process operates in a loop, continuously monitoring user inputs, detecting wake words, and executing commands in response to user interactions. The system iterates through the flowchart, adjusting its behavior dynamically based on changing conditions and user preferences. This iterative process ensures seamless operation and responsiveness, providing users with a reliable and intuitive interface for controlling the wheelchair and home automation devices.

### 3.6 Circuit Diagram
The circuit diagram (see Figure 2) shows the voice-controlled wheelchair, which encompasses various interconnected hardware components to enable seamless functionality. It visually represents the electrical connections and signal flow within the system with the master ESP32. Starting with the input stage, the INMP441 microphone module is interfaced with the ESP32 to capture voice commands from users. The microphone module converts sound waves into electrical signals, which are then transmitted to the ESP32 for further processing. This connection ensures that voice inputs are accurately captured and transmitted to the microcontroller for analysis.

Next, the ESP32 is connected to the L298 motor driver, which serves as the interface between the microcontroller and the DC motors responsible for propelling the wheelchair. The L298 motor driver receives control signals from the ESP32 and translates them into appropriate voltage levels to drive the motors in the desired direction.

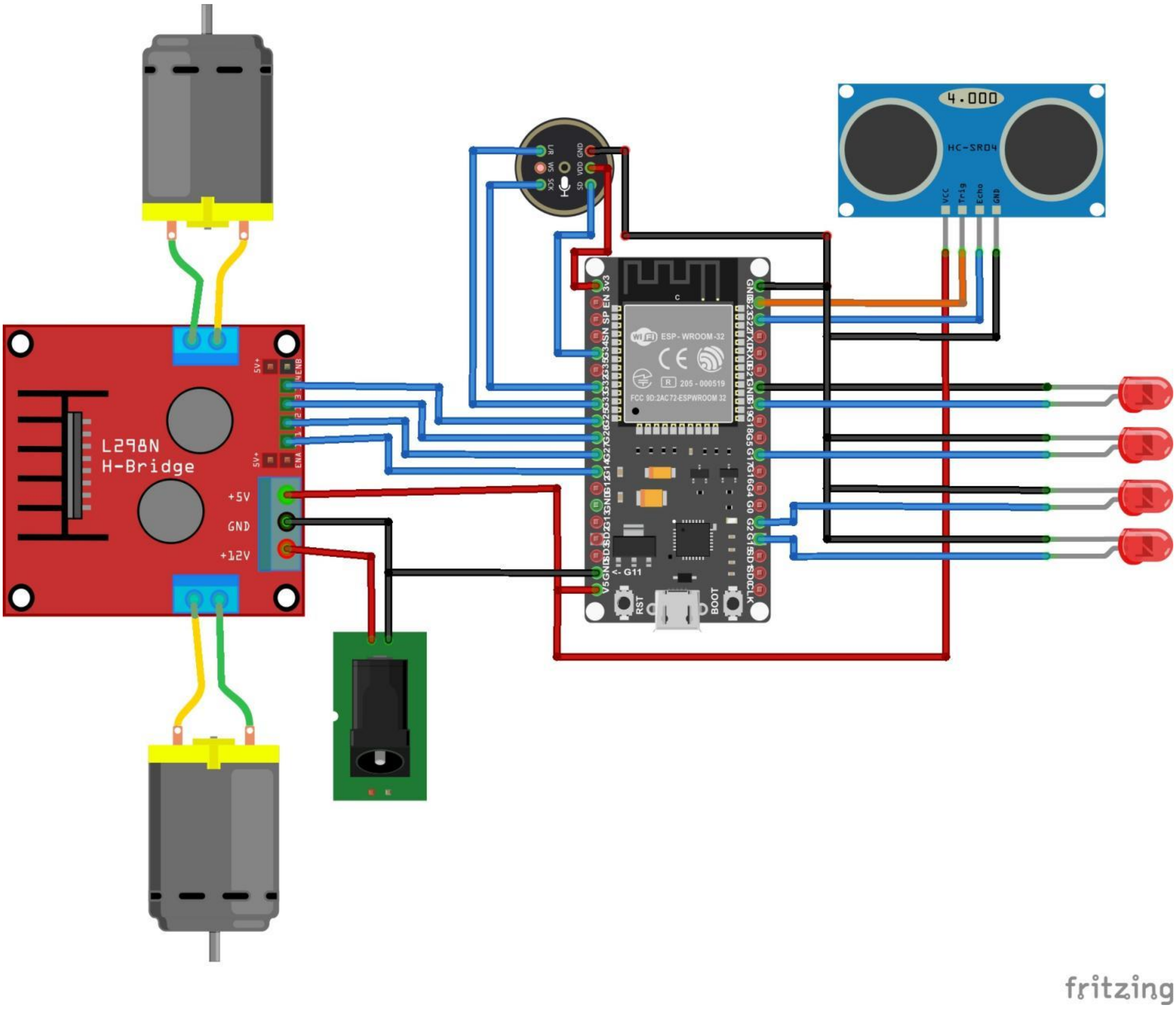


**Fig 2: Circuit Diagram**

By modulating the voltage supplied to the motors, the L298 motor driver enables precise control over the wheelchair's movement, allowing it to move forward, backward, turn left, turn right, or stop in response to user commands.

Additionally, the circuit incorporates ultrasonic sensors to detect obstacles in the wheelchair's path and ensure safe navigation. These sensors emit ultrasonic pulses and measure the time it takes for the pulses to reflect off nearby objects. The distance to the obstacle is then calculated based on the time delay, allowing the ESP32 to adjust the wheelchair accordingly. This obstacle detection mechanism enhances the safety and usability of the wheelchair, enabling it to navigate complex environments with minimal risk of collisions.

Furthermore, LED indicators are integrated into the circuit to provide visual feedback to users and caregivers. These indicators illuminate to convey information about the wheelchair's operational status, such as movement direction, system activation, and obstacle detection. By displaying clear visual cues, the LED indicators enhance user awareness and facilitate smooth interaction with the wheelchair.

Overall, the circuit diagram serves as a comprehensive blueprint for assembling and integrating the hardware components of the voice-controlled wheelchair system. It outlines the connections between various modules and devices, facilitating the construction and deployment of the system in real-world applications.

## 4. RESULT

The results of the voice-controlled wheelchair with home automation integration project (see Figure 3 and Figure 4) demonstrate significant advancements in assistive technology, particularly in enhancing mobility and independence for elderly and disabled individuals. The project achieved remarkable outcomes across multiple dimensions. Firstly, the wake word detection model achieved an impressive accuracy of 95.7%, ensuring reliable recognition of the trigger word "Marvin".

Secondly, the successful integration of home automation devices with the wheelchair adds a new dimension of functionality to the wheelchair, allowing users to control various smart devices in their environment. This integration enhances user convenience and accessibility, empowering individuals to manage their homes more efficiently without any assistance. Thirdly, the implementation of obstacle detection using ultrasonic sensors detects obstacles; if any obstacle is present under 40 cm, then the wheelchair stops automatically.

And lastly, LED indicators give the status of the wheelchair to the people behind it. Further enhancing the usability and safety of the wheelchair in diverse environments.

Overall, the results of the project signify a significant step forward in assistive technology, offering a user-friendly, intuitive, and comprehensive solution for improving the quality of life and autonomy of wheelchair users.

**Fig 3: Voice-Controlled Wheelchair**

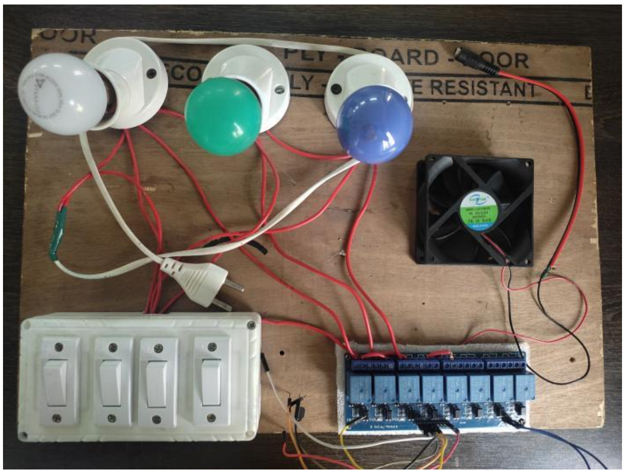

**Fig 4. Home Automation Devices**

## 5. DISCUSSION

The results of the voice-controlled wheelchair with home automation integration project hold significant implications for the field of assistive technology, particularly in addressing the mobility and independence needs of elderly and disabled individuals. However, certain limitations were encountered during implementation:

**Real-World Environment Challenges:** In real-world environments, varying noise levels outdoors reduced the model's accuracy from 95% to 85% in detecting the wake word. The presence of unexpected obstacles outdoors also posed challenges.

**Model and System Optimization:** The project could benefit from further refinement and optimization. Improvements are needed to enhance the robustness of the wake word detection model and to ensure the system's scalability and compatibility with different wheelchair models and home automation setups.

**Future Work**

Future work could explore the integration of additional sensors and advanced technologies, such as:

- Camera Module: For real-time object detection.
- LiDAR: To create a 2D occupancy grid map of the surroundings for self-obstacle avoidance.
- High Processing Boards: Using devices like the Raspberry Pi to process advanced machine learning algorithms for more accurate and adaptive navigation

## 6. CONCLUSION

In conclusion, this project has demonstrated the feasibility and effectiveness of integrating voice-controlled wheelchair technology with home automation, offering a solution to address mobility challenges faced by elderly and disabled individuals. The main findings include the successful development and implementation of a custom wake word detection model, enabling interaction between users and the wheelchair through voice commands. Additionally, the integration of home automation devices adds a new dimension of functionality, allowing users to control smart devices in their environment effortlessly. The project's contributions lie in its holistic approach to assistive technology, combining advanced voice recognition, obstacle detection, and home automation integration to enhance user independence and quality of life. The voice-controlled wheelchair system can be deployed for real-world use in environments such as homes, hospitals, and care facilities. By bridging the gap between mobility assistance and smart home control, this project sets a new standard for intelligent wheelchair design and paves the way for future advancements in the field of assistive technology.

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