Grenze International Journal of Engineering and Technology, January Issue

Design and Implementation of an AI-based Voice Controlled Wheelchair

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***Abstract*— The paper, focuses on developing a voice-controlled smart wheelchair designed to provide enhanced mobility and independence for individuals with physical disabilities. Unlike the traditional manual or joystick operated wheelchair, the voice-controlled wheelchair uses voice commands of the user for navigation which is greatly helpful for persons with limited upper body mobility. The system is powered by an Arduino Uno, which serves as the core controller, integrating Bluetooth technology for receiving voice commands, ultrasonic sensors for obstacle detection, and a motor driver to control the wheelchair's movement. Users can operate the wheelchair effortlessly through simple voice commands, enabling them to move forward, backward, turn in specific directions or halt. To ensure safety, the ultrasonic sensors constantly monitor the surroundings for obstacles, and a buzzer provides minimal delay feedback to the user if any obstacles are detected. The wheelchair is designed to deliver a combination of accessibility, safety, and reliability. Through this paper, we aim to create a practical solution that not only improves mobility but also enhances the confidence/independence and quality of life of users by giving them greater control over their environment with enhanced safety measures.**

***Keywords*— Speech Recognition, Motorized Wheelchair Control, Voice Command Processing.**

I. Introduction

A. Overview

Voice-Controlled Wheelchair is an innovative assistive device which is used to improve mobility and independence for persons having physical disabilities or limited motor skills. In this paper, we developed a wheelchair that moves in response to spoken words, allowing users to control its movement and direction through voice commands thanks the integration of voice recognition technology. Thus, this device offers individuals with severe physical limitations a solution that is both intuitive and liberating: in contrast to traditionally operated manually-driven and powered wheelchairs, which require the use of hand or joystick controls, this design allows near contactless operation.

B. Problem Statement

Persons with physical disabilities, especially those suffering from conditions such as quadriplegia, muscular dystrophy, or age-related mobility impairments, often find it extremely difficult to operate conventional manual or joystick-controlled wheelchairs.

Grenze ID: 01.GIJET.12.1.189

These limitations can hinder their independence and reduce their quality of life. There is a critical need for a more accessible and user-friendly mobility solution that minimizes the physical effort required to control the wheelchair.

With advancements in voice recognition technologies and embedded systems, it is now feasible to develop a wheelchair that responds to voice commands, allowing users with limited mobility to navigate their environment with greater ease and autonomy.

C. Objectives

The work focused on the following objectives after a detailed Background Study

- To design and develop a wheelchair that can be controlled through voice commands, enhancing mobility for physically challenged individuals.
- To integrate a reliable voice recognition module capable of understanding basic navigation commands like "forward", "backward", "left", "right", and "stop".
- To ensure the wheelchair responds accurately and swiftly to user commands with minimal latency.
- To implement safety features that prevent collisions or accidental movements, such as obstacle detection using sensors.
- To build a cost-effective and energy-efficient prototype suitable for practical use. • To test and evaluate the system in real-world environments to validate its performance, usability, and reliability.

D. Motivation

To empower individuals with severe physical disabilities who cannot use their hands to operate traditional wheelchairs.

- To leverage advancements in voice recognition and embedded systems to create smarter, more accessible assistive technologies.
- To address the lack of affordable and user-friendly mobility solutions in developing countries.
- To contribute to inclusive technology design that promotes independence and improves quality of life for the differently-abled.

II. LITERATURE REVIEW

Nishant et.al., in their work, lay the groundwork for designing a voice activated wheelchair. It highlights how technologies like Arduino Uno, ultrasonic sensors, and Bluetooth can work together to create a functional system for mobility. The paper focuses on safety and usability through simple voice commands. Similarly, here in our work we have incorporated components, especially, ultrasonic sensors, to ensure smooth navigation and avoid obstacles [1].

S. Natarajan et al., in their paper, have not only focused on voice commands but also integrated features to bridge communication between users and caregivers. It emphasized safety and reliability, making it a very user-focused design. The work lacked interaction with the environment [2].

A. Kumar et al., in their work have explored how voice modulation can improve command recognition and overall navigation. It highlighted the importance of hardware components like microphones and sensors in achieving accuracy and reliability. The work does not focus on the role of hardware in improving real-world usability, especially when dealing with diverse environments and user [3]

III. PROBLEM ANALYSIS AND DESIGN

A. Analysis

The primary challenge faced by individuals with severe physical disabilities is the inability to operate traditional wheelchairs due to limited or no hand mobility. While powered wheelchairs exist, they often rely on joysticks or other manual controls, which are not accessible to all users. There is a pressing need for a cost-effective, hands-free mobility solution that uses voice commands to control movement. This paper analyses the feasibility and effectiveness of implementing a voice-controlled system to enhance mobility, independence, and quality of life for users with limited motor function.

- Identify the target audience, individuals with physical disabilities or limited motor skills and identifying issues faced while using traditional wheelchairs.
- Understanding user needs, such as Voice commands for movement (forward, backward, left, right, stop).
- Safety features like obstacle detection and buzzer alarm.

B. Hardware Requirements

Components

- Microcontroller (Arduino Uno): Core control unit.
- DC Motors and Motor Driver: For directional control of the wheelchair wheels.
- Bluetooth Module (HC-05): For wireless communication with mobile application to process voice commands.
- Ultrasonic Sensor (HC-SR04): For real-time obstacle detection.
- Buzzer: For auditory alerts in case of obstacles.
- Power Supply Unit (Three 3.7v Li cells): To power all components.
- Basic parts like wooden chair, wheels and jumper wires.

C. Software Requirements

Develop code for

- Voice Command Recognition: Interpreting commands received via Bluetooth mobile application.
- Obstacle Detection and Avoidance: Using ultrasonic sensors to calculate distances (formula=duration/58.9) and stop when obstacles are too close. (>14cm).
- Motor Control: Implement logic to move the wheelchair in directions based on commands.

D. Hardware Technology Diagram

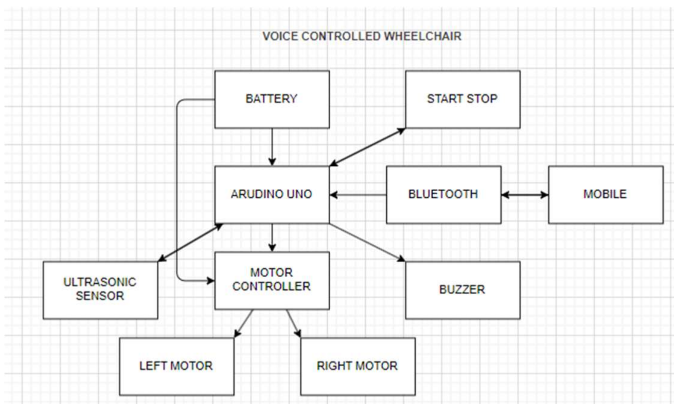

Figure. 1 Architecture Diagram

E. Operational Blocks in the Proposed Prototype

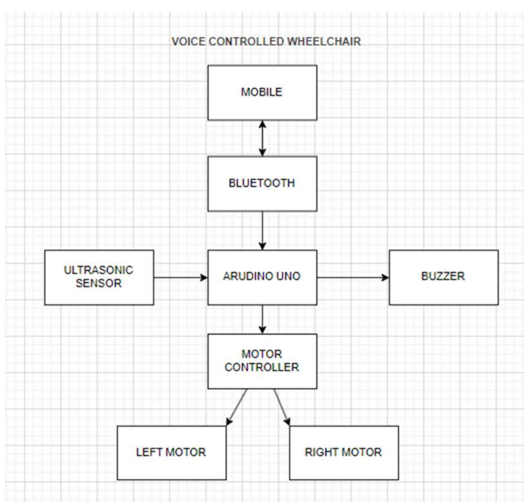

Figure 2. Design: Operational Blocks in the proposed prototype

F. Working Model: Design and Implementation

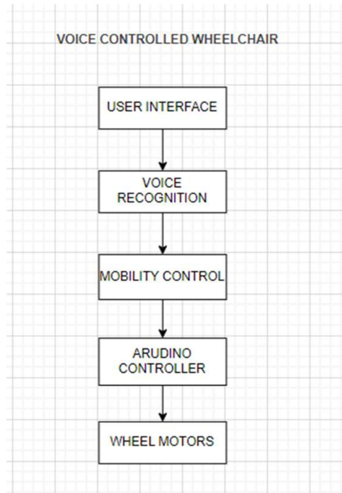

Figure 3. Diagram depicting working model

IV. Implementation

A. Overview of System Implementation

The voice-controlled wheelchair is designed to assist individuals with mobility impairments by responding to voice commands to move in specific directions such as forward, backward, left, right, and stop. The system uses a microphone to capture the user's voice input, which is then processed using a voice recognition module or software such as Google Speech API or an offline speech-to-text engine. The recognized command is interpreted by a microcontroller (e.g., Arduino or Raspberry Pi), which controls the movement of the wheelchair via motor drivers connected to DC or stepper motors

The system includes:

- ➢ Sensor integration with real-time data acquisition.
- ➢ Signal processing on the Arduino.

B. Module Description

Microcontroller Module (Arduino Uno)

- ➢ Interpret voice command signals received via Bluetooth.
- ➢ Make decisions based on sensor input.

Power Supply Unit:

- ➢ Regulate voltage using a buck converter if needed (to maintain 5V/12V levels).
- ➢ Ensure stable power supply for consistent performance.

Motor Control Module

- ➢ Convert low-power Arduino signals into high-power control for motors.
- ➢ Enable bidirectional motor control.

Communication Module (Bluetooth - HC-05)

- ➢ Establish serial communication with Arduino.
- ➢ Transmit user voice input (converted to text commands) from mobile to Arduino.

Obstacle Detection Module (Ultrasonic Sensor)

- ➢ Measure distance using sound waves (echo time).
- ➢ If an obstacle is detected within a threshold (e.g., <20 cm), halt movement.

C. Algorithms

Initialization

- ➢ Initialize Motors:

- Set up motor pins and define motor speeds.
- Initialize Bluetooth:
  - Set up communication with Bluetooth module for receiving commands.
- Initialize Ultrasonic Sensor:
  - Set up the sensor for obstacle detection.
- Initialize Buzzer:
  - Set the buzzer for alerting when an obstacle is detected.

Main Loop

- Receive Voice Command:
  - Wait for a voice command from the mobile device via Bluetooth.
  - If a command is received, proceed to the next step.
  - If no command is received, continue waiting for a valid command.
- Process Command:
  - If Command = 'F' (Move Forward):
  - Activate both motors to move the wheelchair forward.
  - If Command = 'B' (Move Backward):
  - Activate both motors to move the wheelchair backward.
  - If Command = 'L' (Turn Left):
  - Activate the left motor forward and right motor backward to turn left.
  - If Command = 'R' (Turn Right):
  - Activate the right motor forward and left motor backward to turn right.
  - If Command = 'S' (Stop):
  - Stop both motors, ceasing the wheelchair's movement.

Obstacle Detection (using the Ultrasonic Sensor)

- If Distance < 20 cm: Sound the buzzer to alert about the obstacle.
- Stop both motors immediately to avoid collision.
- Else: Continue normal movement.

Repeat the Process

- Continuously check for new commands and sensor readings

D. Code Snippets

```
#include <AFMotor.h>
#include <NewPing.h>
// Pin definitions
const int triggerPin = 9;
const int echoPin = 10;
const int buzzerPin = 8;
// Motor initialization
AF_DCMotor motor1(1);
AF_DCMotor motor2(2);
// Ultrasonic sensor initialization
NewPing sonar(triggerPin, echoPin, 200);
char receivedCommand;
long distance;
void setup() {
  motor1.setSpeed(255);
  motor2.setSpeed(255);
  Serial.begin(9600);
  pinMode(buzzerPin, OUTPUT);
}
void loop() {
  if (Serial.available() > 0) {
    receivedCommand = Serial.read();
```

```
    processCommand(receivedCommand);
  }
  distance = sonar.ping_cm();
  if (distance > 0 && distance < 20) {
    digitalWrite(buzzerPin, HIGH);
    stopWheelchair();
  } else {
    digitalWrite(buzzerPin, LOW);
  }
}
void processCommand(char command) {
  switch (command) {
    case 'F':
      moveForward();
      break;
    case 'B':
      moveBackward();
      break;
    case 'L':
      turnLeft();
      break;
    case 'R':
      turnRight();
      break;
    case 'S':
      stopWheelchair();
      break;
    default:
      stopWheelchair();
  }
}
void moveForward() {
  motor1.setSpeed(255);
  motor2.setSpeed(255);
  motor1.run(FORWARD);
  motor2.run(FORWARD);
}
void moveBackward() {
  motor1.setSpeed(255);
  motor2.setSpeed(255);
  motor1.run(BACKWARD);
  motor2.run(BACKWARD);
}
void turnLeft() {
  motor1.setSpeed(255);
  motor2.setSpeed(255);
  motor1.run(FORWARD);
  motor2.run(BACKWARD);
}
void turnRight() {
  motor1.setSpeed(255);
  motor2.setSpeed(255);
  motor1.run(BACKWARD);
  motor2.run(FORWARD);
}
void stopWheelchair() {
```

```
  motor1.run(RELEASE);
  motor2.run(RELEASE);
}
```

V. TESTING

A. Unit test case

Table 1, depicts the various test cases carried to understand the performance of the proposed model

TABLE I. DIFFERENT TEST CASES CARRIED TO UNDERSTAND THE MODEL PERFORMANCE

Sl. No.	Test Parameter	Observed Results	Remarks
1	Voice Recognition Accuracy	94% (in quiet environment)	Drops to ~85% in moderately noisy conditions
2	Response Time	Average 0.8 seconds	Time between command and movement initiation
3	Command Set Tested	Forward, Backward, Left, Right, Stop	Basic movement commands only
5	Obstacle Detection Capability	~20 cm (with IR sensors)	Basic avoidance; no advanced path planning
6	Battery Backup	Approximately 5 hours	On full charge under average usage
7	Microphone Range	Effective within 1.5 meters	Performance drops beyond 2 meters
8	Hardware Platform	Arduino Uno + Motor Driver + Bluetooth Module	Controlled via Android app with voice input
9	Speech Recognition Type	Offline, English-only	No cloud support; limited to predefined commands

VI. RESULTS

The voice-controlled wheelchair prototype was successfully designed and developed as shown in figure 6.1, it was tested with following outcomes:

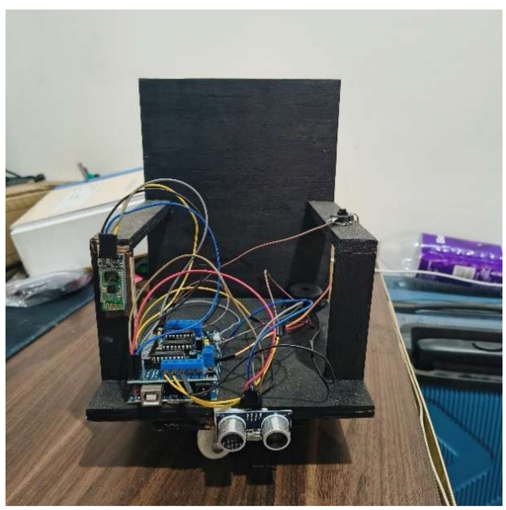

Figure 1: Voice Controlled Wheel Chair

A. Voice Command

The wheelchair responded properly to the predefined voice commands:

- Forward (1): The wheelchair moved forward.
- Backward (2): The wheelchair moved backward.
- Left (3) and Right (4): The wheelchair executed turning maneuvers.
- Stop (5): The wheelchair halted movement.

B. Obstacle Detection

- The ultrasonic sensor effectively detected obstacles within a range of 2 to 20 cm:
- At distances <14 cm, the wheelchair stopped, and the buzzer alerted the user.

C. Bluetooth Connectivity

- Bluetooth communication between the voice recognition device and the microcontroller was stable within a range of 10 meters.
- Latency in command transmission was negligible (<100 ms), suitable for real-time response.

D. Motor Control and Speed

- The wheelchair moved smoothly and maintained directional stability.
- Speed was adjustable via the transmitted command, providing flexibility for user preferences.

E. User Feedback

- Users reported high satisfaction with the ease of operation and responsiveness.
- Some challenges were noted in noisy environments, which affected voice recognition accuracy.

VII. CONCLUSION

The development of the voice-controlled wheelchair demonstrated the feasibility of using voice recognition technology to enhance mobility and independence for individuals with physical disabilities. The system successfully executed directional commands, ensured user safety through real-time obstacle detection, and provided an intuitive hands-free interface.

The integration of a Bluetooth module, ultrasonic sensors, and motor control mechanisms resulted in a functional and user-friendly prototype. Feedback from initial testing indicated moderate satisfaction, though challenges such as noise interference and limited obstacle detection for transparent objects were identified.

Overall, the paper represents a significant step forward in assistive technology, offering a practical and accessible mobility solution. With further refinements, such as advanced voice recognition systems and enhanced sensor arrays, the voice-controlled wheelchair has the potential to become a robust and widely adopted tool for individuals requiring mobility assistance.

FUTURE SCOPE

- Improved Voice Recognition
  - AI-based noise filtering for better accuracy in noisy environments.
- Enhanced Safety
  - Multi-sensor setups (LiDAR, infrared) for better obstacle detection of the tiniest objects.
  - 360-degree coverage for improved safety
- Autonomous Features
  - GPS-based path planning and navigation (something like auto pilot mode)
  - Advanced collision avoidance algorithms to automatically change paths.
- Design Improvements
  - Wheelchair could include further health monitoring systems (BP, glucose levels, HR etc)
  - Enhanced battery efficiency or usage of self-charging batteries.
- Accessibility and Affordability
  - Cost-effective manufacturing to reach underserved populations.

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