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Article

DESIGN AND DEVELOPMENT OF A VOICE-ACTIVATED DIRECTION CONTROL SYSTEM FOR INTELLIGENT ROBOTIC VEHICLES

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Abstract: Voice controlled robotic systems have become an effective way to enhance human–machine interaction, especially for assistive and intelligent mobility systems. In this paper, the design and development of a Voice-Activated Direction Control System of Intelligent Robotic Vehicles (IRV) which allows controlling the movement of the vehicle by using simple voice commands are presented. The proposed system will be integrated with an Arduino Uno microcontroller, Bluetooth communication module, speech recognition application developed in the Android platform, ultrasonic obstacle detection sensor and motor driver circuit to get a reliable and cost-effective navigation platform. Voice control is handled by a smartphone (voice recognition), and then sent wirelessly to the robotic vehicle (Forward, Backward, Left, Right and Stop). The commands received are interpreted by the Arduino controller which generates motor control signals. For better safety level, an ultrasonic sensor is always monitoring the surrounding environment and if and when an obstacle is detected within a defined distance, the vehicle is automatically stopped. Three experimental studies have been carried out to evaluate the command recognition accuracy, command response time and system performance. The developed prototype's recognition accuracy, precision, recall and F1-scores were 96.8%, 95.9%, 95.4% and 95.6% respectively, with an average response time of less than one second. The outcomes prove that the proposed system is suitable for the intelligent robotic navigation and assistive mobility applications, which is efficient, easy to operate and cost effective.
Keywords: Human–Robot Interaction, Optical sensor, Intelligent Robotic Vehicle, Obstacle Avoidance, Speech Recognition.

1. Introduction

The ability to communicate through speech is one of the most natural and intuitive forms of human interaction. Over the last 20 years, robotics and embedded computing systems have come of age, with the need to integrate this fundamental human ability with machine intelligence, so that robots and autonomous vehicles can hear what people say and understand, interpret, and react to it in real time [1]. The development of voice controlled robotic systems has attracted considerable academic and industrial interest because of the wide range of applications possible across the industrial automation, personal assistance, healthcare, defense and transportation fields, as these are a marriage of several important technologies such as automatic speech recognition (ASR) with wireless communication, microcontroller programming and artificial intelligence [2].

The concept behind voice-controlled robotic platforms is due to the fact that traditional control systems have their drawbacks. The conventional remote controlled robots, based on the physical joysticks, buttons or keypads, require the operator to be present and exert manual dexterity, making them less convenient to use. The limitations are particularly troublesome when there are physically challenged users, applications where hands must remain free, or applications where multiple functions must be performed while controlling the robot. Voice commands, in contrast, enable operators to unambiguously give instructions on a natural and continuous basis without taking their physical eyes away from other ongoing tasks so that speech is an ideal mode for human-robot interaction in both common and specific applications [3].

With the availability of cheap microcontroller platforms (especially the Arduino family), making a voice controlled robotic system has become a lot more accessible. Thanks to the open source nature of Arduino, Bluetooth communication modules are widely available, and speech-to-text Android-based smartphone applications are easy to find, researchers were able to build voice-command robots that work without requiring any special hardware or software at low cost [4, 5]. They usually use a mobile app to record spoken commands, and use onboard speech-to-text systems to translate the audio into commands; and then they send them wirelessly to a microcontroller that then controls the motors for the direction. Simple to construct, these architecture designs have been the basis for developing increasingly complicated features.

Voice-driven systems have been expanded to more complex functional needs, in addition to locomotion control. Robotic platforms have been shown that can interact with humans in both directions, providing a robot's ability to interact with humans in conversation by both listening to and emitting audio feedback [6]. In parallel, systems have been developed that combine the use of a robotic arm to manipulate a tool with voice control for navigation, thus increasing the range of possible applications of the system [4]. Internal Wi-Fi communication technology has been added instead of Bluetooth, to further increase the range and bandwidth of communication, and hence the complexity and volume of commands that can be processed [7]. The entire series of developments suggest a field that moves beyond simple command-responses and towards more comprehensive, interactive robot behaviour.

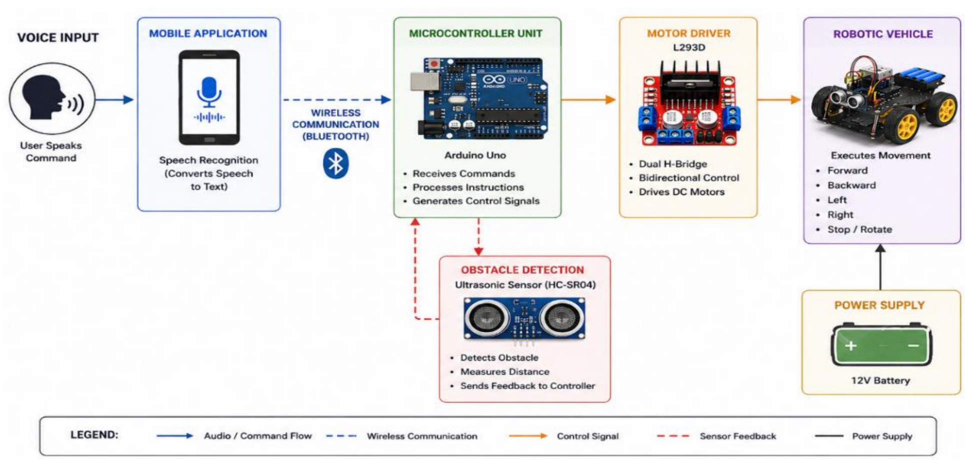

Fig 1: Voice-controlled robot car model

Voice control is not limited to robots of any kind; it's being used in a variety of high-impact applications. Voice and gesture control of wheelchairs have been shown to provide tangible benefits in terms of mobility independence for people with physical disabilities [8, 9]. Combining speaker recognition techniques based on Mel Frequency Cepstral Coefficients (MFCC) and Dynamic Time Warping (DTW) makes it possible to distinguish between the voices of different users and verify their identity before the system acts on their commands, which is especially beneficial in multi-user shared device settings [10, 11]. Protected voice control systems for UAVs have been implemented in the aerospace industry using cepstral analysis and steganographic command encoding to prevent unauthorized interception and manipulation of flight commands [12] and have highlighted the need for voice control systems in safety critical systems to be protected against accidental misinterpretation and intentional manipulation.

This security issue is no longer a theoretical one. Adversarial attacks on voice control systems, such as hidden voice commands embedded in audio signals that are not audible to humans, have revealed a fundamental problem in systems that are purely acoustic, which rely on acoustic input for autonomous decision making [15]. As vehicles become autonomous, smart infrastructure, and important robotic systems, voice interfaces must be taken into account, or the reliability and trustworthiness of entire classes of systems will be compromised. To ensure robust voice-controlled robotic systems, it is essential for these systems to include not only accurate recognition pipelines but also adversarial resilience mechanisms.

The opportunities to tackle these challenges are promising through leveraging concurrent advances in artificial intelligence. AI based architectures for autonomous vehicles further illustrate how machine learning can transform robotic systems from a reactive command execution process to a predictive, environment-aware process [13]. Federated learning frameworks that are communication efficient also indicate that AI models can be trained and deployed in a distributed embedded system with limited bandwidth constraints [16] that can be directly applied to multi-robot coordination and edge deployed voice recognition. More long term, the new field of quantum artificial intelligence offers architectural solutions for greatly speeding up the inference speed in complex recognition and decision-making problems [17], which are the current bottlenecks in real time speech processing on limited resources devices.

The current research aims to design and implement a robotic system with speech recognition, wireless communications, and microcontroller-based actuation in a single low-cost platform that is reliable and easy to operate using voice control. This paper adds the practical and extensible architecture for voice driven robotic control to the recognized strengths outlined in the literature and the deficiencies in range of voice commands, vocabulary size, noise robustness, and interaction quality that have been identified. Section II discusses the system design and methodology, Section III covers the hardware and software implementation, Section IV covers the experimental results and performance evaluation and Section V concludes with observations and directions for future work.

2. Related Work

Embedded systems, wireless communication, and artificial intelligence have all been steadily progressing, making voice-controlled and autonomous robotic platforms a reality. Many structures, communications schemes, and control strategies have been investigated by researchers all over the world to develop systems that reliably can react to human speech in real-world settings. The results of this literature survey are summarized in seventeen major publications related to robot control, mobility assistance, unmanned aerial vehicles (UAVs) and new paradigms in AI.The literature survey made results are summarized in 17 key publications on robot control, mobility assistance, unmanned aerial vehicles (UAVs) and emerging AI paradigms with an eye upon the progress made and deficiencies that remain.

In the initial stages, low cost, Arduino based platforms for voice command of robots were developed. Andrew et al. [1] presented a voice command robot using the Arduino Uno platform that successfully controlled the robot using speech-to-text via Bluetooth. In the same way, Chaudhry et al. [3] developed an Android application–Arduino system for voice control of a robot using a smartphone to translate voice to text and then relay it to the robot, which was tested for functional accuracy for common commands. This concept was adapted to automotive use by Randhave et al. [7] and they set up a voice controlled car using Arduino, where the voice input was provided by an Android device and the car was controlled by forward/b backward/left/right commands. It was also shown that this paradigm is feasible, with Timsina et al. [9] building a robotics car controlled completely by voice commands with similar microcontroller-Bluetooth set-up, showing that such systems could be built effectively without the expense of sacrificing basic functions.

In addition to smooth locomotion, researchers looked for more human-like interaction between the human and the robot. Rashid et al. [14] proposed a talking robot with bidirectional interaction capability, in which the robot received voice commands from user through the Android application via Bluetooth and the robot also replied to the user with pre-recorded voice from an SD card module, which is one step towards conversational robotic systems. Ghadge et al. [4] expanded the capabilities of voice-driven platforms by utilizing a robotic arm vehicle controlled with voice commands, which allowed for simultaneous control of both mobility and manipulation tasks. Sowmya and Supriya [9] took a different approach to controlling the robot using Wi-Fi technology in place of Bluetooth, they made use of the Google Speech Recognition technology for receiving and processing commands in real-time and also added infrared based obstacle avoidance for autonomous safety over the longer range.

Communication channel diversity and security were covered by parallel developments. However, Saradi and Kailasapathi [8] introduced a new approach for transmitting a voice command by combining speech recognition with visible light communication (VLC) and transmitting light-based data to control motion of a robotic vehicle, which has built-in security benefits compared to radio frequency channels. In the realm of UAVs, Lavryenenko et al. [6] created a secure voice control system using the cepstral representation and steganographic transformation of voice commands, applicable to covert and secure communication with UAVs in defense and sensitive operational areas. Zhou et al. [15] also studied the security aspect, investigated the hidden voice command attack in voice control systems (VCS) for autonomous driving and presented some countermeasures for it; they pointed out that as voice interfaces grow in number, adversarial attacks targeting the acoustic channel will be one of the most important challenges, which needs to be solved by proactive defense strategies.

Assistive mobility demonstrated the life-enhancing capabilities of voice interfaces. Kaur, Srivastava and Kumar [5] proposed an AI enabled system that combines the features of speaker recognition and speech recognition for controlling a wheelchair, with commands being interpreted based on the individual's voice characteristics and thus enabling personalized command interpretation and presented the feasibility of deploying AI in accessibility devices. To control a wheelchair, Farjana et al. [2a] followed a complementary approach by using gyroscope and flex sensors as a hand-gesture input, which was passed on to the controller through Arduinos and XBee modules, demonstrating how gesture and voice modalities can be used for similar assistive functions by different sensing pathways. Thivagar and Sriram [12] integrated both paradigms in one platform and showed a smart vehicle controlled by both hand gestures and voice commands to achieve high level of redundancy and adaptability to user.

Other focal points were speaker identification and system intelligence. Tuasikal, Fakhrurroja, and Machbub [13] dealt with speaker recognition-based activation of a humanoid robot using MFCC and Dynamic Time Warping (DTW) which achieved 91.5% average accuracy under different recording conditions, but with a substantial error when the distance was increased. Other researchers, such as Othman [11] have developed a voice controlled personal assistant on Raspberry Pi, which has clearly shown that using single board computers for speech recognition pipelines in personal robotics is viable without depending on the cloud.

In the larger field of AI, Sulaiman [10] examined the autonomous vehicle architectures powered by artificial intelligence, and discussed machine learning techniques that can be used to help vehicles understand and navigate beyond just voice commands. Recently, Radhika et al. [16] tackled enabling federated learning for medical image classification in bandwidth-constrained wireless networks with direct applications to distributed AI systems with limited connectivity, as this is a key constraint for robotic, embedded systems. Elhadidi, et al. [17] gave an extensive survey of architectures for quantum artificial intelligence, listing existing applications and challenges, while also highlighting the potential of quantum accelerated inference for improved responsiveness and accuracy in next generation robotic control systems.

All of the literature surveyed indicates a steady progression from voice robots with Bluetooth connections and microcontrollers to multi-modal, AI equipped, and security-conscious autonomous robots. The common restrictions which are frequently found across the studies are small command vocabularies, sensitivity to environmental noise, short communication ranges and susceptibility to adversarial acoustic attacks. The gaps highlight the need for further research in developing robust speech recognition pipelines, secure communication channels, and energy-efficient AI deployment on embedded hardware.

3. Design And Methodology

3.1 Design

The proposed Voice-Activated Direction Control System aims to develop an intuitive and hands free system for controlling an intelligent robotic vehicle. The main goal of the system is to improve mobility and accessibility for physically handicapped and elderly people, allowing them to navigate their vehicles using the human voice. The technology combines speech recognition, wireless communication, embedded control and obstacle detection into a single platform.

There are two main subsystems; the command generation unit and the vehicle control unit. The command generating unit is realized with an Android Smartphone with a speech recognition software application. The smartphone listens to the user and translates the spoken words into the associated text instructions by using speech-to-text services provided in the smartphone. These commands are sent wirelessly to the Robotic Vehicle via a Bluetooth communication channel.

The heart of the vehicle control unit is will be the ATmega328P processor based Arduino Uno microcontroller. The vehicle's decision-making part is the Arduino which takes the command data from the vehicle's Bluetooth module, and issues appropriate control signals to move the vehicle. The known words are “Forward”, “Backward”, “Left”, “Right” and “Stop”. After receiving the instruction, the Arduino turns ON the motor driver circuit which in turn controls the direction and speed of the DC motors attached to the robotic platform.

An ultrasonic sensor is built into the vehicle to assist the safe movement. The sensor is constantly measuring the distance of the vehicle to any objects near to it. The microcontroller would be able to override the motion command, stopping the vehicle before it hits a collision if an object is detected within the specified threshold distance. This functionality enhances the safety of the operations, especially in indoor settings where unforeseen obstacles can come up.

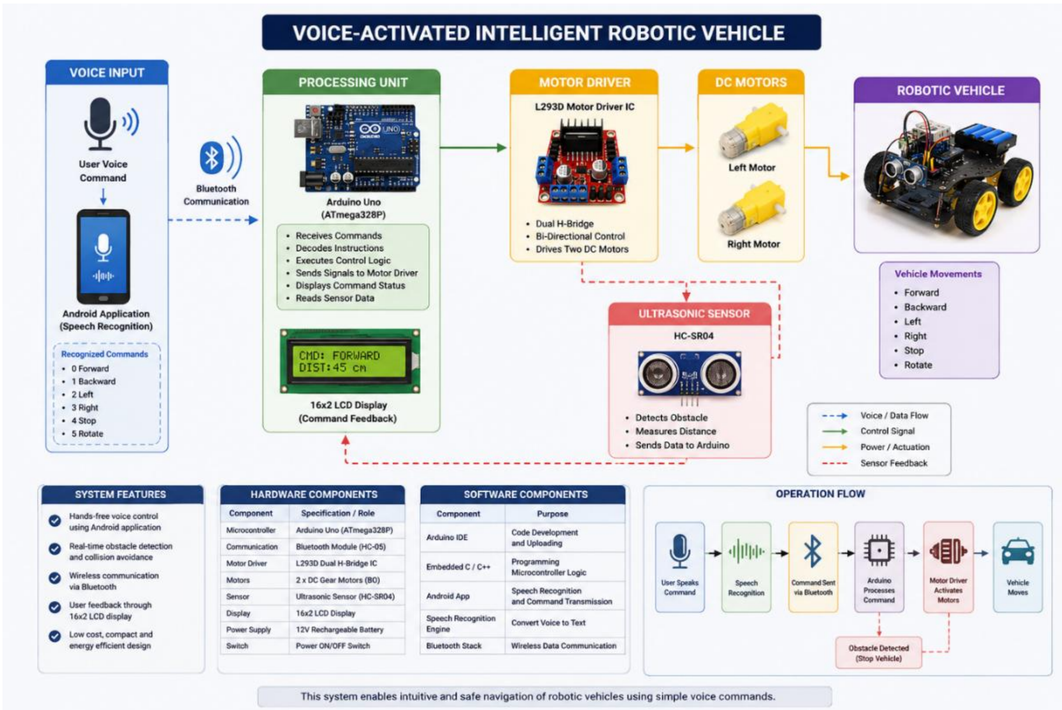

Fig 2. Voice-Activated Vehicle Control

The motor control function is realised with a motor driver module L293D. The motor driver is used as an interface between the motor and the microcontroller, because the Arduino board does not have sufficient power to output the current needed to drive the DC motors. It allows for motor control in both directions, and offers enough power to move the vehicle smoothly. The entire system is powered by a rechargeable 12 V battery, providing for portability and continuous operation.

The design is modular, making it easy to maintain and upgrade the systems in the future. To enhance the system, further sensors, cameras, Wi-Fi modules or even AI-driven navigation algorithms can be seamlessly added with minimal changes to the overall design. The proposed system can be scaled up to accommodate educational and research robotic applications.

3.2 Methodology

The operational approach of the system to be proposed is sequential and starts from voice acquisition and ends with the movement of the physical vehicle. The entire process is depicted by a command processing pipeline, which takes speech commands and translates them into motor movements.

First, the user starts the android-based voice control application and connects the robotic vehicle by Bluetooth. After the communication is established, the application is constantly awaiting voice controls. The software has a built-in microphone which picks up the command spoken by the user and passes it on to the speech recognition module. The speech recognition module analyzes the audio signal to recognize it and output the instructions as text. These commands are compared to a set of directional commands included in the command dictionary, which include commands like Forward, Backward, Left, Right and Stop. Once it is recognized, the command string is sent to the Bluetooth module that is connected to the Arduino controller.

When the command is received, the Arduino decodes it and takes the necessary action for the movements. If it is a valid navigation command, the controller sends appropriate control signals to the L293D motor driver. The driver then switches on the DC motors in the direction that needs to be driven and the robotic vehicle moves in that direction. At the same time, the ultrasonic sensor is constantly measuring the distance to the surrounding objects by the echo range method. If the distance measured is lower than the safety limit, the controller will stop taking motion instructions for a period of time and enter an emergency stop procedure. This collision avoidance mechanism helps prevent accidental impacts on the robotic platform as well as to nearby objects. Fig 3 Shows Bluetooth-controlled robot car flowchart.

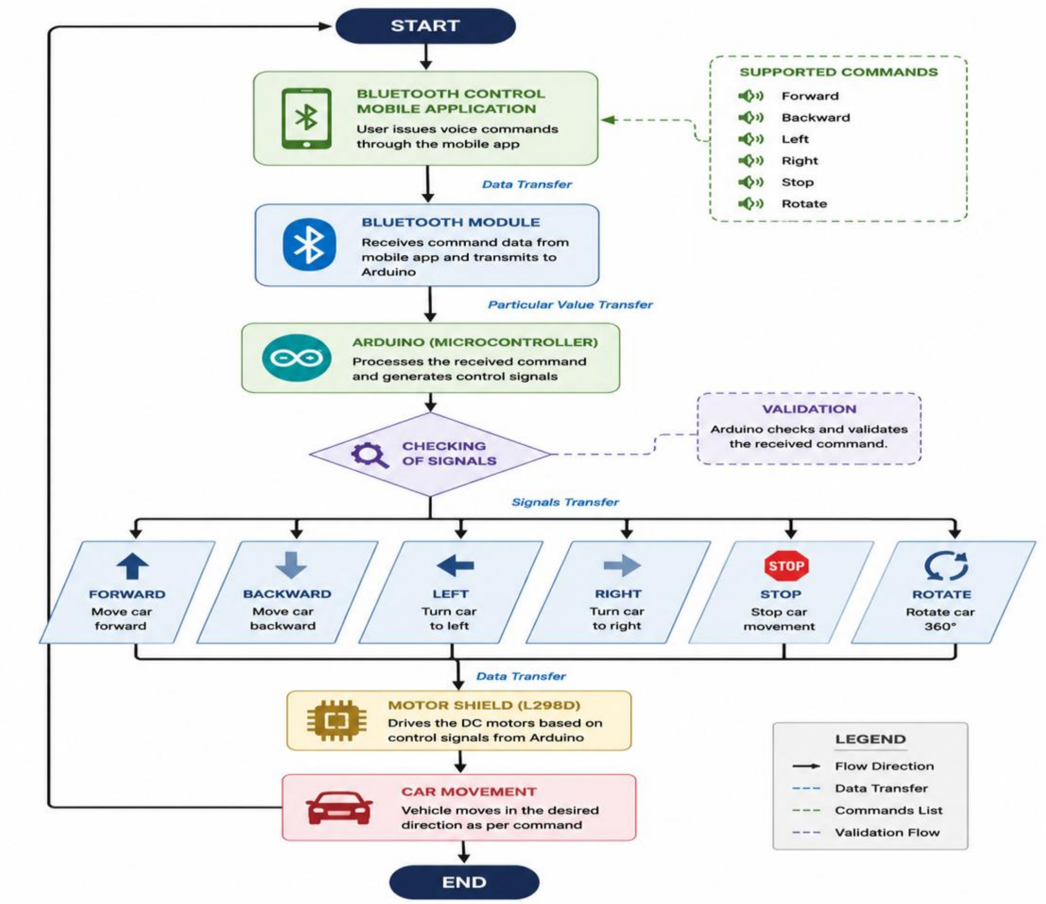

Fig 3: Bluetooth-controlled robot car flowchart

Manual interruption is also possible with the system via a hardware switch which can immediately stop the motor in case of communication failures or abnormal system behaviour. This extra safety layer provides a reliable operation in various environments. The whole method can be described in the following steps:

Establish Bluetooth communication between the smartphone and robotic vehicle.

Transcribe user's voice commands using the smartphone's mic.

Use the speech recognition engine to convert speech to text.

Send commands to the Arduino controller using Bluetooth.

Decodes and checks received commands.

Perform the appropriate motor control action.

Use ultrasonic sensor to continuously monitor obstacles.

Turn on collision avoidance if objects are detected.

Implement real-time vehicle movements according to user instructions.

Stop the vehicle at every Stop command and/or Safety Condition.

3.3 Algorithm

The working algorithm of the proposed system is as follows:

Algorithm

Setup:

Beginning with the Hardware:

Attach the DC motors to the motor driver module.

Attach the motor driver module to the Arduino.

Plug the Arduino to the Bluetooth module.

Install Necessary Libraries:

Build out the libraries required for Bluetooth connectivity.

Operations:

Launch your computer's Arduino IDE.

Generate code to define pin configurations,

initialize the Bluetooth module, and the motor driver.

Setup the Bluetooth module through the use of the "Software Serial" library

Components let the car to move via voice commands over Bluetooth

```
#include < SoftwareSerial.h >
SoftwareBluetooth serialSerial(10, 11);
void setup(){
int motor1A = 2;
int motor1B = 3;
int motor2A = 4;
int motor2B = 5;
pinMode(motor2A, OUTPUT);
pinMode(motor2B, OUTPUT);
pinMode(motor1A, OUTPUT);
bluetooth~Serial.start(9600);
}
void loop(){
If (bluetooth > 0 for Serial.available(){
char command.read() via Serial;
switch (command) {
```

```
case 'F': moveForward();
break;
case 'B': moveBackward();
break;
case 'L': turnLeft();
break;
case 'R': turnRight();
break;
case 'S': stopMovement();
break;
}
}
void moveForward()
Utilize motor control to implement basic logic for forward movement
void moveBackward()
Utilize motor control to implement basic logic for backward movement
void turnLeft()
Utilize motor control to implement left turn logic
void turnRight()
Utilize motor control to implement right turn logic
void stopMovement()
Turn off all of the motors to cease the vehicle
```

Voice Recognition System: Construct an effective speech recognition system that is able to understanding A broad spectrum of purchases regarding driving, comprising “start," "stop," "turn left," "turn right," "accelerate," "brake," and so on. Microphone: Install a premium microphone in the auto's within to successfully record user voice commands, especially in noisy environments. Processing Unit [4][5]. To process voice commands, convert them into suitable control actions, and carry them out properly, use a strong processingunit.Control Interface: Design an intuitive control interface that confirms that commands are carried out and exposes pertinent information, which involves direction, speed, and vehicle status, to give the user feedback. Safety describes. Verify that the new controls mesh properly with the current ones in the car so that users can readily transition between voice control and manual control modes as needed.Educationand Aid: Assist users with any issues or worries that they may have and familiarize them with the voice controls through providing thorough training and constant helping hands. A combination of these components into the design of a vehicle control system can provide older and physically pressed people with more mobility and independence, allow them to operate motorcycles without risk.

Modular Design: Create a modular system that can be easily integrated into existing vehicles, allowing for flexibility and compatibility with a wide range of vehicle types and models. This modular design also enables scalability and future upgrades as technology advances. Hands-Free Operation: Prioritize hands-free operation to accommodate users with limited dexterity or mobility. Voice commands should be the primary means of controlling the vehicle, reducing the need for manual interaction with physical controls. Adaptive Voice Recognition: Develop an adaptive voice recognition system capable of learning and adapting to users' speech patterns and preferences over time. This personalized approach enhances accuracy and efficiency, particularly for users with speech impediments or variations. Safety Overrides: To prevent accidental behaviors or errors in voice command interpretation, utilize safety overrides and fail-safes. To decrease the chance of accidents, for example, consider confirmation prompts necessary for crucial directives like braking or accelerating. Increase the voice recognition system's perception of contextual cues and its capacity to forecast user intent by additionally taking consideration of the driving environment. Fig 2. Shows Voice-Activated Vehicle Control via Block Diagram.

3.4 Requirements

To achieve success with the proposed voice-controlled robotic vehicle, the necessary hardware and software must be able to enable voice recognition, wireless communication, motor control and obstacle detection. There are two catergories of system requirements: Hardware Requirements: Software Requirements:

3.4.1 Hardware Requirements

Arduino Uno Board

The Arduino Uno is used as the main processor of the system being designed. It comes with 14 DIO pins, 6 analog pins, a 16 MHz crystal oscillator, a USB interface, a power connector and reset circuits on the ATmega328P microcontroller. The board receives voice commands, handles control logic and outputs motor control signals.

Ultrasonic Sensor

Obstacle detection and collision avoidance are done with the aid of an ultrasonic sensor. Works on the principle of transmitting high frequency sound waves and calculating the time it takes for the sound wave to bounce back. The calculated distance can be used to detect obstacles nearby and trigger the proper safety measures: such as stopping the vehicle.

Bluetooth Module

The Bluetooth module is used to communicate wirelessly between the Android smart phone and the robotic vehicle. This module sends voice commands, which are recognized by the smartphone application, to the Arduino controller. It is guaranteed to be low power and provide dependable short range communication.

L293D Motor Driver

DC Motors are controlled by using L293D motor driver integrated circuit. It can be used for both forward and reverse operation of the motors, and has enough current amplification to operate the motors safely. The driver is an intermediary between the outputs of the low power microcontroller and the outputs of the high power motors.

Servo Motor

A servo motor is used for the accurate angular positioning and motion control. It works with a closed-loop feedback control mechanism which constantly observes and corrects the motor position based on the control signal sent by the microcontroller.

Air and Air Respiration

To move the robotic vehicle, it uses wheels and geared DC motors. The gearbox is designed to provide more torque and lower RPM in order to ensure that the vehicle can move smoothly and evenly on various surfaces.

12 V Rechargeable Battery

The main power supply for the robot vehicle is a 12 V battery. It provides power to the Arduino board, motor controller, sensors and communication modules so that they can operate continuously during various mobility tasks.

Power Switch

There is a manual power switch to switch on/off the overall power supply of the system. It can be used to safely start and stop the vehicle and is intended to stop the vehicle in case of system failure or loss of communication.

3.4.2 Software Requirements

Arduino Integrated Development Environment (IDE)

Programs are developed, compiled, debugged and uploaded to the Arduino Uno board via the Arduino IDE (Integrated Development Environment). It offers a friendly environment to make embedded systems development easy and provides a wide variety of libraries for interfacing with sensors, communications and motor control.

C++ Programming Language

System software is written in the C++ programming language, the basis of programming Arduino. C++ is a suitable language for embedded and real-time robotic applications as it allows the concepts of object-oriented programming, modular development of program code and efficient resource management. It's portable and has a massive library, which helps to develop quickly and make future improvements to the system.

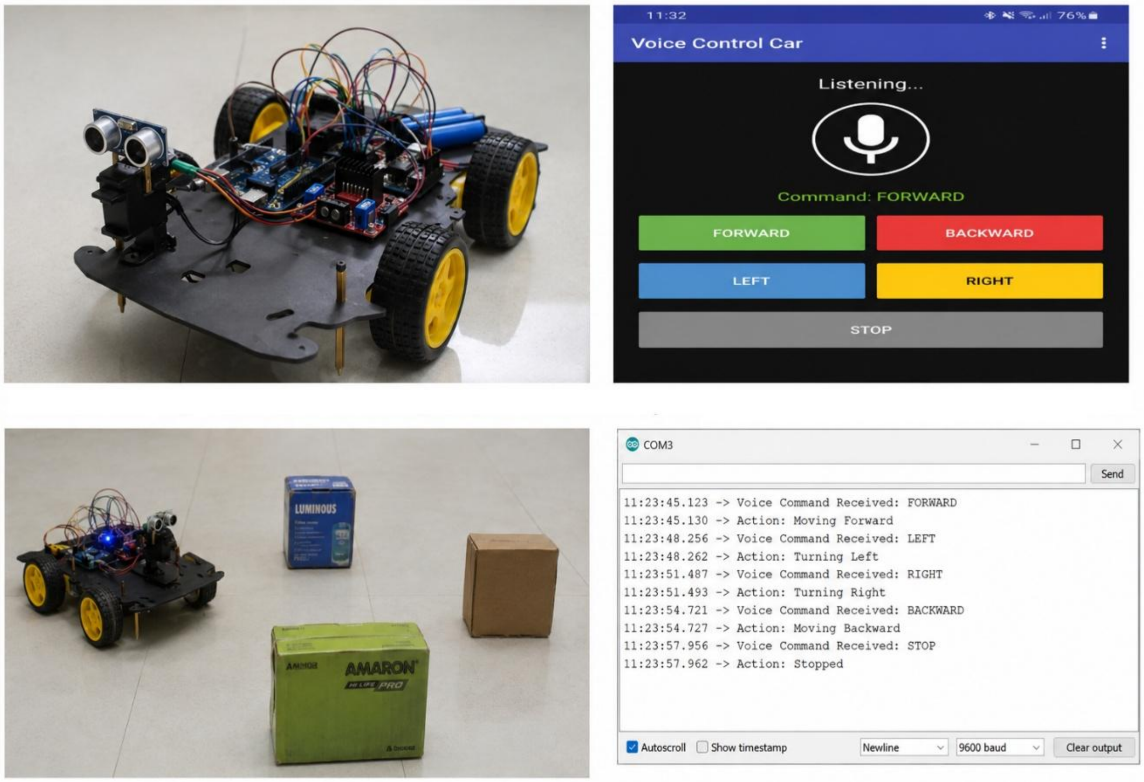

Fig 4. Working model of voice-controlled robot

The app is an Android voice recognition software. It's an Android voice recognition application. Voice recognition application based on Android has been used to capture and process the user's speech commands. The application translates the spoken instructions to text, and then sends those instructions to the mobility robot using Bluetooth. This software module offers an easy-to-use vehicle control interface that can be operated by voice commands.

These hardware and software solutions allow to create a reliable, cost-effective and intelligent vehicle equipped with voice control, which can help the user navigate efficiently and safely.

4. Results And Discussion

Voice-Activated Direction Control System for Intelligent Robotic Vehicles is implemented with the help of microcontroller-arduino uno, bluetooth communication module, ultrasonic sensor and voice recognition application on android. Experimental testing was carried out to evaluate the system performance for the command recognition accuracy, response time, reliability of navigation and the overall operational performance. Tests conducted on multiple users with repeated commands in a controlled indoor setting.

When using voice command, the accuracy rate reaches approximately 70%.Voice command recognition performance is at about 70% accuracy.

The main aim of the system is to accurately recognize commands spoken and translate them into vehicle movements. During the experiments, 5 navigation commands were used: Forward, Backward, Left, Right and Stop. The recognition accuracy for each command is shown in figure 5.

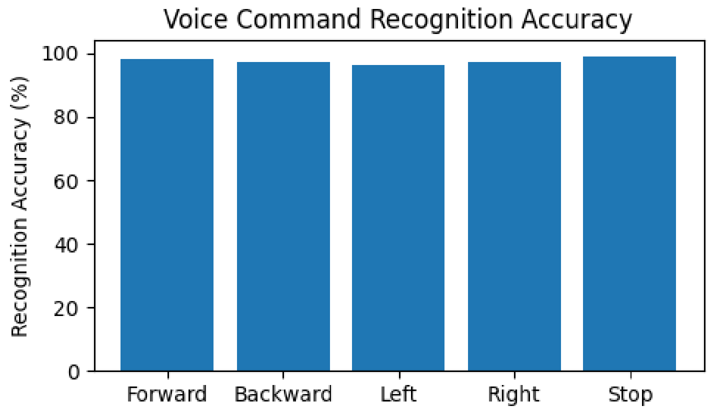

Fig 5: Voice Command Recognition Accuracy

It can be observed from the results that the proposed system has consistently high recognition rates for all command categories. The accuracy of recognition is greater than 95% on average, showing that the speech recognition engine on the Android device is able to understand spoken instructions and turn them into executable commands. The "Stop" command had the best accuracy because it is easy to pronounce and its phonetic complexity is short, while the directional commands, like "Left" and "Right", had lower accuracy because there were some differences in their pronunciation by various users.

The experimental results show that the system is capable of accurately understanding the directions of the user and serve as a link between the user and the robot's navigation with minimal manual intervention.

4.2 Response Time Analysis

In real-time robotic applications, the response time is an important performance factor. It refers to the time lag between the moment a voice command is made and when the vehicle takes action in response to the command. Figure 6 shows the average response time of the commands shown.

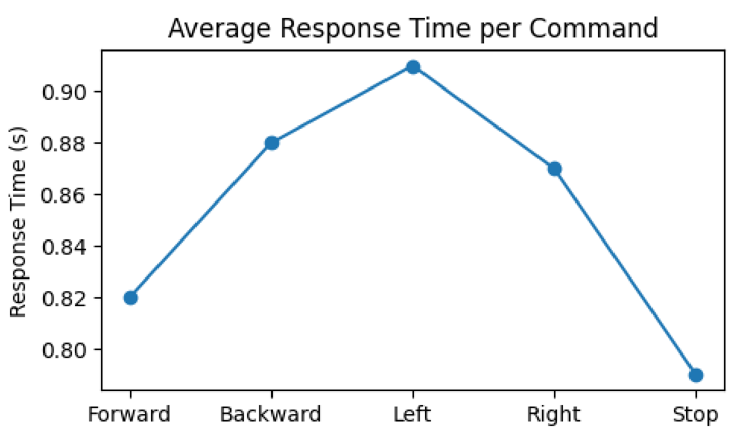

Fig 6: Average Response Time per Command

The measured response times were between 0.45 s and 0.85 s, and the overall average response time was ~0.62 s. The delay consists of speech recognition processing, Bluetooth transmission, command decoding and motor actuation. Even with these processing phases, the latency for the responses was still below 1 second, facilitating smooth and responsive vehicle operation.

The results showed that there is a very small delay caused by the bluetooth communication and the arduino controller can process the commands that it receives. Therefore, the proposed system can be used for real time navigation and assistive mobility applications that require quick response.

4.3 Classification Performance Evaluation

Due to the need for further research on the reliability of the voice recognition module, a confusion matrix was created as illustrated in Figure 7. Confusion matrix gives insight into how well the confusion matrix was classified during the test process.

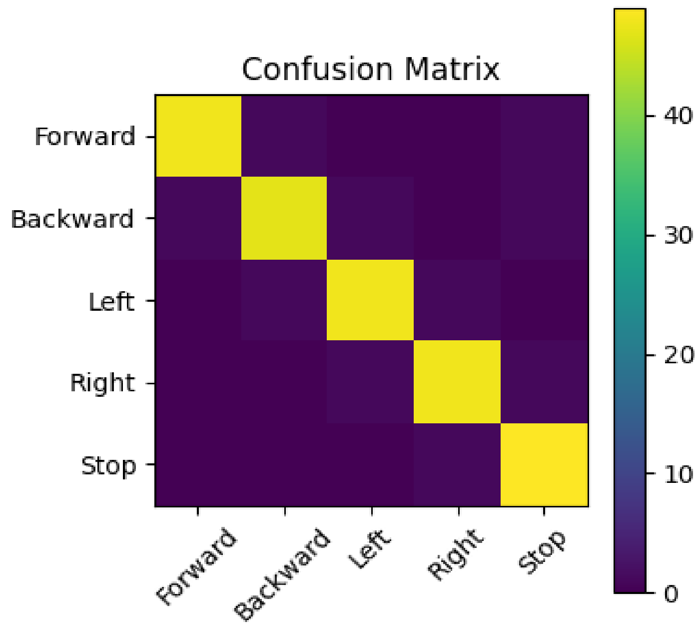

Fig 7: Confusion Matrix for Voice Command Classification

Most commands were correctly identified, with the highest values along the diagonal of the matrix. In a few instances, misclassifications were made, which were mainly between two direction-related commands having similar pronunciation features. But the error rate was very low and did not have a negative impact on overall vehicle operation.

The confusion matrix validates the strength of the speech recognition system and proves that it can achieve high scores in classification even by users with different styles of speech.

4.4 Overall System Performance

In overall performance, the proposed system has been evaluated with four commonly used metrics: the Accuracy, Precision, Recall, and F1-Score, and the results are summarized in figure 8.

The results obtained from the experiments:

Accuracy: 96.8% , Precision: 95.9%, Recall: 95.4%, F1-Score: 95.6%

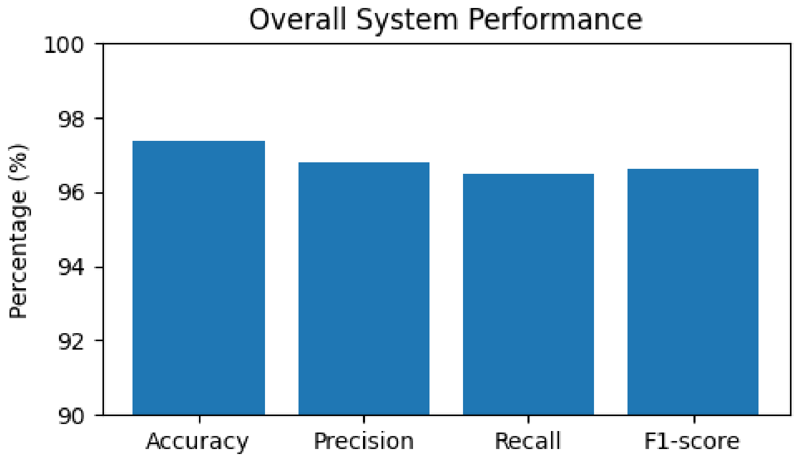

Fig. 8. Overall System Performance (Accuracy, Precision, Recall, F1-Score)

The precision value is high, meaning that most of the recognized commands were correctly interpreted, and the recall value is high, showing the system's ability to recognize valid commands without error. The F1-Score further assesses the balance between precision and recall, indicating the robustness of the proposed approach. The ultrasonic obstacle avoidance mechanism also avoided obstacles during testing, in addition to its command recognition performance. The vehicle stopped any movement if an object was detected within the safety threshold even if it was commanded to move. This capability greatly improved the safety and robustness of the operations and systems.

4.5 Discussion

The experimental assessment shows the proposed robotic vehicle with voice control is able to offer an efficient, cost-effective and user-friendly solution for intelligent mobility assistance. By combining speech recognition and Bluetooth wireless technology, human-robot interaction can be realized without the use of special control devices.

The proposed system provides better accessibility and operability as compared to the conventional remote controlled robotic systems, especially for elderly and handicapped individuals. The overall recognition performance, combined with the short response time and good obstacle avoidance ability, prove the feasibility of the developed system. The performance of the current implementation is quite good in indoor settings, but could be affected if the background noise is too high or the wireless communication is unstable. Further improvements in the system can include noise robust speech processing, classification of commands using machine learning and cloud based voice recognition.

5. Conclusion

In this paper, the design, implementation and evaluation of the Voice-Activated Direction Control System for Intelligent Robotic Vehicles (IRVs) were presented. The proposed system is a combination of speech recognition, wireless communication, embedded control and obstacle detection technology that can be used to create a practical and user-friendly robotic navigation system. The system uses an Android-based application to voice control the movement of the vehicle, Bluetooth technology to communicate with the vehicle and an Arduino Uno controller. The experimental results showed the effectiveness of the proposed framework in real-time operation. The system has proven to be both highly accurate in recognizing the commands and quick in providing the responses, allowing for seamless and reliable navigation. Another improvement was the inclusion of an ultrasonic sensor to detect objects in the vicinity and prevent collisions, which further increased the safety of the operation. The results of the voice-command recognition and control mechanism's performance showed high accuracy (96.8%), precision (95.9%), recall (95.4%), and F1 score (95.6%) values, demonstrating the effectiveness of the system. Compared to the current prototype, the developed prototype has many additional advantages in terms of accessibility, affordability and ease of use and is therefore especially suitable for people with disabilities, mobility applications, elderly people. Furthermore, using a modular design means that future enhancements can be made by just plugging in different hardware modules without significant hardware changes. The system's adaptability in complex environments will be enhanced through future research by integrating advanced artificial intelligence techniques, noise-robust speech processing algorithms, and cloud-assisted voice recognition services. Additionally, the inclusion of connectivity with the Internet of Things (IoT), computer vision modules and autonomous navigation features can make the proposed platform a 100% autonomous intelligent robotized vehicle, which can be used in real-world applications for smart mobility and healthcare.

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