Design and Implementation of a Voice-Controlled Robotic Vacuum Cleaner for Smart Home Applications

Kirti Chavan[1], Nishita Wani[2], Aryan Patil[3], Rupali Chaudhari[4]

[1,2,3] *Electronics and Computer Engineering, PES's Modern College of Engineering, Pune, India.*

[4] *Professor, Electronics and Telecommunication Engineering, PES's Modern College of Engineering, Pune, India*

***Abstract*—Robotic vacuum cleaners have become an important component of smart home automation because they reduce manual effort and improve cleaning efficiency in indoor environments. However, many low-cost systems still provide limited voice interaction, insufficient obstacle detection, and inefficient navigation in dynamic household settings. This paper presents the design and implementation of a voice-controlled robotic vacuum cleaner that integrates embedded control, wireless communication, and sensor-based autonomous movement. The proposed system employs an Arduino-based control unit, an ESP32 module for voice-enabled connectivity, ultrasonic sensing for obstacle detection, and motor drivers for motion control. The developed prototype accepts user commands, navigates indoor spaces, and performs cleaning operations with minimal human intervention. Experimental observations indicate that the system offers reliable command execution, basic autonomous navigation, and practical cleaning support while maintaining affordability and implementation simplicity. The study demonstrates that combining voice interaction with low-cost robotic navigation can improve accessibility and usability in smart home cleaning applications.**

***Index Terms*—Voice Control, Robotic Vacuum Cleaner, Arduino, ESP32, Smart Home, Automation**

I. INTRODUCTION

Robotic systems are increasingly integrated into domestic environments to automate repetitive tasks and improve user convenience. Among such applications, robotic vacuum clean-ers are especially significant because they reduce human effort in routine floor cleaning while supporting efficient operation in homes, offices, and small indoor spaces. Recent progress in embedded systems, wireless communication, and low-power sensors has enabled these platforms to evolve from simple automated devices into intelligent smart home assistants.

Conventional robotic vacuum cleaners commonly rely on predefined movement patterns or basic remote control. Al-though these approaches provide partial automation, they often lack intuitive human–machine interaction and struggle in cluttered or changing environments. In addition, many economical systems do not provide adequate obstacle detection or efficient control strategies, which reduces their reliability and limits their suitability for practical household use.

To address these limitations, this work proposes a voice-controlled robotic vacuum cleaner that combines wireless voice interaction with sensor-based navigation. The system is designed around readily available hardware components, including an Arduino controller, an ESP32 communication module, ultrasonic sensors and motor drivers. The objective is to develop a practical and cost-effective cleaning platform that supports user commands, autonomous movement, and obstacle avoidance within a smart home environment.

II. LITERATURE SURVEY

Autonomous mobile robots have been extensively studied for indoor navigation, localization, and motion planning, and these principles form the foundation of robotic cleaning systems [1]–[3]. In the context of household cleaning, robotic vacuum cleaners are designed to operate safely in constrained spaces while adapting to furniture layouts and moving obstacles. Prior work in domestic robotics shows that successful performance depends on reliable sensing, low-complexity control, and robust mechanical integration.

Voice-enabled control has also become a major area of interest in smart home research because it improves accessibility and user convenience. Speech-based interfaces allow users to issue commands without manual interaction, making them suitable for elderly users, users with mobility constraints, and routine home automation scenarios. In low-cost embedded implementations, wireless modules and microcontrollers are typically used to interpret and execute voice-triggered commands with acceptable response times [4], [5].

Many reported low-cost robotic cleaners use ultrasonic or infrared sensors for obstacle detection because these sensors are inexpensive and easy to integrate. Such designs are practical for basic indoor navigation, but they often rely on simple reactive motion strategies and therefore may not achieve optimal path coverage or intelligent room mapping. More advanced systems employ simultaneous localization and mapping, probabilistic planning, or vision-based control; however, these methods increase computational complexity and cost [2], [3].

The literature therefore indicates a need for a balanced system that combines affordability, voice interaction, and dependable autonomous behavior. A practical design should preserve low implementation cost while improving user interaction and navigation capability for everyday smart home cleaning applications.

III. REQUIREMENTS

3.1 Hardware

3.1.1 ESP-32

Fig 3(a) shows the key hardware of the prototype ESP32 module. This microcontroller is used to interface the hardware and software components of the system. A USB cable is required for programming and uploading the code into the ESP32. Once the code is uploaded, the module can operate independently using a battery supply without requiring a PC or laptop .The ESP32 is a powerful microcontroller with built-in Wi-Fi and Bluetooth capabilities, making it suitable for IoT-based applications. It features multiple digital and analog input/output (I/O) pins that can be interfaced with various sensors, actuators, and expansion modules. The board typically provides more GPIO pins compared to traditional microcontrollers and supports PWM, ADC (Analog to Digital Conversion), and DAC (Digital to Analog Conversion). The ESP32 can be programmed using the Arduino Integrated Development Environment (IDE) via a USB cable. It operates at a higher processing speed and offers better performance, enabling advanced functionalities such as wireless control, real-time monitoring, and smart automation in the robotic vacuum cleaner system.

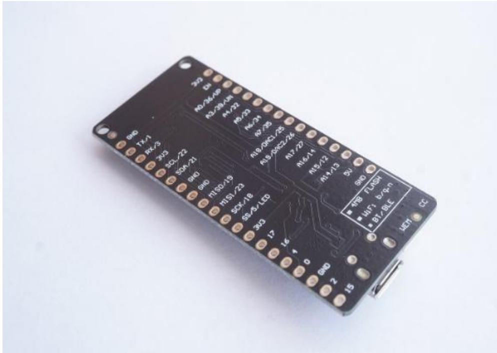

Fig 3(a) ESP32 Microcontroller

3.1.2 Lithium Batteries

These batteries are a type of primary (non-rechargeable) lithium battery, and are cylindrical and coin. It is a light and highly reliable battery with an operating voltage of 3V and can operate over a wide range of temperatures.

Fig 3(b) Lithium ion batteries

3.1.3 Suction Motor (High Speed DC Motor)

Fig 3(c) shows the suction motor used in the vacuum cleaner. A high-speed DC motor (around 18000 RPM) is used to create suction. This motor generates airflow that helps in collecting dust and debris into the dust container. It is one of the most important components responsible for the cleaning

Fig 3(c) High Speed DC Motor

3.1.4 Ultrasonic Sensor

An electronic instrument that uses ultrasonic sound waves (through air) to measure the distance between the target object and reflected sound is converted into an electrical signal

Fig 3(d).Ultrasonic sensor

3.1.5 Male and female pins

Male and female pins are used to describe the two parts of a mating connector, where the male connector has a pin or pins that fit into the socket of the female connector.

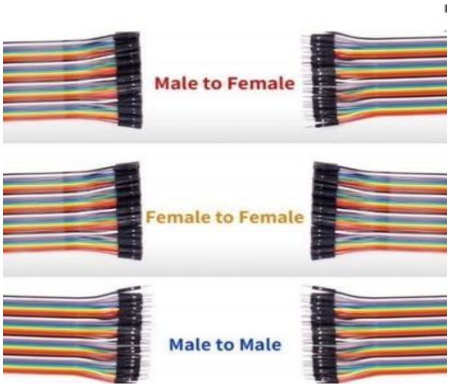

Fig *3(e). Male and female pins*

3.1.6 L298N Motor Driver

Fig 3(f) shows the L298N motor driver module used in the robotic vacuum cleaner. The L298N is a dual H-bridge motor driver that allows control of the direction and speed of DC motors. This module acts as an interface between the ESP32 microcontroller and the DC motors. It enables the robot to move forward, backward, left, and right by controlling the rotation of the motors. The speed of the motors can be controlled using Pulse Width Modulation (PWM) signals from the microcontroller. The L298N can drive two DC motors simultaneously and operates on a wide voltage range, making it suitable for robotic applications. It also includes onboard voltage regulation and protection features for reliable operation.

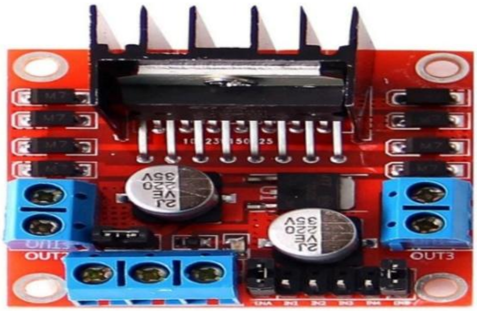

Fig 3 (f) L2928N Motor Driver

3.1.7 Wheels and Caster Wheel

Fig 3(g) shows the wheels used in the robotic vacuum cleaner. The wheels are attached to the shafts of the DC geared motors and are responsible for the movement of the robot. They provide stability and smooth motion across different floor surfaces. The use of properly aligned wheels ensures balanced movement and efficient navigation. The wheels enable the robot to perform directional movements such as forward, backward, left, and right turns.

In this system, two driving wheels are used along with a supporting caster wheel to maintain balance and improve mobility.

Fig 3(g) Wheels and caster wheel

3.1.8 IR Sensor

Fig 3(h) shows the IR (Infrared) sensor used in the robotic vacuum cleaner. It is used for line detection and edge detection. The IR sensor works by emitting infrared light and detecting the reflected signal from surfaces. Based on the reflection, it identifies differences between surfaces such as floor and edges. This sensor helps the robot follow a predefined path and prevents it from falling off edges like stairs. It improves navigation accuracy and enhances the safety of the system.

Fig 3(h) IR Sensor

3.2 Software

Fig 3(i) shows the software used in this project, the Arduino IDE. This application is written as C and C ++. Programs can be written and uploaded to the Arduino boards. The version used in here was 1.8.9.

Fig 3(i) for Software coding

IV. METHODOLOGY

The proposed system was developed as an embedded robotic platform that integrates control, communication, sensing, and actuation subsystems. The overall design is intended to support voice-enabled operation and autonomous indoor cleaning with minimal hardware complexity.

A. *System Architecture*

The robotic vacuum cleaner consists of an Arduino-based controller, an ESP32 module for wireless voice communica-tion, ultrasonic sensors for obstacle detection, motor drivers for wheel actuation, and a vacuum mechanism for dust col-lection. The Arduino processes sensor inputs and generates control signals for movement, while the ESP32 receives voice-related commands from the user interface and forwards the corresponding instructions to the controller.

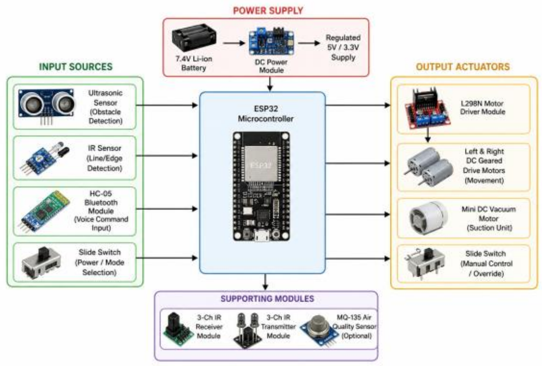

Fig. 1. System architecture of the voice-controlled robotic vacuum cleaner.

B. *Voice Command Processing*

Voice commands are used to initiate and regulate cleaning operations such as start, stop, forward motion, left turn, right turn, and return behavior. The ESP32 serves as the communication bridge between the user and the robotic platform. Once a valid command is received, the Arduino interprets the instruction and coordinates the required motor actions. This arrangement improves usability by allowing hands-free interaction with the cleaning device.

C. *Obstacle Detection and Navigation*

Autonomous navigation is achieved using ultrasonic sensing. The sensors continuously measure the distance to nearby objects, allowing the robot to detect walls, furniture, and other obstacles. When an obstruction is identified within a predefined threshold, the control logic triggers an avoidance maneuver by stopping, changing direction, and selecting an alternate path. This reactive navigation method is computation-ally efficient and suitable for low-cost

D. *Motion and Cleaning Mechanism*

The wheel motors are driven through a motor driver interface that enables forward, reverse, and turning operations. The suction unit is mounted within the chassis to collect dust during movement. The motion and suction functions are coordinated so that the system can perform cleaning while navigating through the environment. The selected hardware architecture prioritizes simplicity, affordability, and ease of implementation.

E. *Implementation Flow*

The operational flow begins with system initialization, followed by command reception and sensor monitoring. The controller then evaluates the command state and obstacle conditions to determine the appropriate movement. If no obstacle is detected, the robot continues cleaning along the selected direction. If an obstacle is present, the controller modifies the path and resumes operation after the avoidance maneuver.

V. RESULTS

The developed prototype was evaluated in a controlled indoor environment containing common household obstacles such as chairs, walls, and table legs. The system successfully responded to basic voice-triggered commands and executed movement actions in accordance with the received instructions. The ESP32-based communication mechanism provided dependable command transfer for routine operational tasks The ultrasonic sensing subsystem enabled the robot to detect nearby obstacles and perform avoidance maneuvers with acceptable consistency. The platform was able to continue movement after changing direction, which supported uninterrupted cleaning in small indoor areas. The integrated suction mechanism functioned as intended during robot motion and demonstrated the feasibility of combining cleaning and navigation in a compact embedded design. Overall, the experimental observations confirm that the pro-posed system can deliver practical voice-assisted cleaning behavior with modest hardware requirements. the prototype demonstrates that useful autonomous vacuum cleaning can be achieved with low-cost components and straightforward control strategies.

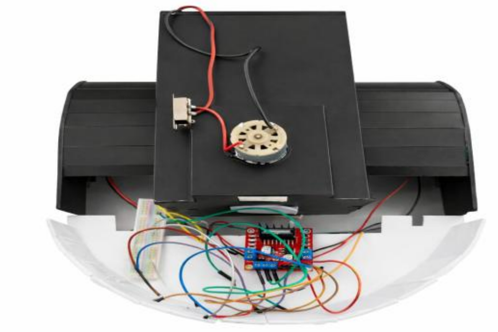

Fig 5.1 Output Device

VI. DISCUSSION/ ADVANTAGES

The proposed robotic vacuum cleaner offers several practical advantages for smart home applications. First, voice-based interaction improves usability by allowing users to operate the robot without direct physical contact. This feature is especially useful in daily domestic settings where convenience and accessibility are important .Second, the use of commonly available components such as Arduino, ESP32, ultrasonic sensors, and standard motor drivers makes the system economical and easy to replicate. The design therefore provides an accessible platform for educational, experimental, and low-budget home automation applications. Third, the embedded obstacle detection mechanism im-proves operational safety and supports autonomous movement in constrained environments. Although the system does not implement advanced mapping, the reactive navigation approach is computationally light and suitable for practical deployment in small indoor spaces. Finally, the overall architecture is modular and can be extended in future work. Additional features such as battery monitoring, automatic docking, path optimization, app-based control, or machine learning-assisted navigation can be integrated without fundamentally altering the core design.

VII. CONCLUSION

This paper presented the design and implementation of a voice-controlled robotic vacuum cleaner for smart home applications. The proposed system integrates voice interaction, embedded control, wireless communication, obstacle detection, and motorized cleaning within a low-cost robotic platform. The developed prototype demonstrates that practical cleaning automation can be achieved using simple hardware and reactive navigation methods. The results indicate that the system is capable of executing user commands, avoiding obstacles, and supporting indoor cleaning with minimal human intervention. The work con-firms that combining affordability with voice-enabled control can improve the accessibility and functionality of household robotic cleaners. Future enhancements may focus on intelligent path planning, improved coverage efficiency, and more advanced sensing to further strengthen performance in real-world environments.

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