



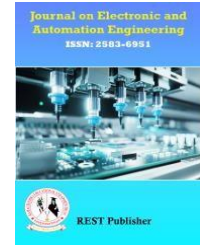
Journal on Electronic and Automation Engineering

Vol: 4(2), June 2025

REST Publisher; ISSN: 2583-6951 (Online)

Website: <https://restpublisher.com/journals/jeae/>

DOI: <https://doi.org/10.46632/jeae/4/2/54>



Voice Controlled Robotic Arm

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Abstract: *This paper outlines the development of a voice-controlled robotic arm using an ESP32 microcontroller and a smartphone app, which aims to improve user interaction and automation. The system enables the robotic arm to be controlled via voice commands sent from an Android device via Bluetooth. The robotic arm, mounted on a mobile chassis, is capable of moving freely in all directions. It has a gripper mechanism for picking and placing objects, which mimics the movement of a human hand with three degrees of freedom: shoulder, elbow, and fingers. DC motors with a reduction gear mechanism power both the vehicle and the robot functions, including gripper control. A heavy-duty battery ensures continuous operation, while servo motors provide precision in joint movements. The smartphone app serves as an intuitive interface for issuing voice commands and adjusting parameters such as the speed and direction of the robotic arm. This integration of voice control not only increases accessibility, but also enables remote and hands-free operation, making it ideal for applications in industrial automation, warehousing, and educational settings. Experimental tests confirm the reliability, accuracy, and consistent operation of the system, demonstrating its potential for real-world implementation and scalability for advanced automation tasks in various domains.*

1. INTRODUCTION

In today's rapidly evolving technology landscape, voice-controlled systems have become increasingly important in improving human-machine interaction. One notable application is the creation of a voice-controlled robotic arm using an ESP32 microcontroller and a smartphone. The project demonstrates the integration of voice recognition, embedded systems, and robotics to create a user-friendly and efficient solution for remote object handling. The ESP32, with its built-in Wi-Fi and Bluetooth capabilities, acts as a central controller, receiving voice commands from a smartphone and performing precise actions through servo and DC motors. The robotic arm, designed with three degrees of freedom, mimics human hand movements – allowing it to pick up objects and place them in designated locations. This pick-and-place operation demonstrates how embedded systems and control mechanisms can be combined with mechanical design to automate complex tasks. The system is powered by a heavy-duty battery and mounted on a mobile chassis, enabling movement in multiple directions. Such robotic arms are increasingly relevant in industrial automation, warehousing, and educational environments due to their ability to increase productivity, reduce manual effort, and ensure accuracy. The project not only highlights the potential of voice-controlled embedded applications, but also reflects the growing importance of integrating intelligent systems into real-world operations for improved efficiency.

2. OBJECTIVES OF THE PROJECT

This project focuses on integrating an ESP32 microcontroller with a robotic arm to enable voice-controlled functionality via a smartphone. A reliable Bluetooth communication link is established between the mobile app and the ESP32 to send voice commands. These commands are then processed by the microcontroller and converted into precise movements such as rotating the arm, adjusting the grip, or lifting objects. The system aims to improve accessibility, including for elderly or physically challenged users, by eliminating the need for manual controls. In addition, it serves as an educational platform for understanding voice recognition, microcontroller programming, and automation in real-world robotic applications.

3. PROJECT OVERVIEW

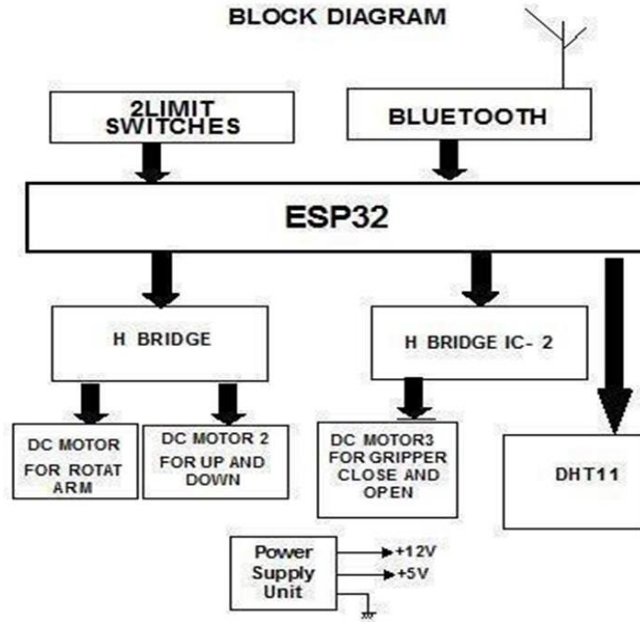


FIGURE 1. Block Diagram

The figure illustrates the block diagram of a voice-controlled robotic arm system. At its core, an ESP32 microcontroller controls all the functions, receiving wireless commands from an Android application via a Bluetooth module. Two limit switches are connected to prevent the robotic arm from exceeding its operating limits. The system uses two H-bridge circuits to control three DC motors: one for rotating the arm, another for vertical arm movement, and the third for gripper operation. The Android application sends voice commands to the ESP32, which then drives the respective motors. A power supply unit provides +12V and +5V to efficiently operate all the components.

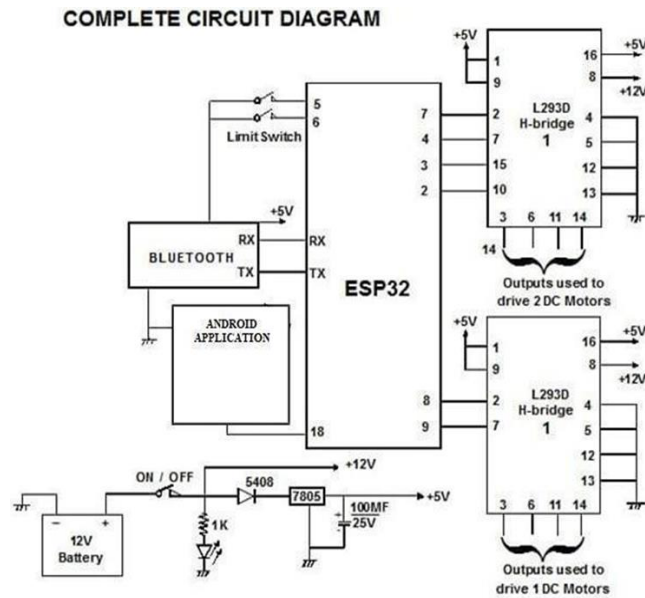


FIGURE 2. Schematic Diagram

The system is powered by a 12V battery, which is regulated to 5V using a 7805 voltage regulator to power components such as the ESP32 and the Bluetooth module. The ESP32 microcontroller receives voice commands via Bluetooth and controls the motor functions accordingly. Two L293D motor driver ICs drive three DC motors for arm rotation, vertical movement, and gripper control. Limit switches are integrated to prevent excessive movement and enhance safety. The Bluetooth module communicates with the Android application via the TX/RX

pins. All components receive regulated power from the battery through safety circuits, ensuring reliable operation of the robotic arm with efficient power delivery and safe motor control.

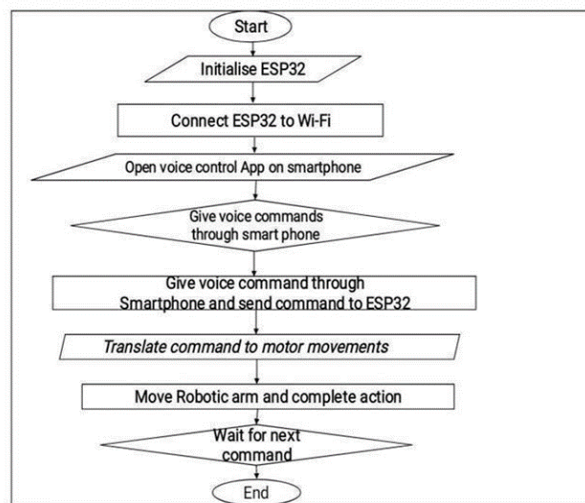


FIGURE 3. Flowchart

This flowchart outlines the operation of a voice-controlled robotic arm using an ESP32 and a smartphone app. It starts with initializing the ESP32, connecting it to Wi-Fi, and receiving voice commands from the smartphone. These commands are translated into motor movements, executed by the arm, and then wait for further instructions.

4. HARDWARE DESCRIPTION

Robotic Arm: A robotic arm is a programmable mechanical device that consists of joints, linkages, and actuators. It is designed to perform precise, repetitive tasks such as lifting, rotating, and positioning objects. The main components include a base for stability, joints for movement, actuators to drive the movement, and an end effector to interact with the environment. The controller acts as the brain, managing all movements and ensuring accuracy. Robotic arms can rotate 360 degrees clockwise and counter clockwise, along with up to 180 degrees of vertical movement, making them highly versatile for industrial, medical, and educational applications.



FIGURE 4. Robotic Base Arm

Dc Motor: DC motors are widely used, inexpensive, small and powerful for their size. They are most easy to control. One DC motor requires only two signals for its operation. They are non-polarized; means you can reverse the voltage without any damage to motor. DC motors have +ve and – ve leads. Connecting them to a DC voltage source moves motor in one direction (clockwise) and by reversing the polarity, the DC motor will move in opposite direction (counter clockwise). The maximum speed of DC motor is specified in rpm (rotation per minute). It has two rpms: no load and loaded. The rpm reduces when moving a load or decreases when load increases. Other specifications of DC motors a DC Motored voltage and current ratings. Below table shows the specifications Every DC motor has six basic parts -- axle, rotor (a.k.a., armature), stator, commutator, field magnet(s), and

brushes. In most common DC motors (and all that Beamers will see), the external magnetic field is produced by high- strength permanent magnets¹. The stator is the stationary part of the motor.



FIGURE 5. DC Motor

Bluetooth Module: A Bluetooth module is a hardware device that enables wireless communication between digital systems and other devices such as computers or mobile phones or wireless headphones. It is ideal for short-range communication with minimal infrastructure. Bluetooth operates in the 2.4 GHz frequency band that is available worldwide and typically supports communication within a range of 10 meters.

Hardware Specifications

- Sensitivity: Approximately -80 dBm
- RF transmit power: Up to +4 dBm
- Built-in antenna and edge connector
- Low voltage operation: 1.8V core, 1.8 to 3.6V I/O

The HC-05 module is a serial communication Bluetooth device designed for easy wireless data transfer. It establishes a bidirectional serial connection between a microcontroller and an Android smartphone. While standard Bluetooth modules offer a range of 100 meters, Bluetooth 5.0 can extend this to around 400 meters.

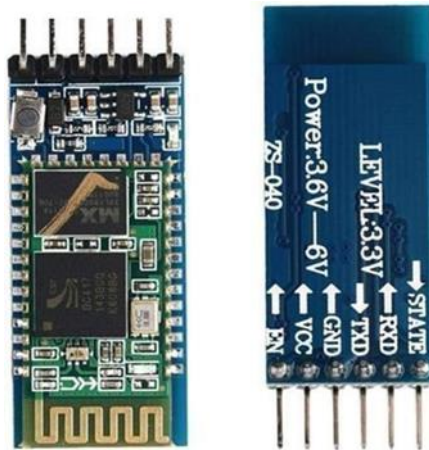


FIGURE 6. Bluetooth Module

L293D motor driver

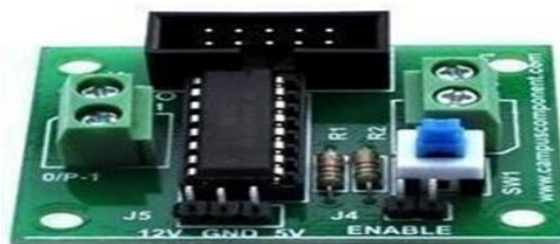


FIGURE 7. L293D Motor Driver

The L293D motor driver is a widely used integrated circuit designed to simplify motor control in embedded applications. It provides a user-friendly interface for controlling motors and is mounted on a high-quality, single-sided non-PTH PCB for durability and reliability. The pins of the L293D IC are connected to external connectors, allowing easy access for interfacing with other devices or microcontrollers. The IC operates as a dual full-bridge driver that can deliver up to 1A per bridge with a supply voltage of up to 24V, making it ideal for driving two DC motors, relays, or solenoids independently. Due to the limited output current capability of microcontrollers, an external driver such as the L293D is necessary to handle the high-current requirements of DC motors. It supports bidirectional motor control and is suitable for applications where motors need to rotate in both forward and reverse directions. The internal H-bridge structure allows for efficient speed and direction control via PWM signals.

ESP32 module:



FIGURE 8. ESP32 Module

The ESP32 module acts as the central controller of the robotic arm, receiving voice-command inputs from a smartphone via Wi-Fi or Bluetooth. The smartphone app converts the spoken commands into text and sends them using protocols such as MQTT or HTTP. Once these commands are received, the ESP32 processes them and sends control signals to the robotic arm's motors or servos to perform the desired action, such as moving left or right or grabbing an object. In addition, the ESP32 can collect feedback from sensors such as limit switches and send it back to the app for real-time monitoring, enabling smooth and intelligent voice-control functionality.

Jumper Wires:



FIGURE 9. Jumper Wires

Jumper wires are used to create electrical connections between different components in a circuit. In the context of a voice-controlled robotic arm using an ESP32 and smartphone, jumper wires would be used to connect various sensors, motors, and other electronic components to the ESP32 microcontroller. These wires allow signals to flow between the different parts of the circuit, enabling the robotic arm to receive commands from the smartphone via the ESP32 and execute actions based on those commands.

H – Bridge:

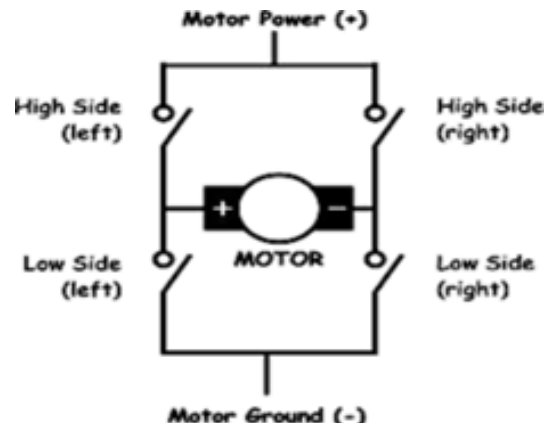


FIGURE 10. H-Bridge Circuit

The name "H-Bridge" is derived from the actual shape of the switching circuit which controls the motion of the motor. It is also known as "Full Bridge". Basically there are four switching elements in the H- Bridge as shown in the figure below. As you can see in the figure above there are four switching elements named as "High side left", "High side right", "Low side right", "Low side left". When these switches are turned on in pairs motor changes its direction accordingly. Like, if we switch on High side left and Low side right then motor rotate in forward direction. Similarly, when you switch on low side left and high side right, the current flows in opposite direction and motor rotates in backward direction. This is the basic working of H-Bridge. We can also make a small truth table according to the switching of H-Bridge explained above.

5. SOFTWARE DESCRIPTION

This chapter focuses on the software tools used in the project, including CATIA, Arduino IDE 1.0.5, voice recognition software, communication protocols, and the user interface design.

5.1 Arduino IDE

Arduino IDE 1.0.5 is an open-source software platform used to program microcontrollers like the Arduino UNO. It provides a simple and user-friendly interface with built-in libraries and example codes, making it accessible for beginners and professionals. This IDE allows users to write, compile, and upload C/C++ based code to the Arduino board, facilitating rapid development and testing of embedded systems.

5.2 Microcontroller Programming

The Arduino UNO microcontroller is used to control the movement and functions of the lawn mower or robotic arm. Commands and sensor-based algorithms are programmed into the microcontroller to allow autonomous operation. The main function is coded using Arduino IDE and converted into machine-level instructions. Sensor inputs, such as ultrasonic sensors, help the robot avoid obstacles by rerouting its path.

5.3 Voice Recognition Software

Voice recognition software captures audio through a microphone and processes it to convert spoken language into text commands. This includes audio preprocessing, feature extraction, pattern matching, and language modeling. The output is a recognized command that is used to control the robotic arm, making the system hands-free and more accessible, especially for elderly or disabled users.

5.4 Communication Protocol

Wireless communication is established between the ESP32 and the smartphone using either Bluetooth or Wi-Fi. Bluetooth is ideal for short-range, low-power applications, while Wi-Fi offers higher speed and greater range. These protocols transmit commands and status updates between the devices.

5.5 User Interface

The smartphone application acts as the user interface, allowing voice command input and providing feedback. It captures user commands, confirms them visually or audibly, and transmits them to the ESP32, enabling smooth interaction with the robotic arm.

6. RESULTS

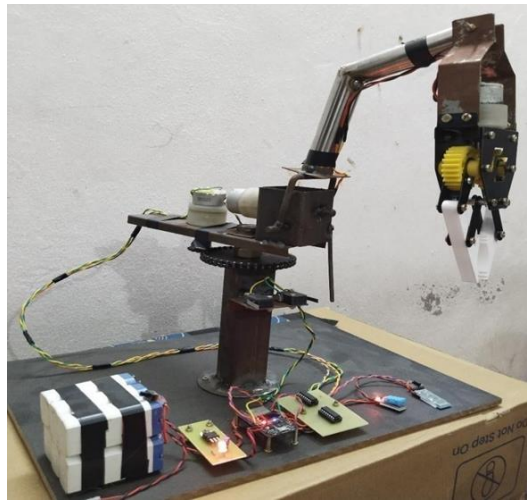


FIGURE 11. Up Motion

These are the six commands which are used to move robotic arm.

1. Go Up (U)
2. Down (D)
3. Clockwise(C)
4. Anti-Clock Wise (A)
5. Hold (H)
6. Release(X)

Commands'' – Up

When the character's' was received, the robotic arm moved upward by activating motor 2 in the forward direction. The motor ran for 1 second, and the movement was executed smoothly with stable performance.



FIGURE 12. Down Motion

Command's' – Down

Upon receiving's', the arm moved downward by reversing motor 2. The motion lasted for 1 second and showed reliable downward movement with no stalling.

7. ADVANTAGES, DISADVANTAGES AND APPLICATIONS

Advantages

This robotic arm provides hands-free operation for environments such as hospitals or laboratories, with a user-friendly smartphone interface for voice control. Wireless connectivity via ESP32 supports both Wi-Fi and Bluetooth, ensuring flexibility. The cost-effective ESP32 enables an affordable solution with accessibility benefits for elderly or disabled users.

Disadvantages

Limited Voice Recognition: Voice recognition may face challenges with accents, background noise, or unclear commands, requiring advanced processing or cloud services to improve accuracy. **Dependency on Internet or Bluetooth:** Reliable internet or Bluetooth connection is essential for voice commands to function properly, which could be limiting in certain environments. **Security Concerns:** Wireless communication and voice commands can be vulnerable to unauthorized access or accidental activations, raising potential security risks. **Power Constraints:** The ESP32 and robotic arm rely on stable power sources, and in mobile setups, limited battery life may restrict operational time. **Latency Issues:** Cloud-based voice assistants may introduce delays between issuing a command and the robotic arm's response, affecting performance.

Applications

Assistive Technology: Used by people with disabilities to perform everyday tasks like picking objects, pushing buttons, etc. **Home Automation:** The robotic arm can assist in tasks like turning switches on/off, lifting small items, or operating appliances via voice. **Industrial Automation:** Useful in small-scale industries for repetitive tasks, especially where hands-free control increases efficiency or safety. **Educational Projects:** A great project for learning about IoT, robotics, microcontrollers, and voice control in STEM education. **Medical and Lab Use:** Can help in handling hazardous materials or performing tasks where sterile or non-contact environments are essential.

8. CONCLUSION AND FUTURE SCOPE

The development of a voice-controlled robotic arm using the ESP32 microcontroller demonstrates the potential of integrating IoT and speech recognition technologies for hands-free automation. This project successfully showcases how voice commands can be translated into mechanical movements, allowing the robotic arm to perform basic tasks efficiently. By leveraging the ESP32's built-in Wi-Fi and Bluetooth capabilities, along with speech recognition modules, we achieved reliable and wireless control. This system can be further enhanced and applied in fields such as healthcare, manufacturing, and assistive technology, proving to be a cost-effective and scalable solution. Overall, the project has met its objectives and lays the foundation for future advancements in human-machine interaction. The voice-controlled robotic arm developed in this project has significant potential for future enhancements. The system can be further refined by integrating advanced speech recognition technologies, improving accuracy, and enabling it to function in noisier environments. Additional degrees of freedom and more motors could be incorporated to perform more complex tasks, while machine learning algorithms could be used to optimize performance over time. Wireless control via mobile apps and integration with AI-based speech systems like Google Assistant or Alexa could provide more flexibility and ease of use. The robotic arm has immense potential in healthcare and assistive technologies, helping individuals with disabilities perform daily activities, and in industrial settings where it can aid in tasks like assembly and packaging. As such, this project lays the groundwork for further developments that could see the robotic arm used across a wide range of applications, improving both efficiency and user experience.

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