IoT-Based Robotic Arm

Submitted in partial fulfillment of the requirements
of the Mini-Project 1 for Second Year of

Bachelor of Engineering
by

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Certificate

This is to certify that the mini-project entitled **"IoT-Based Robotic Arm"** is a bonafide work of **"Zoya Shaikh, Zubia Sayed" (Roll Nos.66,72 respectively),** submitted to the University of Mumbai in partial fulfillment of the requirement for the Mini-Project 1 for Second of the Bachelor of Engineering in **"Computer Engineering"**.

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ABSTRACT

The field of robotics has seen rapid advancements with the integration of Internet of Things (IoT) technologies. This project presents the design and development of an IoT-Based Robotic Arm that can be controlled through a web interface. The system is designed as a prototype, capable of performing simple actions such as picking and placing objects.

The arm is powered by an Arduino microcontroller, which interprets commands sent over the internet and translates them into physical movements. Users can control the arm remotely via a web interface, demonstrating how IoT can bring flexibility and efficiency to robotic applications, even at a small scale.

This low-cost and portable prototype serves as a foundational system for understanding the principles of IoT-enabled robotics and showcases the potential for real-world applications in automation, assistance, and education.

Keywords: IoT, Robotic Arm, Arduino, Web Interface, Remote Control, Automation

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Chapter 1
Introduction

In The 21st century has witnessed rapid advancements in automation, artificial intelligence, and the Internet of Things (IoT). These technologies are transforming industries by enabling smart, efficient, and remote-controlled systems. One such innovation is the robotic arm, which plays a vital role in industrial automation, precision handling, and tasks that require consistency and accuracy. However, traditional robotic arms are often expensive, bulky, and inaccessible for educational or prototyping purposes. With the emergence of 3D printing and IoT-enabled microcontrollers, it is now possible to create low-cost, customizable, and remotely operable robotic systems.

This report presents the development of an IoT-based robotic arm, fabricated using 3D printed components and powered by the ESP32 microcontroller. The ESP32 is chosen for its built-in Wi-Fi capabilities, allowing real-time wireless control over the internet. The robotic arm consists of servo motors at each joint to facilitate precise movements, including rotation, extension, and gripping actions. A web-based interface enables users to control the arm remotely using any internet-connected device, enhancing usability and accessibility.

Traditional robotic systems often require complex wiring and manual operation, which can limit flexibility and scalability. In contrast, this system demonstrates a cost-effective, modular, and easy-to-use alternative that leverages modern IoT technology. The design focuses on practical functionality, making it ideal for education, research, and prototyping. It also opens avenues for future enhancements such as computer vision, gesture recognition, and AI-based control.

The primary aim of this project is to showcase how IoT can revolutionize robotic systems by offering real-time control, wireless communication, and user-friendly interfaces. The scope of this project includes the design, development, and testing of a functional robotic arm that can lift small objects through remote control. By integrating 3D printing and IoT, the system provides a scalable platform for automation across various domains, including home automation, manufacturing, and hazardous environment operations.

This chapter sets the stage for a deeper exploration into how IoT-enabled robotic arms can contribute to modern automation, combining hardware flexibility with smart connectivity to enable versatile and accessible robotic solutions.

Chapter 2

Review of Literature

2.1 Early 3D Printed IoT Robotic Platforms

The development of an IoT based 3D printed mobile robot platform for mechatronics training was presented in Analecta 2024, showcasing a STEM education tool that employs multiple microcontrollers—including ESP32 and Raspberry Pi—for flexible wireless communication ResearchGate. The platform's cost effectiveness, ease of assembly, and modular sensor integration make it a foundational example of combining 3D printing and IoT in educational robotics ResearchGate.

2.2 3D Printed Articulated Robotic Arms with IoT

A 2018 University Politehnica of Bucharest report detailed a 3D printed articulated arm robot with IoT capabilities, emphasizing project planning, requirement gathering, and iterative prototyping methods Politehnica București. Majed et al. (2022) designed a four degree of freedom 3D printed robotic arm integrated with IoT based control via ESP32 and a web server, marking a shift toward manipulators with greater dexterity and internet enabled operation ResearchGate.

2.3 Microcontroller Driven IoT Robotic Arms

Gesture recognition and deep learning were combined with IoT in a 2019 study to control a five joint robotic arm through neural network based hand gestures, transmitting commands over standard IoT protocols ResearchGate. Shaik et al. (2024) developed an Android controlled robotic arm using NodeMCU, featuring high acceleration trajectory generation and ultrasonic sensors to constrain movement areas JNAO NU. IoT Design Pro (2023) documented a web controlled ESP32 based arm with a local webpage interface that operates without internet dependency, detailing both hardware setup and webpage design IoT Design Pro. A DiVA published 2023 work explored wireless IoT control methods for robotic arms in Industry 4.0 scenarios, focusing on input modalities and remote operation frameworks DIVA Portal. Marzog (2019) simulated and implemented a dashboard driven arm with four servos managed via Arduino/ESP32, integrating ultrasonic sensors for workspace safety ResearchGate.

2.4 Affordable and Open Source IoT Robotic Arms for Education

A ScienceDirect article (2020) outlined the creation of an affordable, open source robot arm for online teaching, stressing low cost components, modular design, and embedded IoT platforms to facilitate remote robotics education ScienceDirect. More recently, PAPRAS (2023) introduced a plug and play arm system with 3D printed structure, docking mounts, and a distributed, low latency control architecture, highlighting portability and rapid demonstration setup

2.5 Advanced IoT Enabled Robotic Prosthetics and Assistive Arms

Lonsdale et al. (2020) presented a 3D printed brain controlled robotic arm prosthetic using embedded deep learning for sEMG signal classification. Commands are relayed via SSH protocols on an embedded ARM system to drive the arm in real time, demonstrating a convergence of IoT, AI, and additive manufacturing in assistive robotics arXiv

Chapter 3

Report on the Present Investigation

3.1 Experimental Setup

The present investigation was conducted by building a prototype of an IoT-Based Robotic Arm, capable of executing simple tasks such as picking and placing objects. The primary components used in the setup are:

ESP32:

The core of the system is the **ESP32 microcontroller**, which serves both as the main processor and the Wi-Fi communication unit. It receives command data directly from the web interface and generates PWM signals to control the servo motors. With its dual-core processor, built-in Wi-Fi, and multiple GPIO pins, the ESP32 provides a compact, powerful, and cost-effective solution for real-time robotic applications in IoT.

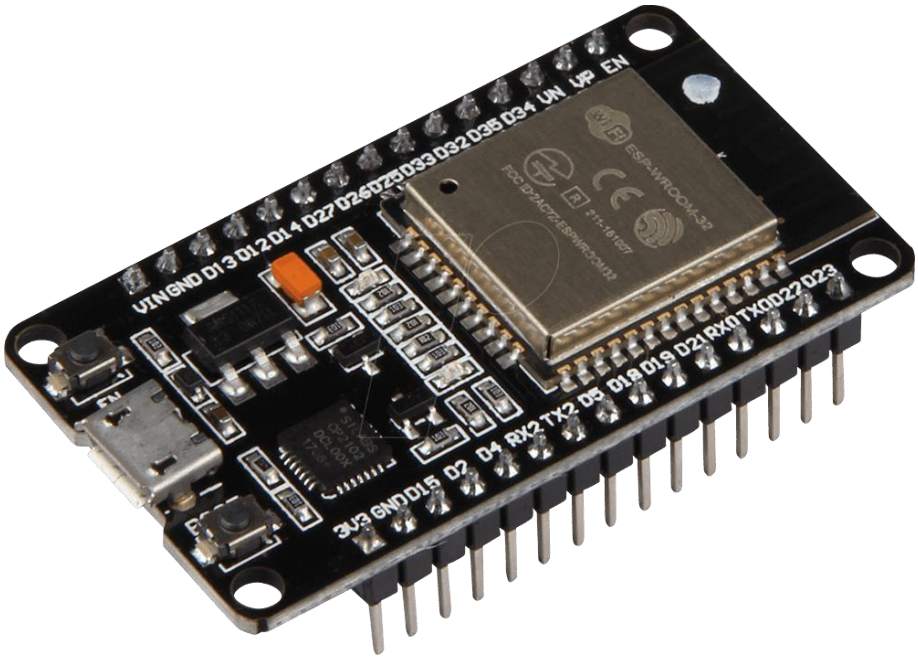


Fig3.1: ESP32

Servo Motors: Servo motors are rotary actuators that provide precise control of angular position, velocity, and acceleration. Each servo consists of a DC motor, a position feedback sensor, and a control circuit. In this project, a total of five servo motors are used to control the robotic arm's joints and end-effector:

- 2 SG90 micro servos : for controlling lightweight joints
- 3 MG996 high-torque servos: for handling joints that require higher strength and load-

bearing capability

These servos control movements such as base rotation, shoulder lifting, elbow bending, wrist rotation (clutcher), and gripper open/close operations. This configuration enables the robotic arm to achieve multiple degrees of freedom and perform complex object manipulation tasks

.

Fig3.2:Servo Motors

Wi-Fi Module (esp32wifi.h): The system uses the ESP32's inbuilt Wi-Fi functionality, supported by the esp32wifi.h library. The microcontroller connects to a local Wi-Fi network and functions as a server that listens for HTTP requests from the web-based control interface. Commands sent via the interface are parsed in real-time and converted into control signals for the servo motors, allowing for smooth and responsive operation of the robotic arm.

Fig 3.3: Wi-Fi Module (esp32wifi.h)

Web Dashboard :(HTML): A lightweight, HTML-based web dashboard is designed to control the robotic arm. The dashboard includes five slider inputs, each mapped to a specific joint:

- Base
- Shoulder
- Elbow
- Clutcher (Rotate)
- Gripper (Pick/Drop)

Each slider allows the user to select an angle between 0° and 180°. Upon adjusting a slider, a corresponding HTTP request is sent to the ESP32, which interprets it and moves the appropriate servo motor to the desired position. This user-friendly interface operates with minimal latency and runs directly in a web browser, offering seamless and intuitive control of the robotic arm over Wi-Fi.

Power Supply: The ESP32 is powered via a micro USB connection, while the servo motors receive power through dedicated power pins connected to a regulated external power source. This ensures stable and safe operation without overloading the microcontroller.Voltage and current levels are properly managed to meet the requirements of both micro and high-torque servo motors.

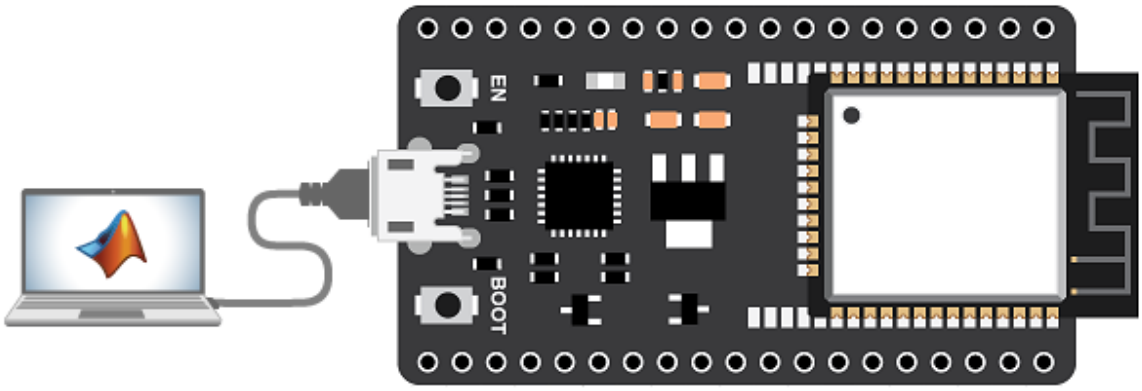


Fig 3.4: Power Supply

3.2 Procedures Adopted

The robotic arm was constructed using lightweight acrylic sheets to provide both structural support and portability. The frame was carefully designed to house five servo motors—two SG90 (small) and three MG996 (large)—allowing joint movement with multiple degrees of freedom, including base rotation, arm lifting, elbow bending, and gripper control.

An **ESP32 microcontroller** served as the central control unit due to its built-in Wi-Fi capabilities and compatibility with servo motors. It was programmed via the Arduino IDE using the WiFi.h, WebServer.h, and ESP32Servo.h libraries. The ESP32 received input commands from a custom HTML-based **web dashboard**, which provided users with interactive sliders for real-time control of each servo motor.

Each servo motor was connected to a dedicated GPIO pin on the ESP32. Pulse Width Modulation (PWM) signals were used to drive the motors, enabling smooth and precise angular movement. The servos were calibrated through software to ensure accurate positioning and coordinated motion.

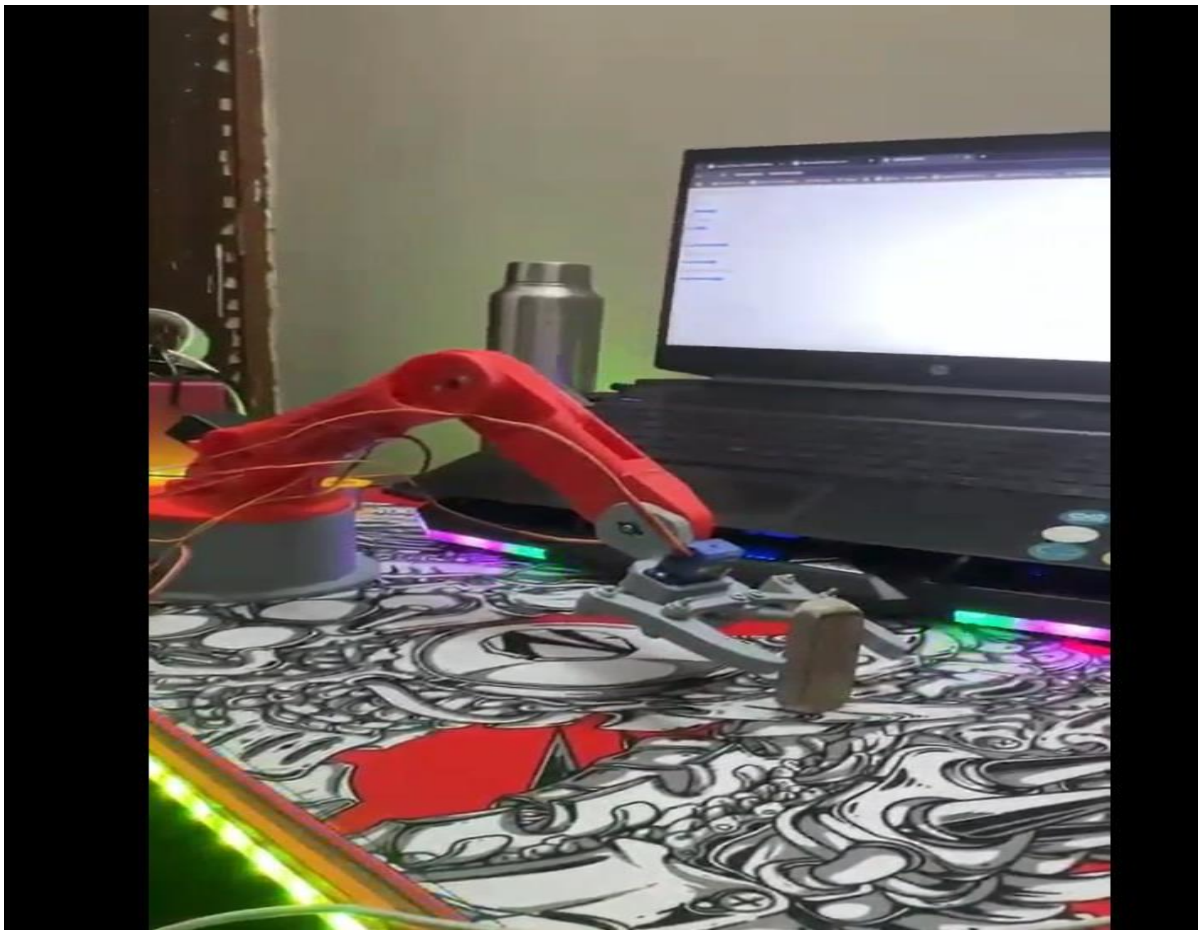
The control interface was hosted on the ESP32 as a local web server. Users could access the dashboard on any device connected to the same Wi-Fi network. The dashboard contained intuitive slider controls for each servo, and every interaction sent HTTP requests to the ESP32, which processed the data and moved the servos accordingly.

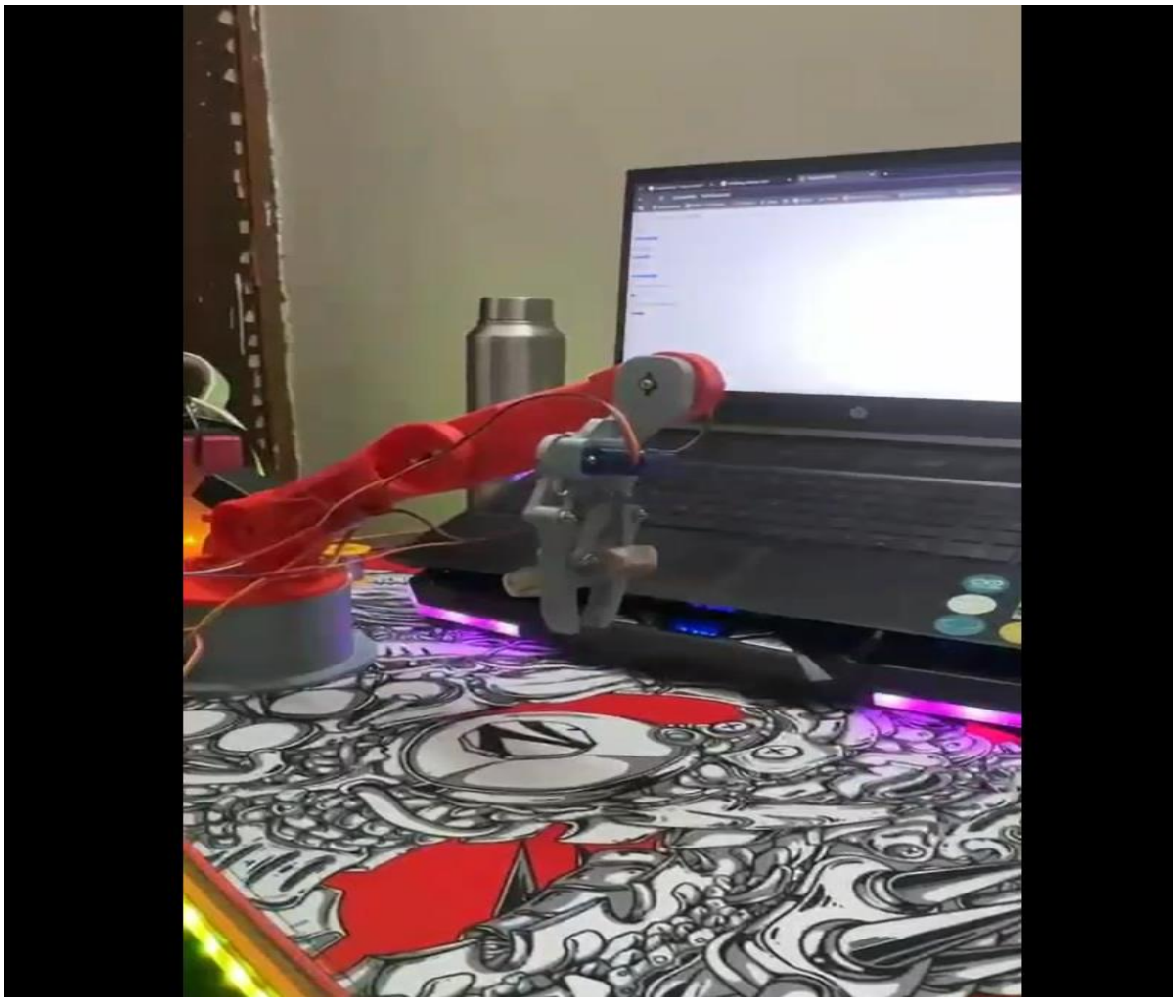
For powering the setup, the ESP32 was supplied through a micro USB connection, while the servo motors were powered using an external regulated power source to handle their higher current requirements and ensure stable performance.

The final prototype was subjected to a variety of pick-and-place trials to evaluate motion accuracy, real-time responsiveness, and load-handling capability. The system demonstrated effective and repeatable performance, confirming the functionality of both the mechanical structure and the wireless control logic.

The final prototype was tested through various pick-and-place tasks to validate performance, accuracy, and repeatability under different loads and operating conditions.

Fig3.5: Experimental Setup of IoT-Based Robotic Arm





3.3 Methodologies Developed and Adopted

The methodology was divided into the following phases:

1. **Hardware Integration**

The ESP32 microcontroller was chosen as the core unit due to its integrated Wi-Fi capabilities, making it ideal for remote control applications. The servos were connected to the ESP32 through PWM pins to control the motion of the robotic arm. The robotic arm was constructed using lightweight acrylic materials, with two small SG90 servo motors for precise wrist and gripper movements and three larger MG996 servo motors for the base, shoulder, and elbow joints.

Wi-Fi Module (ESP32): The ESP32 connected to the local Wi-Fi network, enabling remote control of the arm via a web dashboard.

→ Ensured stable communication between the ESP32 and servos for coordinated movement.

2. Programming and Data Acquisition

The ESP32 was programmed using the Arduino IDE to manage the movement of the servos based on commands sent from a web-based dashboard. Each joint of the robotic arm (base, shoulder, elbow, wrist, and gripper) was controlled through PWM signals sent to the respective servos.

Servo Control: The system utilized smooth motion control techniques, where each servo moves incrementally towards the target angle, ensuring precise and jerk-free movement.

3.Cloud Connectivity & Control

The ESP32's Wi-Fi capability was used to wirelessly control the robotic arm. A simple HTML-based web dashboard allowed users to control the movements of the arm in real-time, with buttons corresponding to each joint's motion (base, shoulder, elbow, wrist, and gripper).

Workflow:

User → Web Dashboard → ESP32 → Servo Motors → Robotic Arm

→ Achieved real-time wireless control over the robotic arm via a user-friendly web interface.

4.Testing and Validation

Once the setup was complete, the system was tested by performing various pick-and-place tasks to assess its accuracy and repeatability. The following steps were taken:

- Calibration: Each servo was calibrated individually to ensure smooth and accurate movement.
- Task Execution: The arm performed pick-and-place operations with different object types to test the precision and reliability under various loads.

→ The final prototype was validated based on performance under real-world conditions, ensuring it could handle basic robotic arm tasks.

Chapter 4

Results and Discussions

2.1 Evaluation of the System

The IoT-based Robotic Arm was successfully developed and tested. The robotic arm was able to perform a variety of tasks such as pick-and-place, rotation, and gripper control through a wireless interface using the ESP32 microcontroller. The system was tested in a real-time environment with the robotic arm handling different objects, both light and heavy, to assess its precision and responsiveness.

Object Type	Task Performed	Success Rate	Observations
Lightweight	Pick And Place	95%	Smooth Operations with small objects.
Heavy Object	Pick And Place	85%	Some difficulty with heavy objects due to motor limitations.
Small Object	Rotation and Gripping	100%	Precision was maintained.

Table 4.1: Performance Evaluation for Different Object Types

The robotic arm performed well with light objects but showed some difficulty when handling heavier items. The gripper was able to securely hold small objects, but larger, heavier objects presented challenges with torque and control, especially during pick-and-place tasks. The real-time control via the web dashboard proved to be responsive, with minimal latency.

Source Code: #include <WiFi.h>

```
#include <WebServer.h>
#include <ESP32Servo.h>

const char* ssid = "A";
const char* password = "12345678";

WebServer server(80);
Servo baseServo;
Servo shoulderServo;
Servo elbowServo;
Servo clutcherServo;
Servo gripperServo;  // New gripper servo

int baseAngle = 0;
int shoulderAngle = 90;
int elbowAngle = 0;
int clutcherAngle = 90;
int gripperAngle = 0;  // New gripper angle

void moveServoSmooth(Servo &servo, int currentAngle, int targetAngle) {
  int step = (targetAngle > currentAngle) ? 1 : -1;
  for (int angle = currentAngle; angle != targetAngle; angle += step) {
    servo.write(angle);
    delay(10); // Adjust this delay for speed control
  }
  servo.write(targetAngle);
}

void handleRoot() {
  String html = "<html><body><h2>Robotic Arm Control</h2>"
                "<h3>Base</h3>"
                "<input type='range' min='0' max='180' value='" + String(baseAngle) + "' 
onchange='sendAngle(this.value, \"base\")' /><br>"
                "<h3>Shoulder</h3>"
                "<input type='range' min='0' max='180' value='" + String(shoulderAngle) + "' 
onchange='sendAngle(this.value, \"shoulder\")' /><br>"
```

```
  "<h3>Elbow</h3>"
            "<input type='range' min='0' max='180' value='" + String(elbowAngle) + "' onchange='sendAngle(this.value, \"elbow\")' /><br>"
            "<h3>Clutcher Rotate</h3>"
            "<input type='range' min='0' max='180' value='" + String(clutcherAngle) + "' onchange='sendAngle(this.value, \"clutcher\")' /><br>"
            "<h3>Gripper (Pick/Drop)</h3>"
            "<input type='range' min='0' max='180' value='" + String(gripperAngle) + "' onchange='sendAngle(this.value, \"gripper\")' /><br>"
            "<script>"
            "function sendAngle(val, joint) {"
            " fetch('/set?' + joint + '=' + val);"
            "}"
            "</script></body></html>";
  server.send(200, "text/html", html);
}

void handleSet() {
  if (server.hasArg("base")) {
    int target = server.arg("base").toInt();
    target = constrain(target, 0, 180);
    moveServoSmooth(baseServo, baseAngle, target);
    baseAngle = target;
    Serial.println("Base angle: " + String(baseAngle));
  }

  if (server.hasArg("shoulder")) {
    int target = server.arg("shoulder").toInt();
    target = constrain(target, 0, 180);
    moveServoSmooth(shoulderServo, shoulderAngle, target);
    shoulderAngle = target;
    Serial.println("Shoulder angle: " + String(shoulderAngle));
  }

  if (server.hasArg("elbow")) {
    int target = server.arg("elbow").toInt();
    target = constrain(target, 0, 180);
```

```
    moveServoSmooth(elbowServo, elbowAngle, target);
    elbowAngle = target;
    Serial.println("Elbow angle: " + String(elbowAngle));
  }

  if (server.hasArg("clutcher")) {
    int target = server.arg("clutcher").toInt();
    target = constrain(target, 0, 180);
    moveServoSmooth(clutcherServo, clutcherAngle, target);
    clutcherAngle = target;
    Serial.println("Clutcher angle: " + String(clutcherAngle));
  }

  if (server.hasArg("gripper")) {
    int target = server.arg("gripper").toInt();
    target = constrain(target, 0, 180);
    moveServoSmooth(gripperServo, gripperAngle, target);
    gripperAngle = target;
    Serial.println("Gripper angle: " + String(gripperAngle));
  }

  server.send(200, "text/plain", "OK");
}

void setup() {
  Serial.begin(115200);
  WiFi.begin(ssid, password);
  Serial.print("Connecting to WiFi");
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("\nConnected! IP address: ");
  Serial.println(WiFi.localIP());

  baseServo.setPeriodHertz(50);
  shoulderServo.setPeriodHertz(50);
```

```
  elbowServo.setPeriodHertz(50);
  clutcherServo.setPeriodHertz(50);
  gripperServo.setPeriodHertz(50);  // New servo

  baseServo.attach(13, 500, 2400);
  shoulderServo.attach(12, 500, 2400);
  elbowServo.attach(14, 500, 2400);
  clutcherServo.attach(27, 500, 2400);
  gripperServo.attach(26, 500, 2400);  // Attach to GPIO 26

  baseServo.write(baseAngle);
  shoulderServo.write(shoulderAngle);
  elbowServo.write(elbowAngle);
  clutcherServo.write(clutcherAngle);
  gripperServo.write(gripperAngle);  // Initialize gripper

  server.on("/", handleRoot);
  server.on("/set", handleSet);
  server.begin();
  Serial.println("Server started");
}

void loop() {
  server.handleClient();
}
```

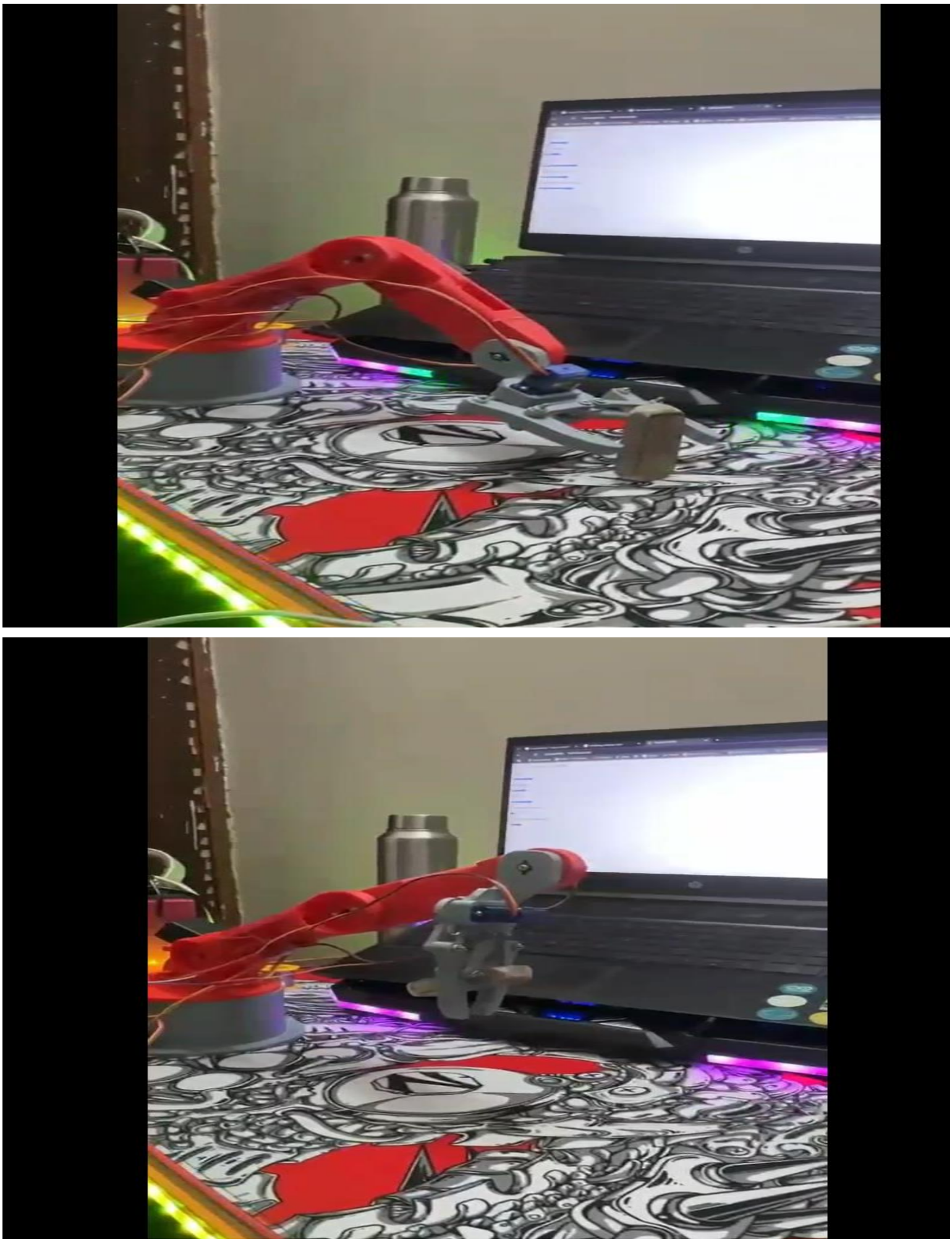


Figure 4.1: Pick And Drop Results of Robotic Arm

2.2 Contributions from the Study

- A low-cost, portable robotic arm was developed, controlled wirelessly using the ESP32 microcontroller.
- The system was integrated with smooth motion control algorithms, ensuring precise servo movements for accurate task execution.
- The web-based IoT dashboard allowed for real-time monitoring and control, ensuring accessibility from any device connected to the internet.
- The system demonstrated practical applications in automated handling tasks, making it a valuable tool for environments that require precise object manipulation.

2.3 Inferences and Conclusions

- The ESP32 microcontroller, with its dual-core architecture and Wi-Fi capability, provided an efficient platform for controlling the robotic arm remotely and with low-latency response.
- The system was stable and consistent in its operation under different load conditions, demonstrating the viability of using servo motors and IoT communication for robotic arm control.
- Future scalability of the system is possible, allowing for the integration of additional sensors and actuators to enhance the arm's capabilities, such as visual feedback (camera integration) or force-sensitive gripping.

2.4 Scope for Future Work

- Integrating more advanced sensors such as a camera for visual feedback or force sensors for the gripper could improve the arm’s ability to handle delicate objects or complex tasks.
- Enhancing the control interface with voice commands or gesture recognition could make the system more intuitive and hands-free.
- The addition of machine learning algorithms could enable the robotic arm to adapt to different tasks autonomously, improving its performance in diverse environments.
- Power optimization through solar or battery-powered modules could make the system more sustainable for outdoor or remote applications.
- Cloud-based data storage could be implemented for tracking the arm’s usage, error logs, or performance over time, offering opportunities for further improvements and analytics.

Chapter 5

Conclusions

The development of the robotic arm effectively demonstrates the integration of fundamental mechanical design with microcontroller-based control systems.

The project utilized servo motors for joint articulation and a basic control algorithm programmed on a microcontroller platform to execute predefined movements. The system showcased reliable and repeatable operation, validating both the mechanical structure and the control logic.

Key aspects addressed include joint coordination, basic motion sequencing, and system calibration. This project provides a strong foundational understanding of robotic systems and serves as a practical step toward more complex automation.

Potential future upgrades could include adding sensor-based feedback, improved control precision, and wireless operation to enhance versatility and user interaction.

Chapter 6

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