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# IOT-Based Robotic Arm to Support Labours in Substations

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***Abstract*— This paper presents the design and implementation of an IoT-based robotic arm aimed at supporting labourers in substation environments. The system employs a Raspberry Pi 3 controller and multiple servo motors to enable six degrees of movement, allowing efficient lifting, rotating, and gripping operations. The robotic arm, built with lightweight 3D-printed parts, is operated via a wireless smartphone interface, enhancing safety and flexibility for workers. Designed for pick-and-place tasks of heavy or hazardous electrical components, the prototype demonstrates practical utility in improving efficiency and reducing risks in substation maintenance. The modular approach facilitates adaptation to various industrial applications. Future enhancements may integrate additional sensors and AI for greater adaptability.***

**Keywords**— Robotic arm, IoT, Raspberry Pi, wireless control, substation automation, industrial safety

## I. INTRODUCTION

A robotic arm integrated with the Internet of Things (IoT) is a programmable mechanical manipulator. That leverages network connectivity to enable remote control and monitoring, allowing for flexible operation. Across various applications by providing tall while minimizing human intervention in hazardous environments. The ability to perform tasks like pick-and-place operational include increased productivity, reduced human error, improved safety in hazardous environments and the ability to perform complex tasks with high precision [1]. The integration of (IoT) enables real-time data and analysis, which helps in optimizing the performance of the robotic arm and allows for predictive maintenance. This technology can be applied in industries such as manufacturing, healthcare, and substations, where automation enhances efficiency, accuracy, and worker safety [3]. Robotic manipulators resembling the human arm is known as robotic arms. They are constructed by a structure consisting of structurally robust links coupled by either rotational joints or translating joints. A robotic arm is thus a type of mechanically coupled or joined arm, run by programmable commands, with similar functions to a human arm [6]. The objective of this study is to design and develop a robotic arm intended for educational and experimental applications.

The proposed system demonstrates the fundamental principles of automation and control, making it suitable for academic demonstrations and research purposes. It is capable of performing pick-and-place operations efficiently, particularly for objects that require precise positioning or delicate handling. This implementation aims to enhance understanding of robotic mechanisms and promote practical learning in the field of robotics and automation. In electrical substations, workers are often exposed to high-voltage environments and hazardous conditions during maintenance or material handling tasks [7]. Repetitive manual operations in such areas increase the risk of electric shock, fatigue, and accidents. This motivated the development of a low-cost, automated prototype robotic arm controlled by a Raspberry Pi 3, aimed at assisting or replacing human labour in performing dangerous or repetitive tasks safely and efficiently [9]. The goal is to enhance worker safety, reduce human error, and improve operational reliability in substations [10]. Now on the main objectives of our project will be derived & briefed out in below phrases.

## II. OBJECTIVES

The primary objective of this project is to design and develop an IoT-enabled pick and place robotic arm using a Raspberry Pi as the central control unit. The system aims to automate the process of identifying, picking up, and placing objects in designated locations with high accuracy and efficiency. By integrating Internet of Things (IoT) technology, the robotic arm can be remotely monitored and controlled via mobile interface, allowing real-time operation from location. This work seeks to: Implement a cost- effective robotic system using open-source hardware and software. Utilize servo motors for precise movement and object handling. Establish wireless communication for remote control and monitoring through the internet.

Demonstrate the application of IoT in robotics for industrial automation, warehousing, and smart systems. Lay the foundation for future enhancements such as AI-based object recognition and advanced motion planning. The project underscores the potential of affordable, programmable systems like the Raspberry Pi in enabling smart, connected, and autonomous robotic solutions. Now on the main robotic arm technology of our project will be derived & briefed out in below phrases.

## III. ROBOTIC ARM TECHNOLOGY

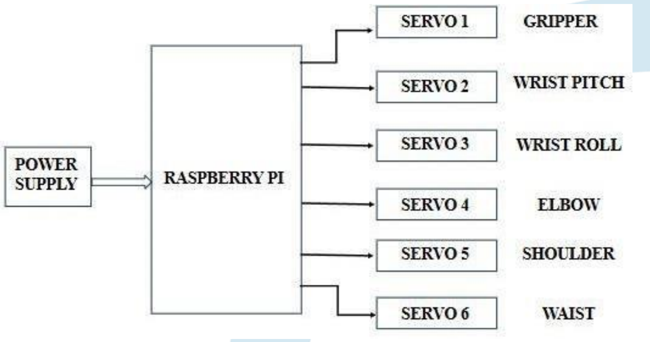


Fig. 1. Block Diagram

The block diagram illustrates the overall structure of the IoT-based Robotic Arm. A power supply unit provides stable voltage to the Raspberry Pi and servo motors. The Raspberry Pi functions as the central controller, receiving control inputs via IoT and sending PWM signals to the servos. Six servo motors are used: one each for the gripper, wrist pitch, wrist roll, elbow, shoulder, and waist enabling smooth and precise multi-axis motion. IoT integration allows remote monitoring and control, ensuring worker safety in substations by minimizing direct human contact with high-voltage areas.

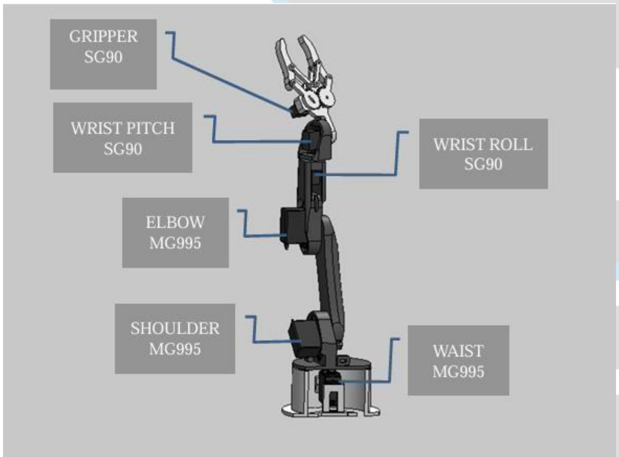


Fig. 2. Robotic Arm Structure

The IoT-based robotic arm operates using a Raspberry Pi as the central control unit, which coordinates the motion of six servo motors—three MG995 and three SG90. The MG995 servos are used for the waist, shoulder, and elbow joints, providing high torque for major arm movements, while the SG90 servos control the wrist pitch, wrist roll, and gripper for precise positioning and object manipulation. The Raspberry Pi receives commands via an IoT interface (such as a web or mobile application) over Wi-Fi. These commands are processed and translated into corresponding PWM signals that drive the servo motors. Each servo motor moves to a specific angle according to the control signals, allowing the arm to perform coordinated actions like picking, placing, and rotating objects. The IoT connectivity enables remote monitoring and real-time control, making the system suitable for applications such as automation, remote handling, and educational robotics. Now on the main circuit diagram of our project will be derived & briefed out in below phrases.

## IV. CIRCUIT DIAGRAM

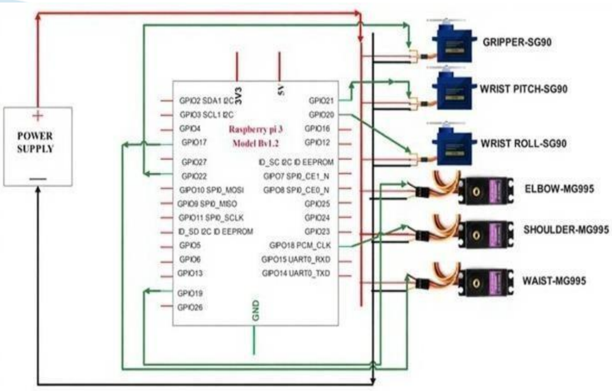


Fig. 3. Circuit Diagram

The circuit uses a Raspberry Pi 3 as the main controller to operate six servo motors forming the robotic arm. External DC power supply provides stable power to all servos; a common ground is shared with the Raspberry Pi. PWM signals from Raspberry Pi GPIO pins control each servo's position. **Servos used:**MG995 (3x) – Waist, Shoulder, Elbow (high torque). SG90 (3x) – Wrist Roll, Wrist Pitch, Gripper (light precision). The Raspberry Pi generates control signals based on commands (via Wi-Fi or web interface). The arm performs pick-and-place tasks, reducing human effort in substations. The setup demonstrates a low- cost, IoT-enabled automation prototype for labour assistance.

## V. EXPERIMENTAL IMPLEMENTATION

The experimental setup of the proposed IoT-based robotic arm system is illustrated in Fig. 2. The entire setup has been designed, fabricated, and tested in a controlled laboratory environment to validate its functional performance and reliability. The system employs a Raspberry Pi 3 Model B as the central processing unit, which serves as the primary controller for real-time computation, servo actuation, and IoT-based communication. The Raspberry Pi was selected due to its compact size, built-in Wi-Fi module, and ability to handle multiple servo control signals efficiently through its GPIO (General Purpose Input/Output) pins.The robotic arm consists of six degrees of freedom (6-DOF) to achieve complex and human-like motion. Three high-torque MG995 servo motors are utilized for the base rotation (waist), shoulder, and elbow joints, enabling the arm to lift and move objects with enhanced mechanical stability and torque support. These joints are primarily responsible for the major positional movements and provide a strong foundation for vertical and horizontal displacement. For finer operations, such as wrist articulation and gripping, SG90 micro servos are employed to control the wrist pitch, wrist roll, and gripper. These lightweight servos offer high precision and rapid response, making them suitable for delicate object manipulation. The control algorithm is implemented in Python, leveraging the RPi.GPIO and time libraries to generate precise PWM (Pulse Width Modulation) signals that determine each servo's angular position. The system's IoT capability is realized through a web or mobile-based dashboard that interfaces with the Raspberry Pi via Wi-Fi. This enables real-time command transmission from the user to the robotic arm over the network. The user interface provides intuitive control options, allowing operators to manipulate the arm remotely, monitor its operational status, and execute pick-and-place commands efficiently. During the experimentation phase, the robotic arm was tested to perform multiple pick-and-place tasks involving objects of varying weights and dimensions. The arm exhibited smooth, coordinated, and repeatable motion, confirming the accuracy of the servo calibration and control algorithm. The latency between command input and mechanical response was found to be minimal, ensuring near real-time operation suitable for practical applications. Furthermore, the Wi-Fi- based IoT connectivity demonstrated stable communication with negligible packet loss, indicating the robustness of the system under continuous operation. The experimental results validate the successful integration of mechanical design, embedded control, and IoT-based communication in a unified platform. The use of the Raspberry Pi not only reduces the overall system cost but also enhances flexibility for future upgrades, such as incorporating machine vision or AI-based automation. This implementation demonstrates the feasibility of deploying an IoT-enabled robotic arm for assisting workers in substation environments, where remote operation can minimize human exposure to high-voltage risks and improve overall safety and efficiency.

## VI. HARDWARE COMPONENTS

Raspberry Pi3 Board**:-**The Raspberry Pi 3 Model B is a single-board computer featuring a quad-core 1.2 GHz processor, 1GB of RAM, on-board Wi-Fi and Bluetooth.

64-bit Cortex-A53 SOC at 1.4GHz, 1GB of RAM,
Supports dual-band Wi-Fi (2.4 GHz and 5 GHz),
Bluetooth 4.2, and Gigabit Ethernet over USB 2.0

PWM-PCA9685**:-** It is a 16-channel, 12-bit Pulse Width Modulation (PWM) servo/LED driver that uses an I2C interface to control up servos or LEDs from a microcontroller with just two I2C pins.
Channels: 16
Power: 5V DC (operating)

MG 996 Servomotor**:-** The Tower Pro MG996 is a high-torque, metal-gear servo motor, known for its strong turning power and accurate handling, suitable for robotics, robotic arms, and RC applications, offering a ~120° rotation range controlled.
MG 996 Servo Motor 4.8V to 6.6V DC

SG 90 Servomotor**:-** The SG90 is a small, affordable, and commonly used micro servo motor, known for its ability to rotate approximately 180 degrees (90 in each direction) and is popular in robotics.
SG 90 Servo Motor 3.0 to 7.2 volts DC

## VII. SOFTWARE USED PYTHON 3.10.13

Python 3.10.13 serves as the primary programming language for the development and control of the proposed IoT-based robotic arm. Python's simplicity, extensive library support, and strong community make it ideal for rapid prototyping and hardware interfacing with embedded systems such as the Raspberry Pi. In this implementation, Python is used to control the robotic arm by generating PWM (Pulse Width Modulation) signals that drive the servo motors, enabling precise movement of each joint. Through Python scripts, the angles, motion sequence, and timing of the servo motors are defined, allowing for accurate and repeatable pick-and-place operations.

Python programs are designed to send specific commands to the servo motors via the Raspberry Pi's GPIO pins, thus controlling the waist, shoulder, elbow, wrist, and gripper motions of the arm. The modular nature of Python makes it convenient to integrate additional functionalities such as obstacle detection, or AI-assisted motion planning. Furthermore, Python's compatibility with IoT frameworks allows real-time data exchange between the robotic arm and a remote user interface over Wi-Fi.

In addition to motor control, Python scripts facilitate communication between the hardware and the web dashboard, enabling users to issue commands remotely and monitor the system status. The interactive Python-based interface ensures smooth synchronization between hardware actions and user inputs. Overall, Python provides an efficient, flexible, and scalable software environment for controlling the robotic arm, making it an essential component in achieving intelligent automation in IoT-based robotic systems.

## VIII. RESULT

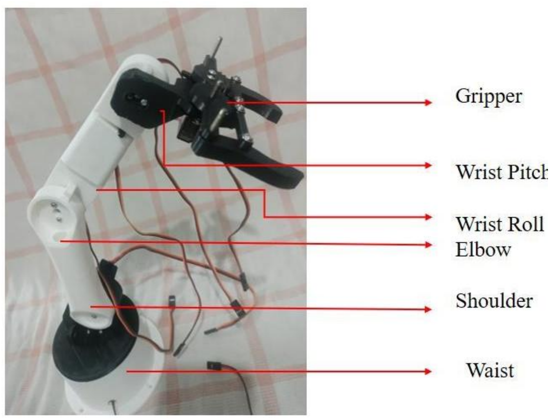


Fig. 3. REAL 3D PRINTED ARM

The developed IoT-based robotic arm using Raspberry Pi 3 was successfully designed and tested, as illustrated in Fig. 3. The arm consists of six degrees of freedom controlled by six servo motors, enabling coordinated movement of the waist, shoulder, elbow, wrist pitch, wrist roll, and gripper

The Raspberry Pi acts as the central controller, generating precise PWM signals to drive each servo according to user commands received through an IoT interface. During testing, the robotic arm demonstrated smooth and stable motion across all joints, effectively performing pick-and- place operations with high positional accuracy. The gripper exhibited reliable gripping action, while the base and shoulder joints provided strong support for lifting small objects. The results confirm that the system is capable of remote operation through Wi-Fi, validating the effectiveness of using Python-based control and Raspberry Pi integration for real-time robotic automation. The custom-built app allowed users to control all six servo motors (S1–S6) individually by entering specific angular values, providing accurate positioning of the waist, shoulder, elbow, wrist pitch, wrist roll, and gripper. The system effectively performed pick-and-place operations for lightweight components, verifying the reliability of angle-based control and IoT-enabled remote operation. Overall, the results confirm that the proposed model can safely and efficiently execute tasks from a mobile device, making it suitable for deployment in substation environments where human presence must be minimized.

| SERVO | OPEN | CLOSE |
|---|---|---|
| GRIPPER | $120^\circ$ - $90^\circ$ | $50^\circ$ - $30^\circ$ |

| SERVO's | STRAIGHT | LEFT ROTATION | RIGHT ROTATION |
|---|---|---|---|
| WRIST PITCH | $180^\circ$ - $120^\circ$ | - | - |
| WRIST ROLL | $120^\circ$ | $>120^\circ$ - $180^\circ$ | $<120^\circ$ - $0^\circ$ |
| ELBOW | $40^\circ$ | $<40^\circ$ - $0^\circ$ | $>40^\circ$ - $120^\circ$ |
| SHOULDER | $150^\circ$ | $150^\circ$ - $180^\circ$ | $90^\circ$ - $150^\circ$ |
| WAIST | $0^\circ$ - $180^\circ$ | – | – |

Fig. 4. Operating Method

## IX. ADVANTAGES

Enhances safety by minimizing human exposure to electrical hazards. Low-cost solution using Raspberry Pi 3 and readily available components. Improves accuracy and efficiency in repetitive or hazardous operations. Easily programmable for various control functions and task customization. Portable and compact, suitable for small-scale substations or labs.

## X. CONCLUSION

The development of an IoT-based robotic arm presents a significant advancement in automating hazardous tasks, particularly within electrical substations. By integrating servo motors, and wireless communication through IoT technology, the system enhances operational safety, accuracy, and efficiency. The prototype successfully demonstrates the ability to pick and place objects remotely, reducing human involvement in high-risk environments. This project not only validates the potential of IoT in industrial automation but also provides a foundation for future enhancements such as AI-based object detection, advanced control algorithms, and real-time data analytics to further improve reliability and adaptability in field applications.Used in electrical substations for handling components and tools in high-voltage zones. Applicable in maintenance and insp ection tasks where direct human contact is risky. Can be adapted for industrial automation, material handling, and laboratory assistance. Limited payload capacity can only lift lightweight objects. Not fully autonomous; still requires manual control or supervision.

## XI. FUTURE SCOPE

AI and Computer Vision Integration: The robotic arm can be enhanced with AI to detect and operate substation equipment automatically.Voice and Gesture Control: Adding voice or gesture recognition will allow easier, hands-free operation of the robotic arm. Improved Load Handling: The design can be upgraded to lift and manage heavier electrical components safely. Cloud-Based Monitoring: Future systems can use cloud platforms for remote operation and real-time data access. Autonomous Mobility: Integrating movement sensors will enable the arm to navigate and perform tasks independently within substations.

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