

Design and Development of a 4-DOF Robotic Arm for Object Manipulation

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Abstract

The design and development of robotic systems have gained significant attention in recent years due to their wide applications in industrial automation, healthcare, and service sectors. This paper presents the design and implementation of a 4-degree-of-freedom (4-DOF) robotic arm for object manipulation. The proposed system utilizes a microcontroller-based control mechanism integrated with servo motors to achieve precise movement and control. The robotic arm is capable of performing pick-and-place operations with improved accuracy and efficiency. The design includes a lightweight mechanical structure, a gripper mechanism, and a user-friendly control interface. Experimental results demonstrate that the system performs smooth and stable operations, making it suitable for educational and small-scale industrial applications.

Keywords- Robotic Arm, 4-DOF, Object Manipulation, Servo Motors, Arduino, Automation

1. Introduction

Robotic arms play a crucial role in automation and manufacturing industries by performing repetitive and precise tasks efficiently. With advancements in embedded systems and control technologies, robotic arms have become more affordable and accessible for educational and research purposes. This study focuses on the design and development of a 4-DOF robotic arm capable of performing object manipulation tasks such as picking, lifting, and placing objects. The objective is to develop a cost-effective and efficient robotic system that demonstrates precise control and flexibility. The proposed system aims to bridge the gap between theoretical learning and practical implementation in robotics.

2. Related Work

Various researchers have explored robotic arm designs with different degrees of freedom and control techniques. Earlier works focused on industrial robotic arms with high precision and complex control systems. Recent studies have emphasized low-cost robotic arms using

microcontrollers such as Arduino and servo motors. Some systems incorporate sensors and vision-based control for enhanced functionality. However, many existing designs are either costly or complex for beginners. This work aims to provide a simple yet effective solution for object manipulation using a 4-DOF robotic arm with improved accuracy and ease of control.

3. Materials and Methods

The proposed robotic arm consists of four servo motors providing four degrees of freedom: base rotation, shoulder movement, elbow movement, and gripper operation. The system is controlled using an Arduino Uno microcontroller programmed via Arduino IDE.

Components used:

Arduino Uno

Servo Motors (SG90 / MG996R)

Power Supply Unit

Robotic Arm Frame (3D printed/acrylic)

Gripper Mechanism

Connecting wires and control circuits

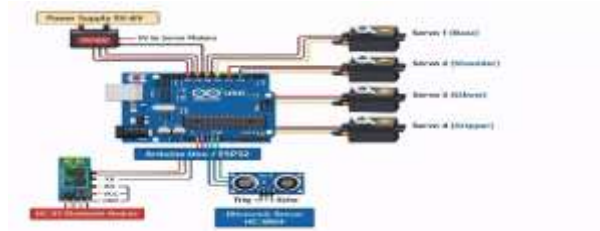


Fig: Circuit Diagram

The control algorithm is implemented using embedded C through Arduino IDE. Each servo motor is controlled using PWM signals to achieve precise angular positioning. The mechanical structure is designed to ensure stability and flexibility. The system allows manual or programmed control for performing object manipulation tasks.

4. Results and Discussion

The developed 4-DOF robotic arm was successfully tested for various object manipulation tasks. The arm demonstrated smooth and coordinated movement across all joints. The gripper mechanism effectively handled small objects with good precision. The system showed reliable performance in pick-and-place operations.

Performance analysis indicates:

Accurate positioning of joints

Stable operation without significant vibration

Efficient object handling capability

However, minor limitations such as limited payload capacity and dependency on manual control were observed. Future improvements may include sensor integration and automation using AI-based control systems.

5. Conclusion

This paper presented the design and development of a 4-DOF robotic arm for object manipulation. The system was successfully implemented using Arduino and servo motors, achieving precise and reliable performance. The robotic arm is suitable for educational purposes and

small-scale automation tasks. Future work can focus on enhancing the system with vision-based control, wireless operation, and increased load capacity to expand its applications.

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