Design and Development of a 4-DOF Robotic Arm for Pick and Place operation

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Abstract - *The increasing demand for automation in industrial and research applications has led to the development of efficient and cost-effective robotic systems. This paper presents the design and development of a four degree-of-freedom (4-DOF) robotic arm for pick-and-place operations using servo motors and an Arduino based control system. The proposed robotic arm is capable of performing multi-directional movements, enabling accurate and reliable object manipulation. Servo motors are utilized for precise control of joint movements, ensuring smooth and stable operation of the robotic arm. The Arduino microcontroller acts as the central control unit, processing user inputs and generating control signals for coordinated motion. The system can be operated using input devices such as a joystick, potentiometer, or pre-programmed commands, providing flexibility in control mechanisms. The developed robotic arm demonstrates effective performance in pick-and-place tasks with satisfactory accuracy. Furthermore, the system provides a scalable platform for future improvements through the integration of advanced technologies such as artificial intelligence and machine learning, contributing to the advancement of intelligent robotic systems.*

Key Words: **Degrees of Freedom (4-DOF),Servo motors ,Arduino control, Pick and Place operation, Inverse Kinematics/Forward Kinematics(for movement calculation), End effector/Gripper, Material handling ,Develop Prototype, DC power supply, Joystick control, Pre-program commands, Code, simulation**

1. INTRODUCTION

Robotics has emerged as a rapidly advancing field in engineering, focusing on the design, development, and control of automated systems. It plays a significant role in modern industrial environments by enabling tasks to be performed with high speed, precision, and efficiency. The adoption of robotic systems has contributed to the reduction of human effort and the enhancement of productivity, particularly in repetitive and time-intensive operations .In industrial applications, robotic systems are extensively utilized for operations such as pick-and-place tasks, material handling, packaging, and assembly. These tasks require accurate positioning, controlled movement, and high repeatability, which can be effectively achieved through the implementation of robotic arms. The integration of such systems ensures consistent performance and improved operational outcomes. Furthermore, the use of robotics minimizes human errors, reduces operational time, and enhances overall system efficiency. It also contributes to improved workplace safety by limiting human involvement in hazardous and high-risk environments. Owing to these advantages, robotic systems have become an essential component of modern industrial automation. This study presents the design and development of a four-axis robotic arm for pick-and-place operations. The proposed system is based on the concept of an open kinematic chain, enabling flexible and controlled motion. The design emphasizes simplicity, cost-effectiveness, and ease of implementation, making it suitable for basic automation tasks as well as educational and research applications.

1.1 Problem Defamation :

In modern industries, automation is very important for improving productivity, accuracy, and efficiency. Pick and place operations, where objects are moved from one place to another, are commonly used in manufacturing and packaging. These tasks are often done manually, which can cause fatigue, slower work, and more errors.

Although industrial robotic arms can automate these tasks, they are usually expensive, complex, and require advanced control systems. Because of this, they are not suitable for small industries, educational institutes, or lab-level projects.

Therefore, there is a need for a simple, low-cost, and efficient robotic arm that can perform pick and place operations with good accuracy. The system should have enough flexibility and be easy to control. This project focuses on designing a 4-axis robotic arm using an Arduino microcontroller. The goal is to develop a cost-effective and simple automation system suitable for education, research, and small-scale applications.

1.2 Literature Survey:

1) Jianqiang Wang, Yanmin Zhang, and Xintong Liu (2021) proposed "Control System of 4-DOF Palletizing Robot Based on Improved R Control Multi-Objective Trajectory Planning." The authors developed a control system for a 4-DOF robotic arm to improve trajectory planning efficiency and motion accuracy. They used a B-spline trajectory planning algorithm along with an improved R-control method for faster interpolation and smoother robotic motion.
Experimental testing in a production environment showed that the system improved path planning speed, control precision, and overall reliability. The study also highlighted better universality and scalability of the robotic arm control system for industrial automation

2) Milind R. Shinde, V. N. Bhaiswar, and B. G. Achmare (2016) proposed "Designing a Suitable Robotic Arm for Loading and Unloading of Material on Lathe Machine Using Workspace Simulation Software." The study focused on automating lathe machine loading and unloading operations to improve productivity and reduce manual effort. The robotic arm was designed using CATIA V5 and simulated in Workspace LT software. The proposed system used a 7-axis robotic arm with a dual gripper mechanism for simultaneous loading and unloading of workpieces. The authors concluded that the robotic arm can increase machine utilization, reduce cycle time, and provide an efficient low-cost automation solution for industries.

3) Amari et al. (2020) proposed a 4-axis shadow robotic arm integrated with flex sensors to mimic human hand and elbow movements wirelessly. The system used sensors to detect finger bending and elbow motion, while Bluetooth communication transmitted signals to servo motors for accurate robotic movement. The robotic arm was designed using SolidWorks and fabricated using 3D printing. Experimental results showed that the arm successfully copied human motions with small error, making it useful for industrial automation and pick-and-place applications.

4) Sanjay L. and Shweta P. (2012) proposed "Position Control of Pick and Place Robotic Arm" presented at the International Conference on Engineering Innovation and Technology, Nagpur. The study focused on the design and position control of a pick-and-place robotic arm for industrial automation and material handling applications. The system used five RC servo motors and a microcontroller-based control system. Forward and inverse kinematics were applied to determine accurate end-effector position and orientation. The results showed effective pick-and-place performance with good accuracy in industrial automation applications.

5) Jianqiang Wang, Yanmin Zhang, and Xintong Liu (2021) proposed "Control System of 4-DOF Palletizing Robot Based on Improved R Control Multi-Objective Trajectory Planning." The authors developed a control system for a 4-DOF robotic arm to improve trajectory planning efficiency and motion accuracy. They used a B-spline trajectory planning algorithm along with an improved R-control method for faster interpolation and smoother robotic motion. Experimental testing in a production environment showed improved path planning speed, control precision, reliability, and scalability for industrial automation applications.

1.3 Inverses and Forward Kinematics-

Forward and inverse kinematics are fundamental concepts used in robotic systems to control the movement of a robotic arm. Forward kinematics refers to the process of determining the position and orientation of the robot's end-effector (gripper) based on the known joint angles and link lengths. In this case, the input is the angles of the joints, and the output is the exact position of the robot's hand in space. It is relatively simple and is mainly used to track the motion of the robot. On the other hand, inverse kinematics is the process of determining the required joint angles to achieve a desired position of the end effector. Here, the position is given as input, and the system calculates the angles needed at each joint. Inverse kinematics is more complex because there can be multiple possible solutions or sometimes no solution at all. Both concepts are essential in robotic arm applications, where forward kinematics helps in understanding the current position, while inverse kinematics is used to control the robot to reach a specific target point.

2. System Overview of Robotic Arm System:

Introduction to System The robotic arm system is an automated mechanical device designed to perform pick and place operations. It mimics the movement of a human arm using multiple joints and links. The system is based on an open kinematic chain, where each link is connected in series, allowing flexible movement in different directions. The system integrates mechanical components, electronic circuits, and control programming to achieve precise motion. It is mainly used for handling objects, reducing human effort, and improving efficiency in repetitive tasks

2 Main Components of the System

2.1 Mechanical Structure

- The mechanical structure consists of:
- Base (provides rotation)
- Shoulder joint (up-down movement)
- Elbow joint (extension)
- End-effector (gripper)
- These components are connected through rigid links forming an open chain structure.

2.2 Actuators (Servo Motors) Servo motors are used to control joint movements. Each motor rotates to a specific angle based on input signals. These motors provide:

- High accuracy
- Controlled movement
- Easy interfacing with microcontroller.

2.3 Controller (Arduino)

The system is controlled using Arduino Uno microcontroller board.

- It acts as the brain of the system.
- Functions of Arduino:
- Sends control signals to motors
- Executes programmed instructions
- Controls movement sequence

2.4 Power Supply

- A DC power supply is used to provide required voltage to:
- Arduino
- Servo motors
- Proper power management ensures stable operation of the system

2.5 End Effector (Gripper)

- The gripper is attached at the end of the arm and is responsible for:
- Picking objects
- Holding objects
- Releasing object
- Working Principle of System The robotic arm operates based on predefined instructions given through programming. Step-by-step working:
- The system is powered ON
- Arduino initializes servo motors
- Input angles are given to joints
- Servo motors rotate accordingly
- Arm moves to pick position
- Gripper closes to hold object
- Arm moves to destination
- Gripper opens to release object
- This process is repeated automatically

2.6 Control System Overview

- The system uses an open-loop control system, meaning:
- No feedback is taken from output
- Movement depends on programmed instructions
- Future systems can use sensors for feedback to improve accuracy

2.7 Kinematic Structure

- The robotic arm follows principles of Forward Kinematics:
- Determines position of end-effector
- Based on joint angles
- Each joint contributes to the overall position of the arm

2.8 System Flow (Block Description) Input → Controller → Actuators → Mechanical Movement → Output

Explanation:

- Input: Programmed angles
- Controller: Arduino processes input
- Actuators: Servo motors move joints
- Output: Object is picked and placed

2.9 System Features

- Low-cost design
- Easy to program
- Compact structure
- for small automation tasks

3.

Potentiometre Pin.	Mode	Servo Object	Servo Signal Pin	Pulse width Ranje	Function
A0	INPUT	Servo-09	D9	500 µs – 2500 µs	Control Sevo 1 angle
A1	INPUT	Servo-10	D10	500 µs – 2500 µs	Control Servo 2 angle
A2	INPUT	Servo-11	D11	500 µs – 2500 µs	Control Servo 3 angle
A3	INPUT	Servo-12	D12	500 µs – 2500 µs	Control Servo 4 angle

Chart -1: components readings (Data)

3.1 Simulation

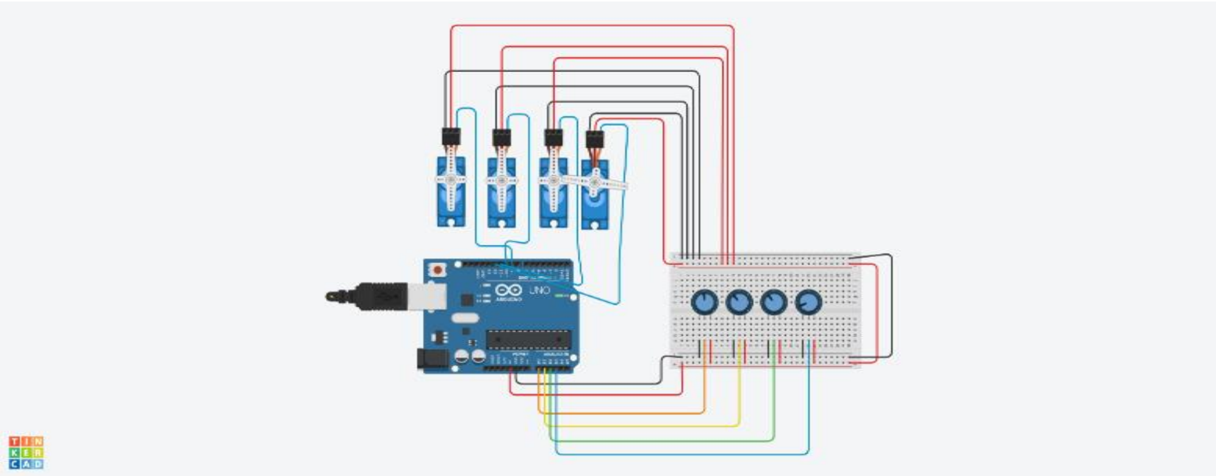

Fig -1: Arduino UNO circuit simulation for controlling 4 servo motors using 4 potentiometers(act as an analog input to adjust the position, angle of a corresponding servo motor.

3.2 PICTURE OF 4DOF ROBOT

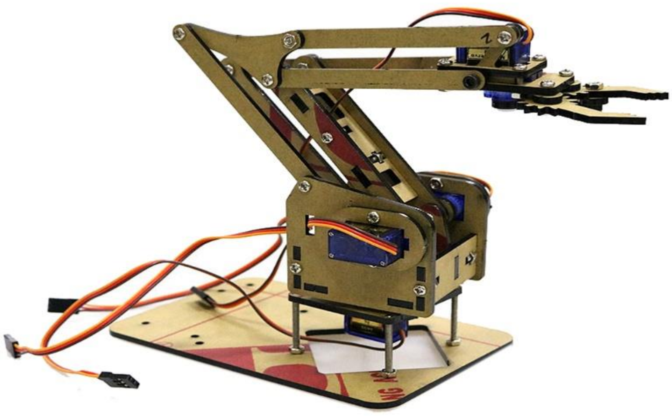

Fig 2: Prototype of a 4 DOF robotic arm

4. CONCLUSION:

This research successfully developed a 4-DOF robot arm for pick-and-place operations. The system was tested practically, and the results show that the robot works accurately with only small errors. The small errors are due to limitations of Servo motors and the mechanical structure. Overall, the robot performs well and can be used for simple industrial tasks. For future improvement, sensors can be added for better gripping, and a camera system can be used to detect object positions automatically instead of using fixed positions.

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