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Design, Fabrication, and Analysis of A4-Dof Manually Controlled Pick-and-Place Robotic Arm

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Abstract- This paper presents the design and fabrication of a manually controlled 4-DOF pick-and-place robotic arm mounted on a four-wheeled mobile platform. The robotic arm is actuated using servo motors and gear motors, with movement controlled directly via push buttons, potentiometers, toggle switches, and a servo tester, eliminating the need for microcontrollers or programmable controllers. The structure is fabricated from lightweight materials such as aluminum and foam board to ensure portability and mechanical stability.The robotic arm includes revolute joints at the shoulder, elbow, wrist, and gripper, each capable of independent and simultaneous motion. CAD modeling was performed using Creo software to visualize and validate the design before fabrication. Inverse kinematics analysis was conducted using RoboAnalyzer software to determine joint angles required for specific end-effector positions. Additionally, finite element analysis (FEA) was performed using ANSYS to evaluate stress and deformation across critical arm components. The resulting system provides a cost-effective and functional platform for basic automation tasks, academic demonstrations, and prototyping. Its simplicity and manual control make it especially suitable for learning environments focused on mechanical design, actuation, and robotic system integration.

Keywords- Pick and Place Robot; 4-DOF Robotic Arm; Servo Motor; Gear Motor; DPDT Switch

I. INTRODUCTION

The development of robotic arms for pick-and-place operations has grown significantly in recent years, particularly in academic, prototyping, and low-cost automation contexts. These robotic systems enable the handling and transfer of objects across defined workspaces and are widely used in manufacturing, inspection, and educational applications. While industrial pick-and-place systems are typically microcontroller-driven and fully autonomous, there is increasing interest in manually controlled or semi-automated alternatives that provide hands-on learning and greater accessibility. Recent research in low-cost robotic arms emphasizes affordability, simplicity of control, and educational utility. Systems are often built using readily available servo or gear motors, open-source electronics, and lightweight structural materials, with control achieved via Bluetooth, mobile apps, voice commands, or manual interfaces like joysticks and switches (Manideep et al. 2024; Hoai et al. 2023; White et al. 2018; Mostaque and Karmakar 2016; Prabhakar et al. 2021; Azlan et al. 2020). These robotic arms commonly offer 4 to 6 degrees of freedom (DOF), enabling useful levels of articulation while keeping mechanical and control complexity manageable (Murthy 2024; White et al. 2018; B.U et al. 2024).In addition, several systems support remote or app-based manual operation using mobile phones or voice commands, often combined with low-latency teleoperation interfaces for flexible pick-and-place functionality (Zughaibi et al. 2020; Murthy 2024; Mostaque and Karmakar 2016). Although many designs use microcontrollers such as Arduino or Raspberry Pi, manual control

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methods remain relevant, especially in environments where programming knowledge is limited or where simplicity is prioritized. In particular, servo testers and toggle switches offer a cost-effective approach for direct human operation without firmware or software development, supporting tactile understanding of motion control and mechanical interaction (Afikh 2009; Manideep et al. 2024).Furthermore, several studies have incorporated additional sensing and vision systems to enhance autonomy, such as cameras or sonar sensors for object detection (Murthy 2024; Mostaque and Karmakar 2016). However, for educational purposes, simpler systems continue to play a vital role in teaching fundamental robotics concepts, such as joint coordination, actuation, and inverse kinematics (White et al. 2018; B.U et al. 2024).

In this regard, the present work focuses on the design, fabrication, and analysis of a 4-DOF manually controlled pick-and-place robotic arm mounted on a four-wheeled mobile platform. The project demonstrates a mechanically robust and operationally simple model, using servo motors, gear motors, DPDT switches, and a servo tester for complete control. The robot is designed to move across locations and perform pick-and-place operations using a gripper-based end effector. The design process includes CAD modeling, inverse kinematics analysis using RoboAnalyzer, and structural validation through finite element analysis (FEA) using ANSYS. The system provides a low-cost platform for understanding robotic motion, mechanical integration, and actuation without microcontrollers or software.

II. METHODOLOGY

The design and fabrication of the manually controlled pick-and-place robot followed a structured, component-driven approach with emphasis on simplicity, cost-effectiveness, and mechanical robustness. The complete system consists of a four-wheeled mobile platform and a 4-degree-of-freedom (DOF) robotic arm, actuated entirely by DC and servo motors without the use of microcontrollers or programmable units.

1. Design Considerations

Several factors guided the development of the system:

- DC servo motors were selected over hydraulic or pneumatic actuators due to their lightweight, low power consumption, and availability, making them well-suited for manual operation.
- All materials used were locally sourced, including aluminum for structural components and foam board for light-duty support, ensuring low cost and easy replacement.
- The arm structure was designed to be lightweight, especially at the base and shoulder regions, to reduce torque load and improve stability during motion.
- Rectangular sheets were used for link fabrication to strike a balance between stiffness and weight.
- Instead of a microcontroller-based system, a servo tester and relay board were used to manually control the servo motors.
- The entire assembly was mounted on a mobile platform with four wheels, enabling the robot to travel to different locations to perform operations.

2. Degree of Freedom (DOF) Selection

The robot was designed with 4 degrees of freedom, adequate for pick-and-place operations requiring movement in three-dimensional space. These DOFs correspond to:

- Shoulder rotation
- Elbow articulation
- Wrist rotation
- Gripper opening and closing

This configuration provides enough flexibility for the robot to reach, lift, and place small objects in a controlled manner.

3. Material Selection

Material selection was driven by three main factors: strength-to-weight ratio, availability, and ease of machining. Among the materials considered, aluminum, Perspex, plastic polymer, and carbon fiber, aluminum was selected as the most suitable due to its high strength, low weight, and machinability, ensuring reliable performance without overloading the servo motors.

4. Robotic Arm Specifications

The robotic arm follows a revolute-joint configuration, modeled loosely on the human arm. It comprises:

- A shoulder joint with 180° rotation using a large-scale servo
- An elbow joint also with 180° rotation
- A wrist joint capable of 180° vertical movement
- A two-fingered gripper, driven by a standard servo with 90° operation

All joints are independently operated, and simultaneous control is possible through manual switches. The full specifications are summarized in Table1.

Table 1. Specification of robotic arm

Specification	Value
Number of axes	4
Horizontal reach	230mm
Vertical reach	130mm
Drives	4 servo motors
Configuration	4 Axes plus gripper. All axes are completely independent. All axes can be controlled simultaneously.
Work Envelope	Shoulder Rotation -150 degrees Elbow Rotation -180 degrees Wrist Rotation -180 degrees Gripper Rotation -90 degrees

2. CAD Modeling

The arm was modeled using Creo software to visualize dimensions, assembly constraints, and movement ranges before physical fabrication. CAD views include:

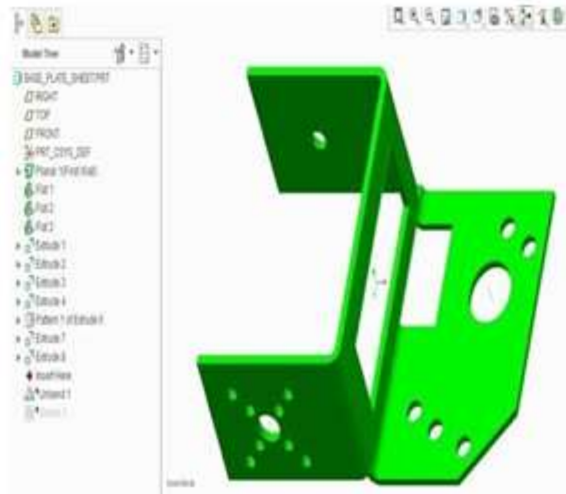

Figure 1. 3D view of Gripper Base

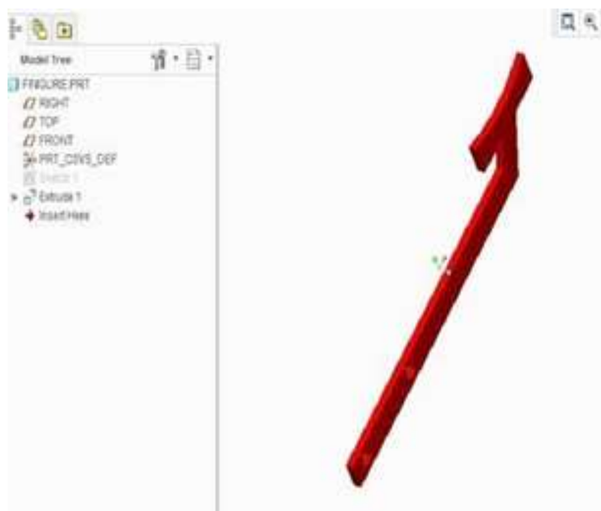

Figure 2. 3D view of Finger

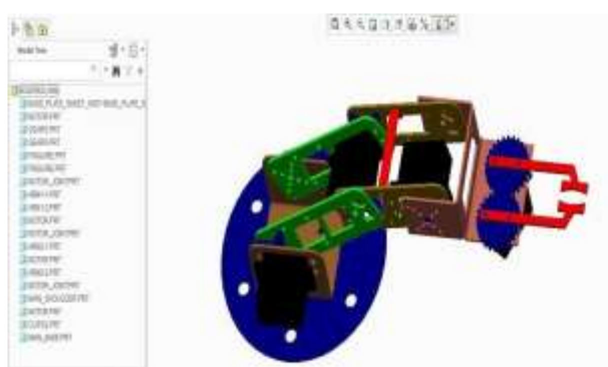

Figure 3. Full arm assembly

These models ensured all components fit correctly and helped anticipate structural stress points.

III. RESULTS AND DISCUSSION

The developed robotic arm underwent performance evaluation using three core tools: CAD modeling, inverse kinematics simulation, and finite element analysis (FEA). These tools were used to verify the mechanical feasibility, joint movement accuracy, and structural strength of the manually controlled 4-DOF pick-and-place robot.

1. CAD Modeling Validation

The complete robotic arm and its components were designed and assembled using Creo CAD software, enabling precise visualization and mechanical integration. The views from Figures 1, 2, and 3 confirmed that all parts were dimensionally compatible and functionally aligned. The design allowed sufficient rotational freedom at the joints and proper placement of servo motors and linkages. The gripper design supported secure grasping using a single standard servo.

2. Inverse Kinematics Analysis

To verify the end-effector's reachability and accuracy in positioning, inverse kinematics simulation was performed using Robo Analyzer, a 3D educational robotics tool developed by IIT Delhi.

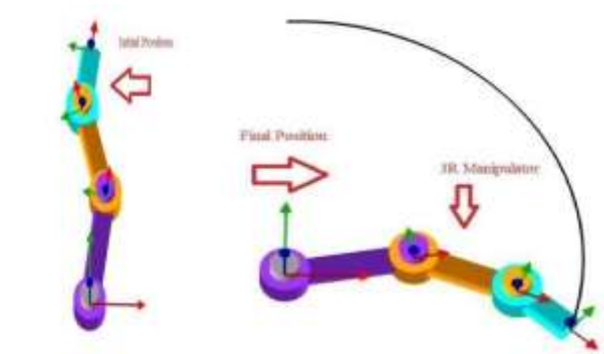

Figure 4.Initial and final position of the robotic arm during a simulated pick-and-place task.

The analysis confirmed that with proper angular input to each joint, the arm could position its end-effector effectively within the designed workspace. The simulated motion followed expected DH parameter-based transformation paths and validated the 4-DOF configuration as sufficient for general object manipulation.

3. Finite Element Analysis (FEA)

Structural evaluation of the robotic arm components was carried out using ANSYS simulation software. Total deformation and stress distribution were analyzed under expected mechanical loads.

Shoulder Base

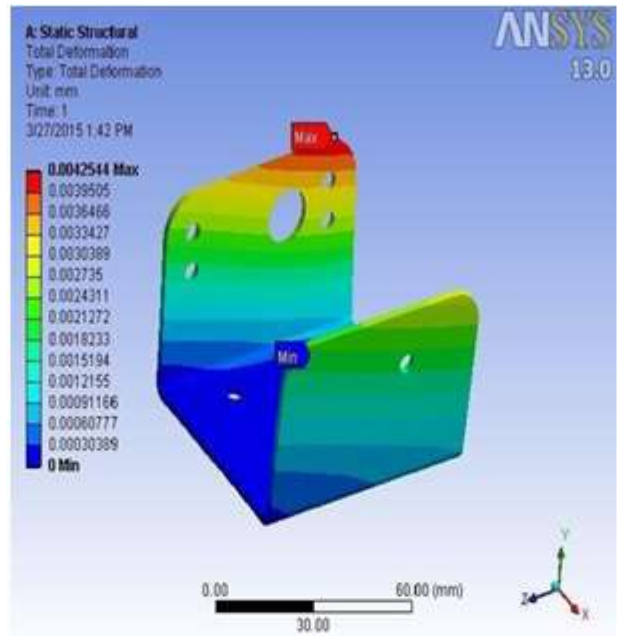

Figure 5. Total Deformation

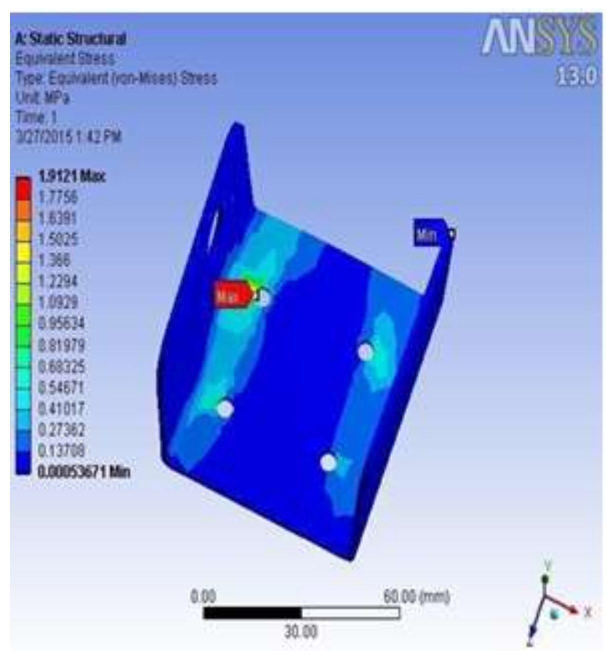

Figure 6. Stress Distribution

Shoulder Arm

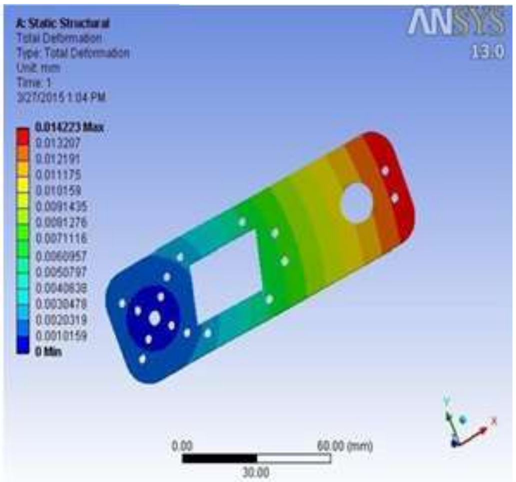

Figure 7. Total Deformation

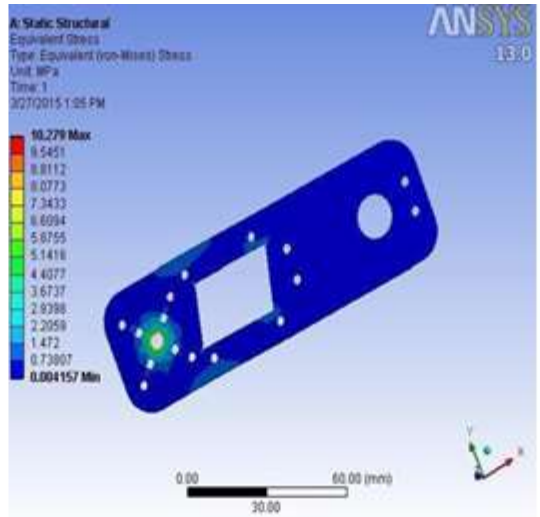

Figure 8. Stress Distribution

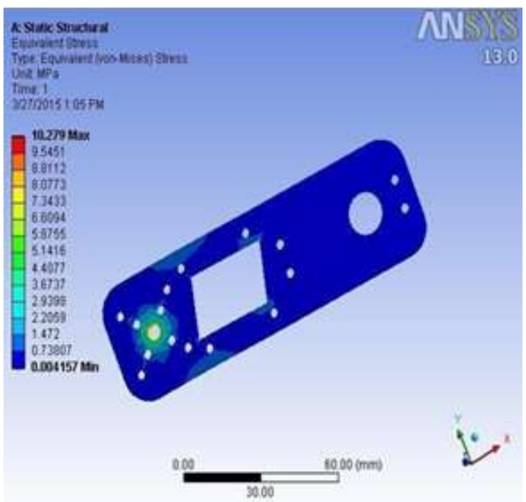

Figure 8. Stress Distribution

Gripper Finger

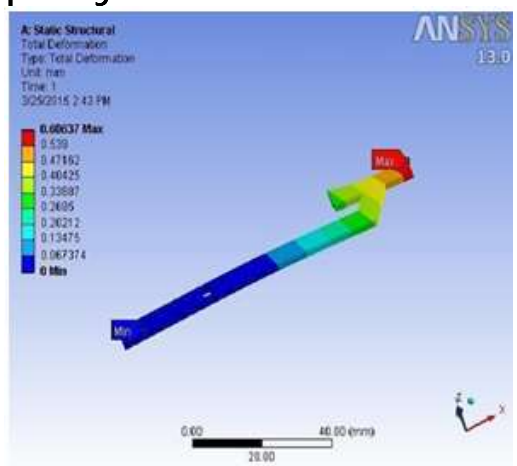

Figure 7. Total Deformation

Elbow Link

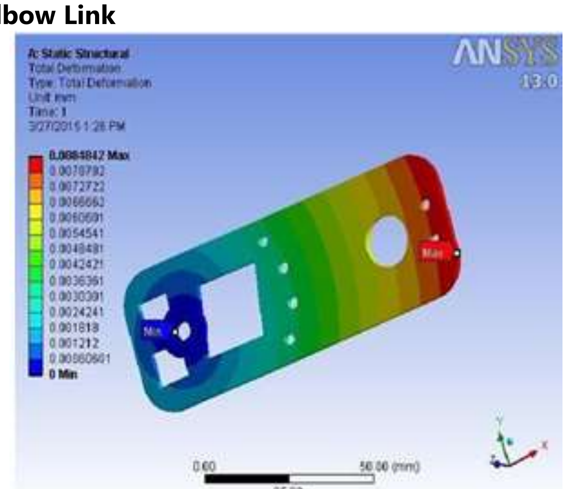

Figure 7. Total Deformation

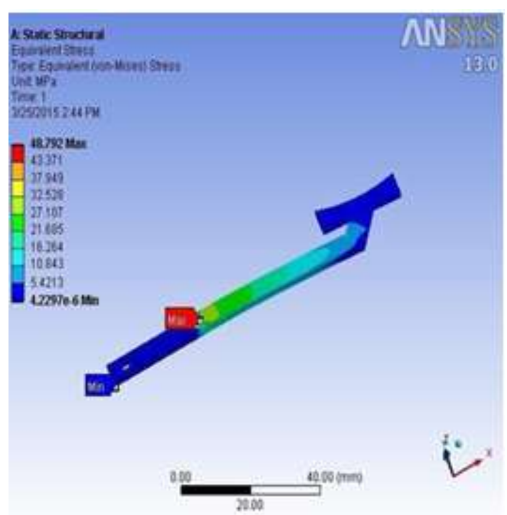

Figure 8. Stress Distribution

The results showed that all parts remained structurally stable under simulated loading conditions. Maximum deformation was within acceptable limits, and stress concentrations were primarily located near fixed joints or load-bearing regions, as expected. The use of aluminum and foam board materials offered an effective balance between weight and strength.

4. System Functionality

Once fabricated, the robot was successfully tested for basic pick-and-place motions under manual control. The push-button and toggle-switch-based control system provided satisfactory responsiveness. Though no automated feedback was used, the system responded reliably to user inputs and demonstrated the feasibility of non-programmable operation for demonstration and prototyping purposes.

IV. CONCLUSION

In this study, a 4 DOF pick-and-place robotic arm was successfully designed, fabricated, and evaluated. The system was entirely manually controlled, using servo testers, toggle switches, and gear motors, without any reliance on microcontrollers or software-based automation. The robot was mounted on a mobile four-wheeled platform, enabling movement across operational zones to perform object manipulation tasks.A detailed design process was carried out, including CAD modeling using Creo software to ensure proper fit and motion compatibility of all mechanical components. The structural materials, primarily aluminum and foam board, were selected to ensure low weight and sufficient rigidity, supporting smooth actuation without excessive load on the motors.To validate the motion feasibility, inverse kinematics analysis was performed using RoboAnalyzer, which confirmed the arm's capability to reach and reposition the end-effector accurately within its workspace. Additionally, FEA using ANSYS software confirmed that the critical arm components remained structurally sound under applied loads, with deformation and stress levels within acceptable limits.

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