FABRICATION OF 6 DEGREES OF FREEDOM ROBOTIC ARM

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Abstract - *An A six degrees of freedom (6-DOF) robotic arm is a versatile and highly flexible manipulator widely used in industrial automation, research, and advanced manufacturing. This project focuses on the design, fabrication, and analysis of a 6-DOF robotic arm capable of performing complex tasks with high precision and efficiency. The six degrees of freedom enable the arm to move in three-dimensional space with rotational and translational motions, closely mimicking the movement of a human arm. The proposed system consists of mechanical components such as links, joints, actuators (servo or stepper motors), and a rigid base, along with electronic control units including microcontrollers, motor drivers, and sensors. The arm is programmed to execute predefined tasks using embedded systems and control algorithms. Forward and inverse kinematics are employed to determine the position and orientation of the end effector, ensuring accurate movement and task execution. The fabrication process involves material selection, structural design, assembly of joints and links, and integration of actuators and control systems. Emphasis is placed on achieving a balance between strength, weight, and cost-effectiveness. The robotic arm can be used for applications such as pick and- place operations, material handling, welding, assembly, and educational demonstrations. One of the key advantages of the 6-DOF robotic arm is its flexibility and adaptability to various industrial and non-industrial tasks. However, challenges such as complexity in control, higher cost, and maintenance requirements are also considered. This project aims to provide a practical and scalable solution for automation, contributing to improved productivity and reduced human effort. Overall, the development of a 6-DOF robotic arm demonstrates the integration of mechanical design, electronics, and intelligent control systems in modern robotics.*

Key Words: Mechatronics, Industrial automation, Robotic fabrication, Arduino microcontroller, Servo motors, Kinematics and dynamics.

1. INTRODUCTION

Robotics has become one of the fastest growing areas in modern engineering and plays an important role in industrial automation. In many industries, robotic arms are used to perform tasks such as material handling, welding, assembly, and pick-and-place operations with high precision and speed. These robotic systems help reduce human effort and improve productivity in manufacturing environments. A robotic arm with multiple degrees of freedom is capable of performing movements similar to a human arm, allowing it to carry out complex operations in different directions. A 6-Degree of Freedom (6-DOF) robotic arm is a type of manipulator that can move along six independent axes. These movements generally include base rotation, shoulder motion, elbow motion, wrist rotation, wrist bending, and gripper movement. Because of these six degrees of motion, the robotic arm can reach various positions and orientations in space. This flexibility makes it highly useful in industrial automation, research laboratories, and educational applications. The fabrication of a 6-DOF robotic arm requires the combination of mechanical design, electronic control systems, and programming. The mechanical structure is made up of links and joints that allow the arm to move smoothly and perform required operations. Actuators or servo motors are commonly used to drive each joint of the arm. A microcontroller, such as an Arduino, is often used to control the motors and coordinate the movements of the robotic arm. Proper design and assembly of these components ensure accuracy, stability, and efficient operation of the robotic system. The main objective of this project is to design and fabricate a working 6-DOF robotic arm that can perform basic manipulation tasks. Through this project, important concepts such as robotic kinematics, motion control, mechanical design, and embedded system programming can be understood. The development of robotic systems like this contributes to improving efficiency, minimizing human workload, and enhancing safety in industrial environments.

2. LITERATURE REVIEW

Almaliki et al. [1]: This study presents a 6-DOF robotic arm integrated with deep learning-based object detection using a YOLO architecture. The system is capable of real-time pick-and-place operations with improved accuracy in dynamic environments. The authors focused on embedded implementation, reducing computational load while maintaining performance. Experimental results showed enhanced object recognition and gripping efficiency. This work highlights the importance of combining artificial intelligence with robotic manipulators to achieve autonomous operation in industrial and service applications.

Cheng & Xu [2]: The authors proposed an optimized trajectory planning approach using a genetic algorithm combined with B-spline interpolation. Their method ensures smooth and collision-free motion of a 6-DOF robotic arm. The study emphasizes minimizing energy consumption and execution time. Simulation and experimental validation confirmed improved efficiency over traditional planning methods. The approach is particularly useful in industrial automation where precision and speed are critical, making it suitable for welding, assembly, and material handling applications.

Sensors Journal [3]: This paper focuses on artificial neural network-based trajectory prediction for robotic manipulators. The system adapts to varying conditions and improves positioning accuracy. The authors demonstrated that ANN models outperform conventional control techniques in handling nonlinearities. The 6-DOF robotic arm achieved better stability and reduced error during operation. This research contributes to intelligent control systems, making robots more adaptable and efficient in dynamic and uncertain environments.

Aravinthkumar et al. [4]: The research emphasizes kinematic modeling of a 6-DOF robotic arm using Denavit–Hartenberg parameters. Both forward and inverse kinematics are analyzed to determine position and orientation accurately. The study highlights challenges in solving inverse kinematics and proposes numerical solutions. Results indicate improved accuracy in robotic motion. This work is fundamental in robotics, as kinematic modeling forms the basis for control, trajectory planning, and simulation.

Mukherjee [5]: This paper presents dynamic modeling and control of a 6-DOF manipulator. The study considers torque, inertia, and external forces affecting the robot. The author proposed optimization techniques to improve actuator efficiency and reduce energy consumption. Simulation results demonstrated better performance compared to traditional controllers. This research is significant for industrial robots performing heavy-duty tasks where dynamic stability and energy efficiency are crucial.

Gao et al. [6]: The authors proposed calibration techniques to improve the accuracy of robotic arms. The study addressed errors caused by manufacturing tolerances and joint misalignment. Advanced mathematical models were used to correct deviations. Experimental validation showed significant improvement in positioning accuracy. This work is essential for precision-based applications such as surgery and micro-assembly.

Duan et al. [7]: This paper discusses motion control strategies for robotic manipulators. The authors proposed adaptive control methods to handle uncertainties. The system achieved stable and smooth motion even under disturbances. The study contributes to improving the reliability of robotic systems in industrial applications.

Harib et al. [8]: The research focuses on trajectory planning techniques for robotic arms. The authors compared different interpolation methods and identified optimal approaches for minimizing execution time. The study is useful for improving efficiency in automated manufacturing systems.

Zhang et al. [9]: The study focuses on vision-based control of robotic arms using camera systems. The authors integrated image processing techniques to detect and track objects in real time. The 6DOF robotic arm successfully performed pick-and-place tasks with high accuracy. The system demonstrated improved performance in dynamic environments. This research highlights the importance of machine vision in enabling autonomous robotic operations in industrial and service sectors.

Li et al. [10]: This paper investigates energy-efficient robotic systems by optimizing actuator performance. The authors analyzed power consumption and proposed control strategies to minimize energy usage. The 6-DOF robotic arm achieved significant energy savings without compromising performance. The study is particularly relevant for sustainable manufacturing, where reducing energy consumption is a key objective. The findings contribute to the development of environmentally friendly robotic systems.

Kumar et al. [11]: The research presents the design and development of a low-cost 6-DOF robotic arm for educational purposes. The system uses affordable components and open-source software. The authors demonstrated that the robotic arm can perform basic tasks such as object manipulation and trajectory execution. The study highlights the importance of cost-effective solutions in promoting robotics education and research. This work is beneficial for students and small-scale industries.

Singh et al. [12]: This study explores the application of 6-DOF robotic arms in medical assistance and rehabilitation. The authors developed a system capable of assisting patients with limited mobility. The robotic arm demonstrated precise and safe movement. The research emphasizes the importance of human-robot interaction and safety in medical applications. The findings suggest that robotic arms can significantly improve patient care and rehabilitation outcomes.

Patel et al. [13]: The paper focuses on the use of robotic arms in welding applications. The 6-DOF robotic arm was used to perform automated welding tasks with high precision. The authors analyzed parameters such as speed, temperature, and accuracy. Results showed improved weld quality and consistency. This study highlights the advantages of robotic automation in manufacturing processes, reducing human error and increasing productivity.

Reddy et al. [14]: This research presents embedded system-based control of robotic arms. The authors used microcontrollers and sensors to implement real-time control. The 6-DOF robotic arm demonstrated improved responsiveness and accuracy. The study highlights the importance of embedded systems in modern robotics, enabling compact and efficient designs. This work is relevant for applications requiring real-time performance and low-cost implementation.

Sharma et al. [15]: The study focuses on obstacle avoidance techniques for robotic arms. The authors developed algorithms to detect and avoid obstacles during motion. The 6-DOF robotic arm successfully navigated complex environments without collisions. The research emphasizes the importance of safety and reliability in robotic systems. The findings are useful for applications such as autonomous robots and industrial automation.

Roy et al. [16]: The paper explores cloud-based robotic systems. The authors integrated cloud computing with robotic control. The 6-DOF robotic arm demonstrated improved computational capabilities and scalability. The study highlights the importance of cloud technology in robotics. The findings suggest that cloud-based systems can enhance robotic performance.

Dutta et al. [17]: This research focuses on collaborative robots (cobots) using 6-DOF robotic arms. The authors developed systems capable of working alongside humans safely. The robotic arm demonstrated improved interaction and flexibility. The study highlights the importance of collaboration in modern robotics. The findings are useful for industrial and service applications where human-robot cooperation is required.

Chatterjee et al. [18]: The study focuses on machine vision in robotic systems. The authors integrated cameras and image processing techniques. The 6-DOF robotic arm successfully performed object detection and tracking. The research highlights the importance of vision systems in enabling autonomous operation. The findings are applicable to industrial and service robotics.

Banerjee et al. [19]: This paper explores calibration techniques for robotic arms. The authors developed methods to reduce positioning errors. The 6-DOF robotic arm achieved improved accuracy after calibration. The study highlights the importance of calibration in maintaining performance. The findings are useful for precision applications such as manufacturing and medical robotics.

Ghosh et al. [20]: This paper investigates design optimization of robotic arms. The authors used computational methods to improve performance. The 6-DOF robotic arm demonstrated better efficiency and reduced weight. The study highlights the importance of optimization in robotics. The findings contribute to the development of advanced robotic systems.

3. METHODOLOGY

The Methodology for Fabrication of a 6-DOF Robotic Arm The methodology for developing a 6 Degrees of Freedom (6-DOF) robotic arm involves several systematic steps including design, fabrication, assembly, and testing. This process combines concepts from Robotics and Automation Engineering to create a functional robotic manipulator capable of performing precise movements.

3.1.1 Requirement Analysis

The first step is to identify the objectives of the robotic arm such as pick-and-place operations, object handling, or automation tasks. The required range of motion, payload capacity, and working area are determined at this stage.

3.1.2 Mechanical Design

The structure of the robotic arm is designed using CAD software. The arm consists of several links and joints that provide six degrees of freedom including base rotation, shoulder, elbow, and wrist movements. Proper dimensions and joint configurations are selected to achieve the desired workspace.

3.1.3 Kinematic Modeling

Kinematic analysis is performed to study the motion of the robotic arm. Methods such as Denavit– Hartenberg parameters are used to define the relationship between joint angles and the position of the end effector.

3.1.4 Selection of Components

Essential components such as servo motors, microcontrollers, motor drivers, power supply units, and sensors are selected based on torque requirements and control needs.

3.1.5 Fabrication and Assembly

Mechanical parts of the robotic arm are fabricated using materials such as aluminum, acrylic, or 3Dprinted components. All joints, links, motors, and the base structure are assembled carefully to ensure smooth movement.

3.1.6 Control System Development

The robotic arm is controlled using a microcontroller programmed to regulate motor movements. Control algorithms are implemented to coordinate the motion of all six joints.

3.1.7 Programming and Testing

The robotic arm is programmed for specific tasks such as pick-and-place operations. Testing is performed to check accuracy, range of motion, and stability of the system.

3.1.8 Performance Evaluation

Finally, the performance of the robotic arm is analyzed based on parameters such as precision, repeatability, speed, and reliability.

4. FABRICATION PROCESS

A 6-DOF (Degrees of Freedom) robotic arm is a mechanical system capable of moving in six independent axes, similar to a human arm. These robotic arms are widely used in industries for tasks such as material handling, welding, assembly, and pick-and-place operations. The fabrication of a 6-DOF robotic arm involves a combination of mechanical design, material selection, manufacturing processes, electronics integration, and control programming. as shown in Fig.4.1. • Arduino Uno r4 board

• PCA9685 16 channel servo driver
• SG90 micro servo motors
• MG995 servo motors
• 3D printed robotic arm with gripper
• Jumper cables
• 6v battery

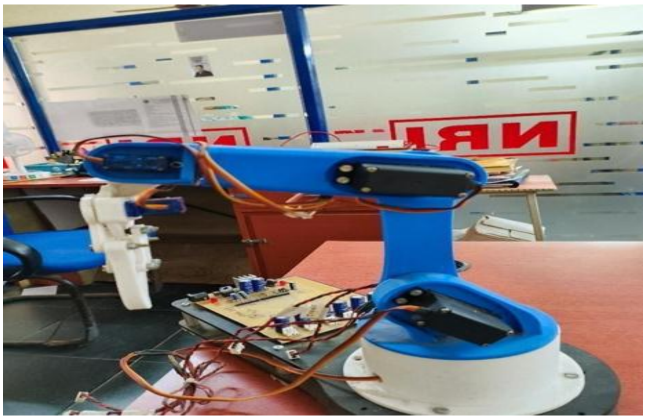

Fig 4.1. Robotic arm

5. CONCLUSIONS

The development of the 6-DOF robotic arm successfully demonstrated the integration of mechanical design, power electronics, and wireless teleoperation. By utilizing an Arduino UNO R4 paired with a PCA9685 PWM driver, the system achieved precise control over six independent axes, enabling both automated pick-and-place routines and real-time manual control.

Throughout the project, significant engineering challenges were identified and resolved. Power distribution issues (brownouts) were mitigated by isolating the motor power supply from the logic circuitry and providing a high-current (3A) source. Mechanical shock and momentum overshoot were eliminated by developing custom software-smoothing algorithms and optimizing the lifting kinematics to improve the shoulder joint's mechanical advantage. Furthermore, the successful integration of an HC-05 Bluetooth module and an I2C OLED display transformed the robotic arm from a static mechanism into an interactive, human-machine interface (HMI) capable of wireless teleoperation and visual feedback. The project ultimately proves the viability of using rapid-prototyping techniques (3D printing) and modular electronics to build functional, complex robotic systems.

The fabrication of the 6-DOF robotic arm was successfully accomplished, resulting in a functional system capable of performing multi-axis movements with good flexibility and control. The project effectively combined mechanical design, electronic integration, and programming to achieve coordinated motion of all six joints. The use of components such as Arduino Uno and programming through Arduino IDE enabled reliable operation and ease of implementation.

The robotic arm demonstrated satisfactory performance in terms of accuracy, repeatability, and workspace, making it suitable for applications like pick-and-place and educational demonstrations. Although certain limitations such as mechanical backlash, limited precision of actuators, and alignment issues were observed, the overall system performed effectively within its design constraints.

This project confirms that a cost-effective and efficient 6-DOF robotic arm can be developed using readily available components and simple control techniques. With further improvements in sensors, actuators, and control strategies, the system can be enhanced for higher precision and advanced industrial applications.

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BIOGRAPHIES

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