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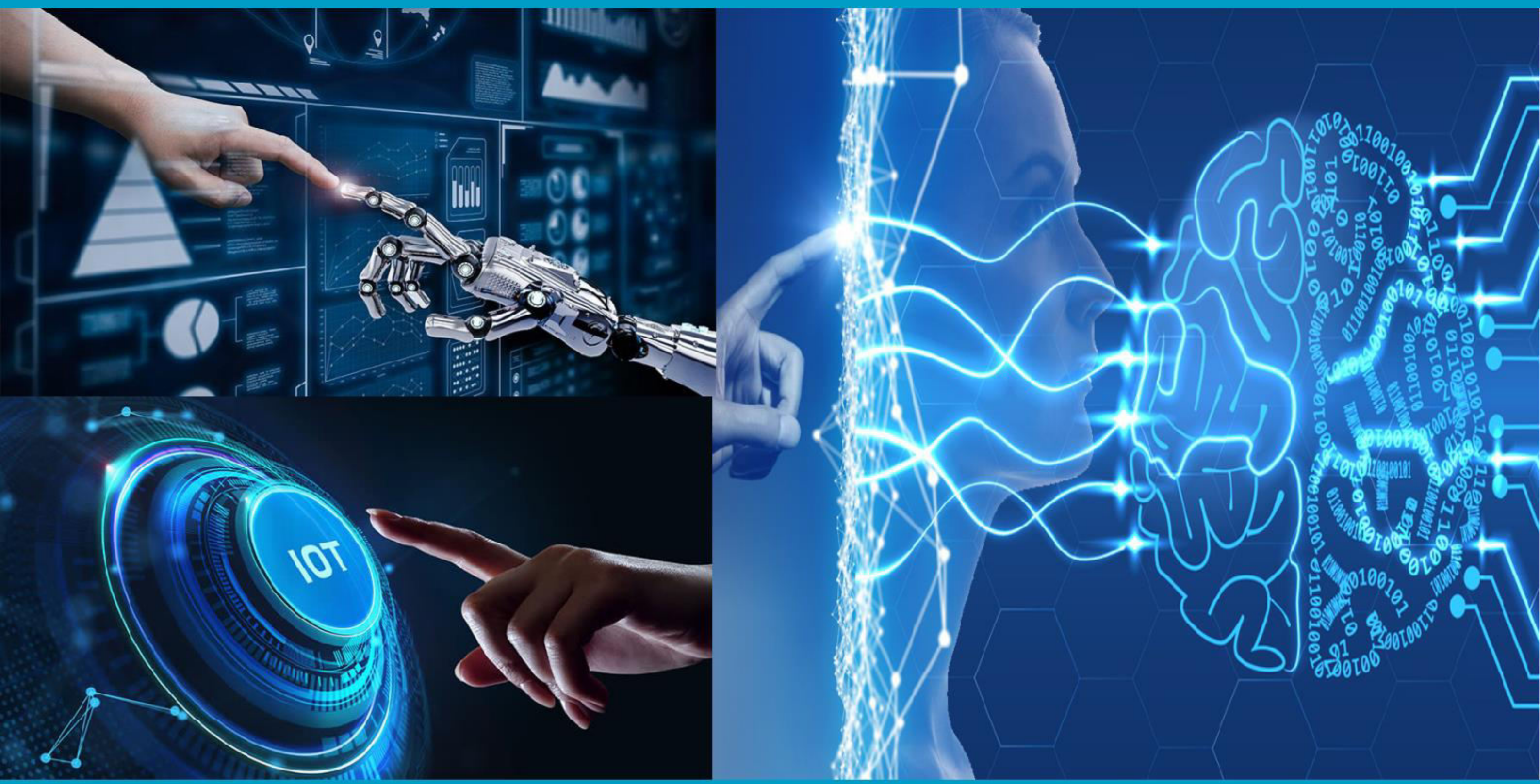

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A Procedural Framework to Design and Fabrication of 6 Axis Robotics Arm

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ABSTRACT: In response to the escalating demands of modern society, technological advancements have led to the proliferation of robotic arm studies aimed at addressing diverse human needs. Robotic arms, capable of executing precise movements with six degrees of freedom, are pivotal in enhancing efficiency and accuracy across various sectors, notably industry and medicine. This research presents a procedural framework for the design and fabrication of a 6-axis robotic arm. The developed arm exhibits versatility in maneuverability, enabling tasks such as material handling, transportation, and mixing. Through integration with an Android application via a Bluetooth module connected to an Arduino Mega 2633 microcontroller, the robotic arm achieves seamless control, significantly reducing human effort in hazardous operations like nuclear waste disposal and bomb disposal. This framework offers a systematic approach to the creation of advanced robotic solutions tailored to meet evolving societal needs.

KEYWORDS: Robotic arm, Six degrees of freedom, Design, Fabrication, Material handling, Automation, Arduino, Bluetooth control, Industrial applications

I. INTRODUCTION

The advent of automation systems has revolutionized modern industries, offering unparalleled precision, efficiency, and flexibility in manufacturing processes. With the ever-increasing demand for high-quality products at competitive prices, there's a pressing need for standardized automation solutions that minimize errors and reduce reliance on highly specialized human labor. Robotic systems have emerged as indispensable components in this quest for enhanced productivity and cost-effectiveness. Integrating principles from Mechatronics, Mechanical, Electrical, and Computer Engineering, robotic arms have become quintessential tools in diverse industrial applications, offering multifunctional manipulators programmable across multiple axes. These arms, whether autonomously operated or remotely controlled, exhibit remarkable accuracy and speed, performing tasks with precision akin to human dexterity. In this context, the development and implementation of a 6-axis robotic arm represent a pivotal endeavor, poised to emulate and enhance human-like functionalities in industrial automation scenarios.

The design and fabrication of a 6-axis robotic arm entail meticulous consideration of both mechanical and software aspects to ensure optimal performance and versatility. By leveraging servo motors, chosen for their superior precision and torque capabilities compared to alternative motor types, the robotic arm can achieve finer movements across its six axes. The integration of an Arduino Mega 2560 microcontroller, programmed in Java, facilitates seamless control and operation of the arm in two distinct modes: Remote Mode, enabling operation via Wi-Fi or the internet, and Auto Mode, allowing pre-programmed execution of tasks without human intervention. Mechanical design, realized through software tools like SolidWorks, ensures precise dimensioning and structural integrity of the robotic arm, while a dedicated power supply ensures consistent performance. Thus, this project represents a fusion of advanced engineering disciplines, culminating in the realization of a sophisticated robotic arm capable of emulating human-like motions for enhanced industrial automation.

II. LITERATURE REVIEW

Jamshed Iqbal et al. (2012) developed a kinematic model for a six-degree-of-freedom (6 DOF) robotic arm, enabling precise control in unstructured environments. Their model, based on the Denavit Hartenberg (DH) parametric system, provides both forward and inverse kinematic solutions. Validation through MATLAB with Robotics Toolbox confirms its accuracy, with experimental results showcasing the arm's ability to point accurately at target coordinates within 0.5cm precision. The methodology offers insights applicable to addressing kinematics challenges in similar robot manipulators.

Rahul Gautam et al. (2017) reviewed the development of an industrial robotic arm emphasizing precise movement control for tasks such as object placement in distant locations. Their design focuses on reducing friction to minimize maintenance costs associated with cable replacement, enhancing longevity and performance. This underscores the importance of efficient design in optimizing industrial robotic arms.

Mahanta G.B et al. (2019) explored soft computing approaches for determining the inverse kinematics of a Kawasaki RS06L 6-DOF robotic manipulator. They compared techniques like artificial bee colony (ABC), firefly algorithm (FA), and particle swarm optimization (PSO), demonstrating efficient reversibility through simulations and real-world experiments. This study underscores the potential of soft computing techniques in enhancing robotic manipulator performance.

N.G. Adar et al. (2016) presented a study on a two-degree-of-freedom (2-DOF) PID controller method for a six-degree-of-freedom rigid robotic manipulator. Their proposed 2-DOF PID controller outperformed traditional PID controllers in real-time manipulator control applications, as validated through Matlab-Simulink experiments.

Ankur Bhargava et al. (2017) surveyed an Arduino-controlled robotic arm with five degrees of freedom (DOF), highlighting its design and fabrication process using potentiometers and servomotors for precise movement control. Their work emphasizes the characterization of the arm's movements through relative link motion.

Ashraf Elfasahany et al. (2011) designed a low-cost robot arm with four degrees of freedom (DOF) using acrylic material and servo motors. Despite limited rotation range, the arm proves feasible for basic industrial applications, showcasing the balance between competitiveness and affordability.

Won-Bum Lee et al. (2017) proposed a novel six-degree-of-freedom collaborative robot with a multi-degree-of-freedom CBM, emphasizing compactness and integration for improved aesthetics and functionality. Their dynamic simulation verifies performance enhancements, contributing to crash safety and energy efficiency in collaborative robots.

Dino Dominic Ligutan et al. (2018) implemented a fuzzy logic-based joint controller (FLJC) on a six-degree-of-freedom robotic arm with machine vision feedback. Their closed-loop system achieves precise object manipulation tasks, demonstrating the potential of fuzzy logic in enhancing robotic control.

Pragathi Praveena et al. (2019) developed an offline method for generating smooth motion trajectories for robot arms, ensuring achievement of user-defined posture goals while avoiding collisions and singularities. Their approach proves effective in producing satisfactory solutions for robotic motion planning.

Hwi-Su Kim et al. (2014) introduced a counterbalance system based on a double parallelogram mechanism to offset gravitational torques induced by robot mass. Their mechanism significantly reduces torque requirements, enabling the use of low-cost motors and slower speeds in 6-DOF robotic applications.

III. FABRICATION OF 6 DOF ROBOTIC ARM

There are serval components that are used in this project. The components of the project are explained in the following sections.

1. Servo Motors

Servo motors detect and correct operation errors in mechanisms, offering precise control in control systems. They come in AC or DC types and are divided into brushless and brushed motors. Typically, they have three cables: power, ground, and control. In the project, MG996R and TD-8120MG metal gear servo motors are used, with maximum stall torques of 11 kg/cm and 20 kg/cm respectively. They operate at +5V and rotate between 0° to 270° or 0° to 360° based on PWM signals. Control is achieved through pulse width modulated (PWM) signals at 10-20 ms, with shaft positions determined by signal duration.

Fig. 1 Servo Motor

2. Arduino Mega 2560 REV3

Arduino, based on Wiring and Processing, has surged in popularity for its user-friendly environment and versatility, even powering projects like UAVs. Its spread is attributed to its platform compatibility, extensive library support, speed, hardware compatibility, open-source nature, and robust community. The Arduino Mega 2560, featuring an ATmega2560 microcontroller, boasts 54 digital I/O pins, 16 analog inputs, 4 UARTs, and various other features. It operates at 5V and can be powered via USB or external sources. With extensive pin mappings and memory capacities, it's programmable via Arduino IDE, ensuring ease of use and protection with built-in features like resettable polyfuse.

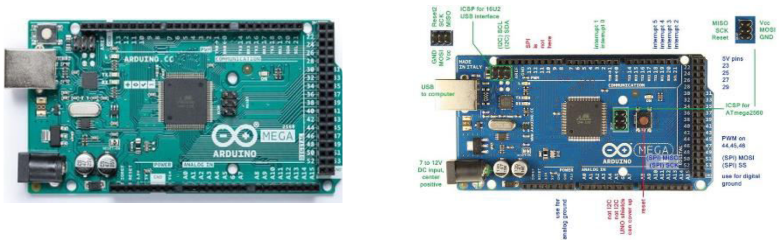

Fig. 2 Arduino Mega 2560 REV3

3. Servo Shield (PCA 9685)

The PCA9685 is a 16-channel LED controller with individual PWM controllers for each channel, offering 12-bit resolution (4096 steps) for precise brightness control. It operates via I2C bus, with adjustable frequency (24 Hz to 1526 Hz) and duty cycle (0% to 100%). Each channel can be configured for open-drain or totem pole output with a 25 mA sink (10 mA source) capability at 5V. Operating voltage range is 2.3V to 5.5V, with 5.5V tolerant inputs/outputs. It's suited for RGB backlighting and supports direct LED connection or external drivers for larger currents/voltages. The PCA9685 belongs to the Fast-mode Plus (Fm+) family, offering higher frequency and denser bus operation.

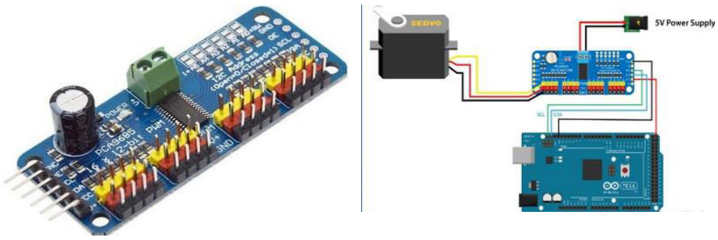

Fig. 3 Servo Shield (PCA 9685)

4. Power Supply

The power supply for the servo motors and Arduino requires 5V. During simultaneous operation of all servomotors, they collectively draw 0.5A. A suitable replacement for the Kung Long WP4.5-6 battery is a maintenance-free sealed lead acid rechargeable battery, offering 6V and 4000mAh capacity. This battery, with dimensions of 2.76 x 1.89 x 4.02 inches and a weight of 2 lbs, meets or exceeds the specifications of the original battery.

Fig. 4 Power Supply

5. Potentiometer

Potentiometers are three-terminal resistors used as adjustable voltage dividers or variable resistors. In this project, 5 potentiometers control each motor, interfacing with the Arduino Mega 2560 REV3. The WX 110(010) 1W Single Turn Wire Wound Potentiometer with 10K ohm resistance and 5% tolerance is utilized. Each potentiometer connects to ground and 5 volts from the Arduino, with the wipers linked to specific analog inputs on the Arduino Mega 2560 REV3: Shoulder (A0), Base (A1), Elbow (A2), Wrist (A3), Pivot (A6), and Jaws (A7). This setup allows for precise motor control via the I2C bus to the PCA9685.

Fig. 5 Potentiometer

6. Person Bearing Kit

The persons bearing kit comprises cup micro ball bearings and M3×10 screws with lock-washers and cap nuts. The metal cup micro ball bearing, sized 3×8×4 mm, reduces friction between moving parts like U-brackets in robotic arms. The M3×10 screws are used for fastening, accompanied by lock-washers for secure attachment. Cap nuts, or acorn nuts, provide a finished appearance and protect external threads when used with threaded fasteners.

Fig. Cap Micro ball Bearing and Cap Nut

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7. Jump wire

Jumper wires are connector wires with pins at each end, used to link points in circuits without soldering. They're essential for prototyping with breadboards, enabling easy circuit modifications. Despite various colors, they function identically; however, colors can differentiate connections like ground or power. Jumper wires come in male-to-male, male-to-female, and female-to-female types, differing in endpoint design. Male-to-male wires, with protruding pins, are most common and versatile for breadboard connections.

Fig. Jump wire

8. Black Wire Spiral Wrap Cable Protector

The Black Wire Spiral Wrap Cable Protector is a flexible solution for organizing and protecting wires. It consolidates multiple wires into one bundle, allowing for easy breakout and re-routing. Its colorful design offers a fun way to personalize cable management, while also serving as a deterrent against chewing pets. Additionally, it provides abrasion resistance and facilitates easy separation of cables from the bundle at any point.

Fig. Black Wire Spiral Wrap Cable Protector

9. Nylon cable ties

Nylon cable ties, also known as zip ties, are fasteners used to hold items together, particularly electrical cables or wires. Made of flexible nylon, they feature a ratchet mechanism that tightens when the free end is pulled, securing the tie in place. With a maximum carrying weight of 8 kg and dimensions of 2.5 x 100 mm, these cable ties are durable and UV-resistant, making them suitable for various applications.

Fig. Nylon cable ties

10. Arduino Charger

This 9V 1A AC/DC power supply adapter (LY-008-9) is specifically designed for Arduino MEGA 2560. It features a UK plug type and output interface compatible with 5.5mm x 2.1mm connectors.

Fig. Arduino Charger

11. Pin Toggle ON/OFF Switch

This switch features a toggle function for ON-OFF operation with a contact rating of 4A @ 125VAC / 2A @ 250VAC. It has dimensions of 1.0″ L x 0.56″ W x 0.52″ D and solder tab terminals measuring 0.18″ W. The switch has two pins and a round lever, with a mounting hole diameter of 0.5″ .

Fig. Pin Toggle ON/OFF Switch

IV. CONSTRUCTION AND WORKING

4.1 Mechanical Design:

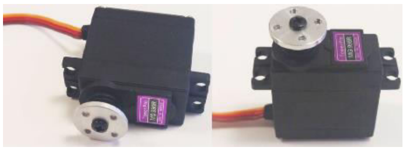
Materials for the mechanical part of the robot arm were supplied and drawn in millimetric form on SolidWorks. The assembly was completed using these materials. CAD models of the mechanical parts are provided.

Fig. 3D CAD Model

4.1.1 Mechanical Part Mounting / Robot Arm Assembly

1. Horn/Servo Motor Holder/Disc Mounting

Install five Aluminum Metal 25T Round Servo Motor Holders/Discs on the servo shafts and tighten the screws.



2. Assemble Claw:

Set both servos to 0-degree position. Position the claw 90 degrees to one of the motors. Insert the servo shaft into the back of the claw assembly, meshing with the gear. Secure the claw back to the motor shaft with horn mounting screws. Manually manipulate claw jaws to the full open position. Insert and tighten the horn mounting screw to secure the claw jaw mechanism to the motor shaft. Test both servo motors for proper operation of the claw.

3. Assemble Shoulder Motor Mount with U Beam Bracket:

Align the U-Beam brackets and fasten them together with screws and nuts. Place the servo mounting bracket on top of the U-Beam brackets and fasten them together. Install the MG996R servo motor on the servo bracket and secure it with screws and nuts.

4. Assemble & Install Base Motor Mount on Shoulder Motor:
Attach the servo mounting bracket to the servo holder/disc and secure it with screws. Insert an M3×10 screw from the Persons Bearing Kit into the servo bracket. Mount the TD-8120MG Servo Motor on the bracket and secure it with screws and nuts.

5. Assemble Double U-Bracket:
Align two U-Brackets and fasten them together with screws and nuts.

6. Assemble & Install Elbow Motor Mount with Brackets:
Place the servo mounting bracket and attach the L-Bracket to the U-Bracket. Fasten the L-Bracket to the servo mounting bracket. Install the MG996R servo motor and secure it with screws and nuts.

7. **Assemble & Install Wrist Motor Mount with Claw Mount:**
Place two servo mounting brackets together and fasten them with screws and nuts. Install the MG996R servo motor and secure it with screws and nuts.

8. Join Base to Double U-Bracket:
Attach one end of the U-Bracket assembly to the base motor mounting bracket and the other end to the servo motor horn. Fasten it with screws.

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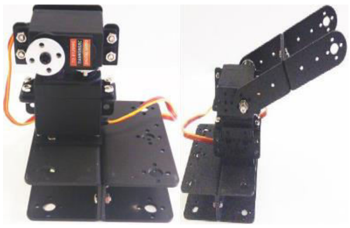
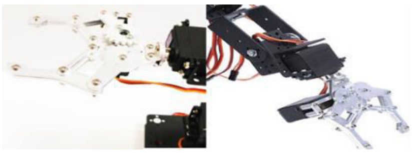


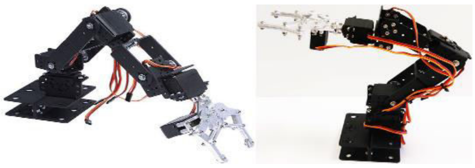
9. Join Double U-Bracket to Elbow Mount with Brackets:
Attach the U-Bracket assembly to the elbow motor mounting bracket and the servo motor horn. Fasten it with screws.

10 Join Elbow Mount with Brackets to Wrist Motor Mount:
Attach the U-Bracket or the Elbow Mount with Bracket assembly to the wrist motor mounting bracket and servo motor horn. Fasten it with screws.

11 Install Claw:
Mount the Claw Pivot servo motor onto the Wrist Motor Mount and secure it with screws.



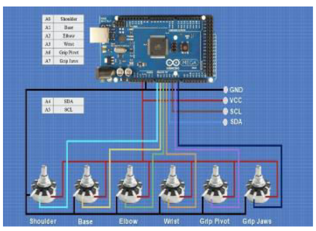
12. Wire & Test:
Complete the mechanical assembly of the arm. Reset and exercise all servo motors to ensure proper functionality and alignment. Wire the Arduino Mega 2560 REV3 with potentiometers and connect to the PCA9685 module. Connect the servo motors to the module and ensure a suitable power supply. Test the arm's functionality.

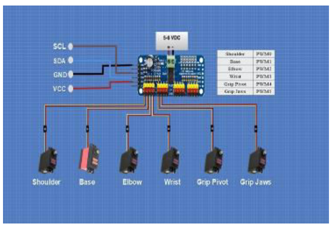


13. Arduino Controller:
Mount a PCA9685 16-channel PWM controller onto the robot arm for motor control. Design a controller using an Arduino Mega 2560 REV3.

14. Arduino Mega 2560 REV3:
Utilize an Arduino Mega 2560 REV3 for the controller, providing ample analog inputs for potentiometers. Connect the potentiometers to the analog inputs and ensure proper board type selection in the Arduino IDE.

15. Wiring up the Controller:
Wire the controller, potentiometers, and PCA9685 module as per the provided diagrams. Connect the potentiometers to analog inputs on the Arduino Mega 2560 REV3 and ensure appropriate power supply connections. Connect the servo motors to the PCA9685 module and supply adequate power.





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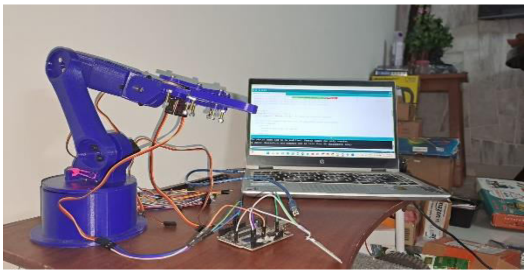
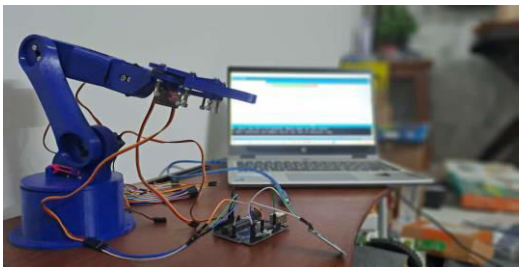
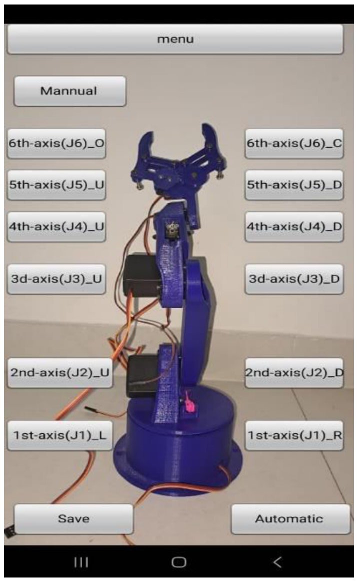
4.2 Working

- The servo robot arm consists of six servo motors that drive its movement, mimicking the joints of a human arm.
- The arm's structure is simple yet effective, utilizing servo motors for precise control without the complexity of additional joints or nervous system components.
- It is capable of performing various movements such as left-right, up-down, forward-backward, roll, pitch, and yaw, allowing for versatile operation.
- The arm's mechanical structure is constructed using a combination of aluminum alloy processing components, ensuring durability and stability.
- Additionally, a wooden robotic arm with potentiometers fixed in each joint serves as a remote control for the aluminum robotic arm.
- As the wooden arm moves, the potentiometers in each joint detect the movement, sending signals to an Arduino card.
- The Arduino card interprets these signals and controls the servo motors accordingly, enabling the aluminum robotic arm to replicate the movements of the wooden arm in real-time.

V. TESTING RESULT



5.1 Testing

The robotic arm project underwent rigorous testing to evaluate its performance and functionality. The results of the testing were overwhelmingly positive, demonstrating that the arm successfully met its design objectives and exhibited excellent capabilities across various parameters.

Testing Procedures:

Step 1. Power-Up and Initialization:

- Upon powering up the robotic arm, all components initialized smoothly without any errors or malfunctions.
- The arm went through its startup sequence correctly, indicating proper functioning of the electronic and mechanical systems.

Step 2. Movement and Flexibility Testing:

- The arm was tested for its ability to move in all six degrees of freedom (DOF) with the expected range of motion.
- Each axis of movement, including left-right, up-down, forward-backward, roll, pitch, and yaw, was tested individually and collectively.

- The arm exhibited smooth and precise movement without any jerking or stuttering, indicating excellent mechanical design and servo motor control.

Step 3. Load Handling and Gripping:
- The arm was tested under various load conditions to assess its ability to handle different weights.
- It successfully lifted and manipulated objects of varying sizes and weights, demonstrating its strength and gripping capabilities.
- The gripper mechanism operated flawlessly, securely holding objects without dropping them or causing damage.

Step 4. Precision and Accuracy Testing:
- Precision tests were conducted to evaluate the arm's accuracy in reaching specific target points.
- The arm demonstrated high precision, consistently reaching targeted positions with minimal deviation.
- Tasks requiring precise manipulation, such as picking and placing objects in designated locations, were performed with accuracy and reliability.

Step 5. Endurance and Durability Testing:
- The robotic arm underwent prolonged operation to assess its endurance and durability.
- It operated continuously for extended periods without overheating or experiencing mechanical failures, indicating robust construction and reliability.

Step 6. Integration and Compatibility Testing:
- Integration tests were conducted to ensure compatibility and seamless interaction with other system components.
- The arm successfully communicated with external devices and controllers, exchanging data accurately and responding to commands effectively.

VI. CONCLUSION AND FUTRE SCOPE

The culmination of our robotic arm project marks a significant achievement in engineering and technology. Through meticulous planning, design, and implementation, we have developed a cutting-edge system that embodies the pinnacle of robotic manipulation. Extensive testing has demonstrated the robustness and efficiency of our design, showcasing its ability to perform tasks with precision and consistency. Moreover, the positive outcomes obtained from our testing reaffirm the viability and effectiveness of our approach. Beyond its technical prowess, our project underscores the collaborative effort and dedication of our team, reflecting our collective commitment to pushing the boundaries of innovation. As we reflect on the journey thus far, we are energized by the possibilities that lie ahead, confident in the transformative impact our robotic arm can have across various industries. With a firm foundation established, we are poised to continue advancing the field of robotics, driving progress and shaping the future of automation.

In the future, we aim to refine our robotic arm's design for greater functionality, potentially integrating advanced sensors and AI algorithms for autonomous operation. Scaling up for industrial use and exploring collaborations in healthcare are also on the agenda, promising significant advancements in automation and technology.

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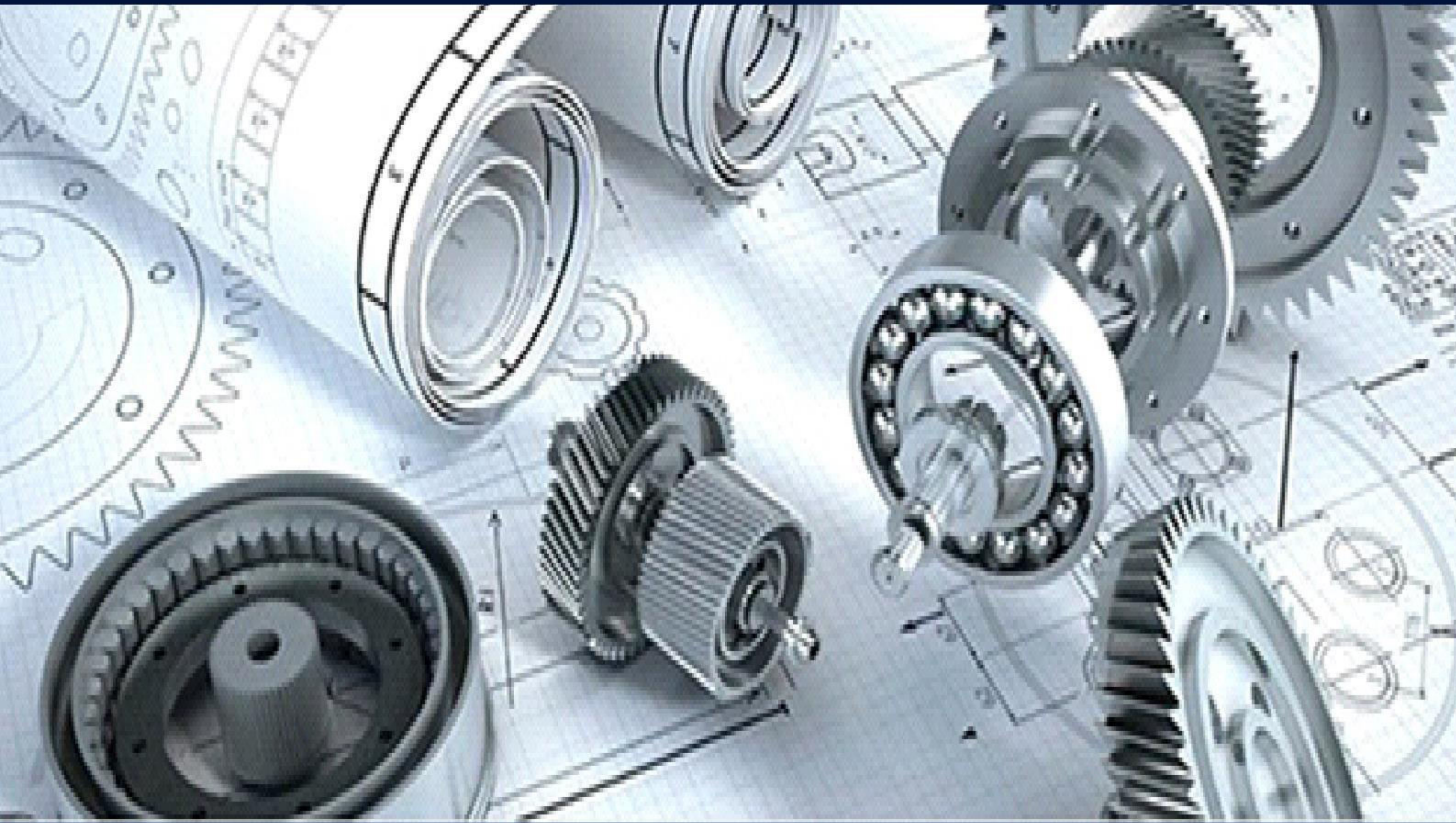

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