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## SIMPLE ROBOTIC ARM PROTOTYPE

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# Abstract

This report presents the design, construction, and evaluation of a low-cost robotic arm prototype developed as a self-directed engineering project. The objective was to explore fundamental principles of robotic arm design, servo-based actuation, and Arduino-controlled motion using inexpensive materials and minimal tooling. The prototype incorporates two degrees of freedom for positioning and a servo-driven gripper to perform basic pick-and-place tasks involving lightweight objects. Through iterative mechanical and electrical design, the project demonstrates how simple prototypes can be used to validate system-level concepts, identify design limitations, and inform future, more advanced implementations.

## 1. Introduction

Robotic arms are widely used in industrial, research, and educational contexts to perform repetitive or precise manipulation tasks. Early-stage prototyping using simplified materials and control schemes can provide valuable insight into kinematic layout, actuator selection, and control logic before committing to complex or costly designs.

The purpose of this project was to design and build a simple robotic arm capable of performing a basic pick-and-place operation. Emphasis was placed on affordability, ease of construction, and experiential learning rather than precision, payload capacity, or durability. The project was completed as a personal, self-directed effort and served as a proof-of-concept platform for understanding mechanical design trade-offs and Arduino-based servo control.

## 2. Design Requirements and Assumptions

### 2.1 Functional Requirements

The robotic arm was required to:

- Pick up and release a lightweight object
- Translate the object through horizontal and vertical motion
- Be controlled manually by a user through simple input devices

A minimum of two degrees of freedom were required to reposition the end effector in space, excluding gripper actuation.

## 2.2 Assumptions

- Payload mass would be negligible (crumpled paper), eliminating the need for torque and stress calculations
- Open-loop servo position control would be sufficient for demonstrating functionality
- Accuracy and repeatability would be evaluated qualitatively rather than quantitatively

## 2.3 Constraints

- Use of low-cost, readily available materials
- No access to 3D printing or precision machining
- Limited breadboard space and Arduino I/O
- Power supplied directly from the Arduino 5 V rail

Given these constraints, structural optimization and safety factor analysis were intentionally omitted.

# 3. Mechanical Design

## 3.1 Overall Architecture

The robotic arm consists of a fixed base, a vertical arm segment, and a simple pincer-style gripper. The total arm length from base to gripper tip is approximately 20 cm, with individual link lengths on the order of 10 cm. All joints are revolute and actuated directly by hobby servo motors.

The base was constructed from wooden sticks and cardboard and was not mounted to an external surface. During testing, the base exhibited instability under the weight of the arm, requiring manual stabilization by the operator.

## 3.2 Degrees of Freedom

The system includes:

- One rotational joint at the base for horizontal motion
- One rotational joint for vertical arm motion
- One servo-driven gripper for object manipulation

The gripper motion was excluded from the degree-of-freedom count, as it does not alter the position of the arm's reference point.

### 3.3 Gripper Design

The gripper design evolved through two iterations. The initial concept employed two independently actuated claws, each driven by a separate servo motor. This approach increased mechanical complexity and wiring requirements without providing proportional benefit.

The refined design uses a single servo motor to actuate one movable claw against a stationary claw. Rubber bands were added to the claw surfaces to increase friction and improve grip reliability when handling smooth or lightweight objects.

## 4. Electrical and Control System Design

### 4.1 Actuation

Motion is generated using Miuzei SG90 9 g servo motors. All servos were powered directly from the Arduino UNO R3. No power brownout or overheating issues were observed during operation, although the configuration is recognized as unsuitable for higher loads or prolonged use.

### 4.2 Control Strategy

The system operates under open-loop control with no positional feedback sensors. Servo positions are commanded through discrete angle values set in software.

User input is provided through pushbuttons for joint rotation and a slide switch for gripper actuation. Joint motion continues as long as the corresponding button is pressed, allowing continuous sweeping motion within predefined angular limits.

### 4.3 Simulation and Programming

Prior to physical assembly, the circuit and control logic were developed and tested using TinkerCAD simulation. This step allowed verification of servo behavior, input logic, and pin allocation before committing to hardware assembly.

Servo angle limits for the gripper were adjusted during testing to prevent mechanical binding and potential damage, with final limits set to approximately 50° for the open position and 120° for the closed position.

## 5. Iterative Development and Design Decisions

Several design decisions were made in response to observed limitations:

- Dual-motor gripper actuation was replaced with a single-motor design to reduce complexity and conserve breadboard space
- A slide switch was selected for gripper control to reduce input pin usage
- A linkage between the base and vertical motors was removed after causing instability due to unfavorable weight distribution

Servo motors were selected over DC motors with encoders due to their low cost, ease of control, and suitability for educational prototyping.

## 6. Testing and Evaluation

### 6.1 Test Procedure

Testing focused on verifying the arm's ability to perform a basic pick-and-place operation using crumpled paper as the test object. Motion repeatability and functional reliability were assessed visually.

### 6.2 Observed Performance

- Horizontal and vertical motions were repeatable within visual tolerance
- Gripper successfully grasped and released lightweight objects
- Motion smoothness was limited by structural flex and servo mounting rigidity

### 6.3 Failure Modes and Limitations

The primary limitations observed were:

- Insufficient gripper friction and strength prior to modification
- Structural fragility due to craft glue joints and lack of mounting brackets
- Base instability resulting from torque generated by the arm mass

These issues did not prevent task completion but reduced robustness and ease of operation.

## 7. Lessons Learned and Future Improvements

Key engineering insights gained include:

- Early-stage prototypes benefit significantly from mechanical rigidity, even when loads are small
- Simplifying actuation and control often improves reliability more than adding functionality
- Simulation tools are effective for validating control logic prior to physical implementation

Future iterations could incorporate:

- 3D-printed structural components and servo mounting brackets
- Hot glue or mechanical fasteners for improved joint strength
- Potentiometers or a joystick for proportional control and reduced I/O usage
- Additional degrees of freedom, such as a wrist joint, for improved dexterity

## 8. Conclusion

The robotic arm prototype successfully achieved its objective as a low-cost, proof-of-concept platform for exploring robotic arm design and Arduino-based control. Despite structural and performance limitations, the system demonstrated reliable basic manipulation of lightweight objects and provided clear insight into mechanical and control-related trade-offs. The project establishes a practical foundation for future robotic arm designs using improved materials, refined actuation strategies, and more advanced control methods.