Design and Implementation of a Haptic Hand (Cobot) for Lifting Objects

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Abstract—The design and implementation of a haptic hand for lifting objects aim to enhance robotic manipulation by integrating force feedback and tactile sensing. This system mimics the human hand's dexterity, using advanced actuators, pressure sensors, and a real-time control mechanism to improve grasping accuracy and object handling. The haptic feedback allows precise control, enabling the robotic hand to adjust grip strength dynamically based on the object's weight and texture. The proposed design is particularly useful in assistive robotics, industrial automation, and prosthetics. Experimental validation demonstrates the effectiveness of the haptic hand in lifting objects of varying sizes and materials, ensuring stability and safety.

This project presents the design and implementation of a haptic hand controlled by an ESP32 microcontroller, capable of lifting objects weighing up to 150 grams. The system integrates force sensors, servo actuators, and a haptic feedback mechanism to replicate human-like grasping and lifting capabilities. The hand model is designed using lightweight materials and optimized finger actuation to ensure efficient force distribution while handling objects. The ESP32 is programmed to process sensor data and dynamically adjust grip strength based on the object's weight and texture. Real-time feedback enhances the precision and stability of object manipulation. The proposed system is useful for assistive applications, robotic prosthetics, and industrial automation where lightweight object handling is required. Experimental validation confirms the system's effectiveness in secure object gripping and controlled lifting operations.

Keywords: Haptic hand, robotic manipulation, force feedback, tactile sensing, prosthetics, object lifting, real-time control, assistive robotics, automation, sensor-based grip adjustment.

I. INTRODUCTION

Collaborative robots, or cobots, are modern, user-friendly alternatives to traditional industrial robots. They are smaller, more affordable, and easier to program, even for non-experts, thanks to intuitive software. Equipped with built-in safety features, cobots can work alongside humans in complex, interactive procedures without requiring safety barriers. Their adaptability and programmability allow them to handle multiple tasks within the same facility, making them cost-effective for manufacturers who previously considered robotic automation out of reach.

What are Cobots?

Traditional industrial robots are designed for specific tasks while keeping human workers at a safe distance. These robots are commonly used for high-volume, repetitive operations such as welding, drilling, painting, material handling, and heavy lifting. Due to their large size, high speed, and powerful operation, they require safety enclosures to prevent human interaction. As a result, conventional robots operate in parallel with workers rather than in collaboration.

Cobots come in various sizes, payload capacities, and speeds, with some compact enough to fit on a workbench or mobile cart, while larger models can be ground-mounted, ceiling-mounted, or wall-mounted, depending on the application. Rather than replacing human labor entirely, cobots assist in repetitive or physically demanding tasks, reducing errors and worker fatigue.

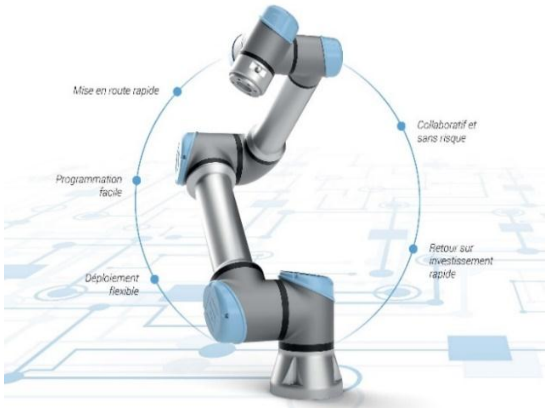


Figure1.1: Robotique Collaborative

Their small size and precise movements make them ideal for tasks that require handling small parts or intricate positioning, such as:

- Pick and Place (e.g., transferring items from a conveyor to a tray)
- Machine Tending (e.g., operating CNC machines or injection molding systems)
- Packaging and Palletizing
- Process Tasks (e.g., gluing, drilling, welding—when equipped with end-effectors)
- Finishing (e.g., sanding, polishing, deburring, trimming)
- Quality Inspection (e.g., vision-based inspection with cameras)
- Assembly
- Dispensing (e.g., applying adhesives, lubricants, or sealants)
- Painting, Coating, and Dipping

How Cobots Ensure Safe Human Interaction?

Cobots are designed to identify and respond to environmental changes using force-limiting sensors and vision systems. These sensors enable robots to detect and react to unexpected contact, ensuring they operate safely around humans.

Why Use Cobots?

The primary goal of automation is to enhance efficiency and reduce costs while minimizing errors and improving productivity. Cobots represent an initial investment but offer long-term savings by:

- Reducing manual labor and fatigue
- Improving production consistency and accuracy
- Allowing human workers to focus on higher-value tasks
- Increasing overall efficiency and profitability
- Industrial Robotics and Automation

Industrial automation has evolved over time, progressing through three key stages:

1. Mechanization – Replacing manual labor with machines
2. Automation & Numerical Control – Machines are given some level of control over processes
3. Full Automation – Machines operate with minimal human intervention, handling raw materials through to final product completion

Cobots fall within the automation spectrum by bridging the gap between fully autonomous systems and human-controlled processes, making them an essential component in modern manufacturing.

Human-Robot Interaction (HRI) and Safety

Human-Robot Interaction (HRI) is a crucial factor in seamless collaboration between humans and cobots. Effective HRI requires cobots to perceive, process, and respond to human actions using advanced sensors and AI-driven control systems. Interaction scenarios can be explicit (e.g., voice commands, touch inputs) or implicit (e.g., gesture recognition, pointing).
Cobots are equipped with virtual safety surfaces, force-sensing capabilities, and motion detection to ensure safe operation. If a human enters the cobot's workspace, it automatically:

- Slows down or stops movement to prevent injury
- Adjusts its path to avoid obstacles
- Limits force and power output for safe collaboration
- Conclusion

Cobots represent a new era of automation, offering a flexible, safe, and cost-effective solution for industries seeking to enhance productivity without eliminating human involvement. With advanced sensing capabilities, force-limiting safety features, and easy reprogram ability, cobots enable businesses to maximize efficiency while maintaining a human-centric approach to automation.

Goal of Work

- To design and developed prototype for Industrial COBOT.
- To overcome the critical safety issue with conventional industrial robots

An incident, in the context of occupational health and safety, is an unintended event that disturbs normal operations. OSHA defines an incident as "an unplanned, undesired event that adversely affects completion of a task." Incidents range in severity from near misses to fatal accidents.

What Are Examples of Industrial Accidents?

♣ Many accidents that occur at plants, refineries, or industrial facilities may entitle you to bring a legal claim.

♣ Common industrial accidents that result in personal injury-industrial accident claims include:

Objectives

- To ensure the safety of machine operators.
- To increase the cycle time due to less human interventions.
- To increase the safety during pre-crash.
- To increase external safety to machine body.
- To ensure the health of Machine by monitoring the joints temperature.

Research Framework

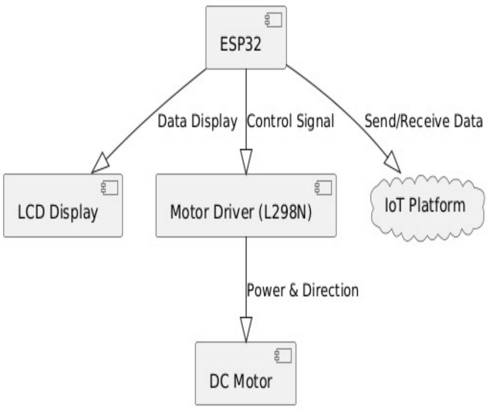


Figure1.3: Block Diagram

II. RESEARCH METHODOLOGY

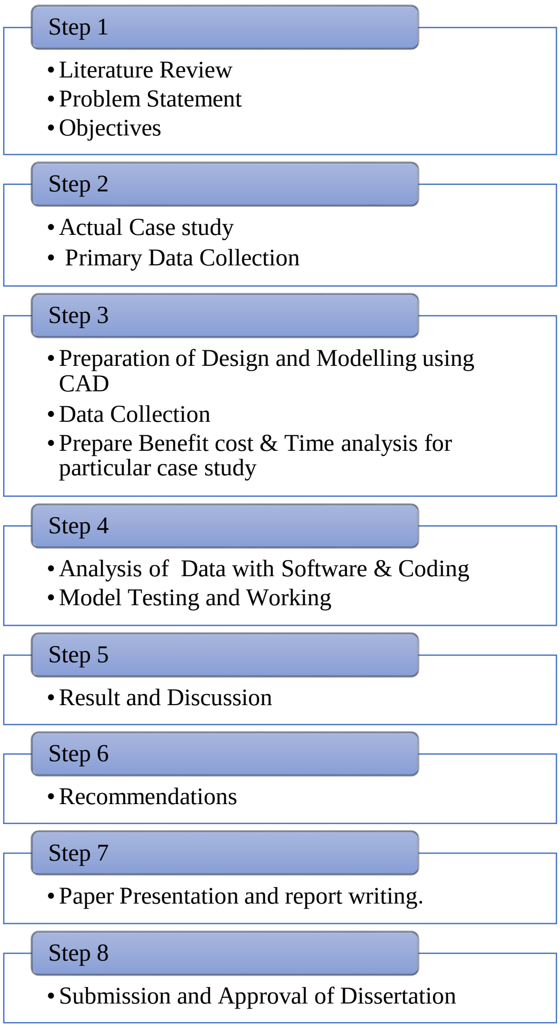


Figure1.2: Research Methodology

Material to be Used

Acrylic Sheet

Acrylic Sheet: Description and Properties

What is an Acrylic Sheet?

An acrylic sheet is a transparent thermoplastic material known for its clarity, strength, and versatility. It is often used as a lightweight and shatter-resistant alternative to glass. Acrylic sheets are made from polymethyl methacrylate (PMMA), a synthetic polymer that offers optical clarity, weather resistance, and durability.

Features and Properties

1. High Transparency – Offers up to 92% light transmission, making it clearer than glass.

2. Impact Resistance – More shatter-resistant than glass, reducing the risk of breakage.
3. Lightweight – Weighs half as much as glass, making it easy to handle and install.
4. Weather Resistance – Resistant to UV rays, moisture, and temperature variations, making it ideal for outdoor use.
5. Chemical Resistance – Can withstand exposure to many chemicals, though some solvents may affect it.
6. Easy to Fabricate – Can be cut, drilled, shaped, thermoformed, and polished with ease.
7. Variety of Finishes – Available in clear, tinted, frosted, and coloured options.

Types of Acrylic Sheets

1. Cast Acrylic – Offers better optical clarity and scratch resistance; ideal for high-end applications.
2. Extruded Acrylic – More cost-effective with easier thermoforming and machining properties.
3. Impact-Modified Acrylic – Contains additives for increased toughness, making it more resistant to breaking.
4. Frosted or Tinted Acrylic – Provides privacy and aesthetic appeal for interior design applications.

Comparison with Other Materials

Property	Acrylic Sheet	Glass	Polycarbonate
Weight	Light (50% of glass)	Heavy	Light
Strength	10x stronger than glass	Brittle	250x stronger than glass
Transparency	92% light transmission	90%	88%
Scratch Resistance	Moderate	High	Low
UV Resistance	High	Moderate	High
Cost	Moderate	Lower	Higher

Acrylic sheets are a durable, lightweight, and versatile material widely used in industrial, commercial, and household applications. Their high clarity, impact resistance, and weatherproof properties make them an excellent choice for glass replacements, display solutions, and creative designs.

DC Motor

A DC motor (Direct Current motor) is an electromechanical device that converts electrical energy into mechanical motion using direct current. It operates based on the principle of electromagnetic induction, where a magnetic field interacts with a current-carrying conductor to produce rotational motion.

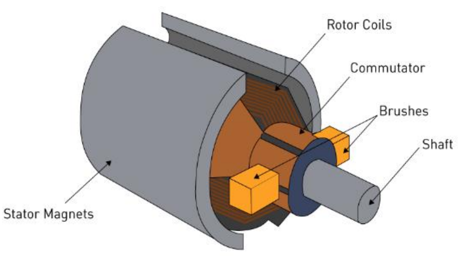


Figure1.4: DC Motor

- Operates on DC power supply (Battery or DC adapter)
- Variable speed control by adjusting voltage or using PWM (Pulse Width Modulation)
- Reversible rotation by switching polarity
- Compact and efficient, widely used in robotics, automation, and electric vehicles

ESP32 Controller

The ESP32 is a low-cost, low-power system-on-chip (SoC) microcontroller with Wi-Fi and Bluetooth capabilities, developed by Espressif Systems. It is widely used in IoT (Internet of Things), smart home automation, robotics, and wireless applications due to its high performance and energy efficiency.

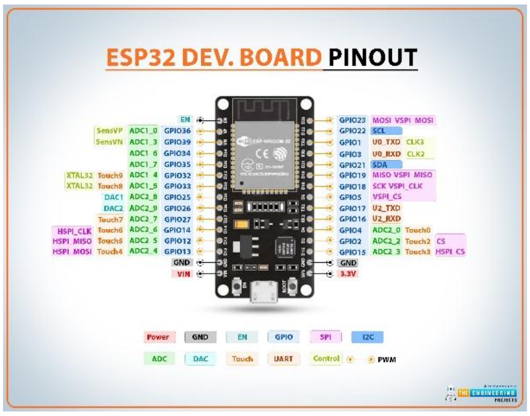


Figure1.5: ESP32 Controller Board

- Dual-core 32-bit Xtensa LX6 processor (160–240 MHz)
- Built-in Wi-Fi (802.11 b/g/n) and Bluetooth (v4.2 BLE & Classic)

- Low power consumption with multiple sleep modes
- Multiple GPIOs with support for ADC, DAC, PWM, SPI, I2C, UART
- Capacitive touch sensors, Hall sensor, and temperature sensor
- Supports FreeRTOS, Arduino, Micro Python, and ESP-IDF

Motor Driver (L298)

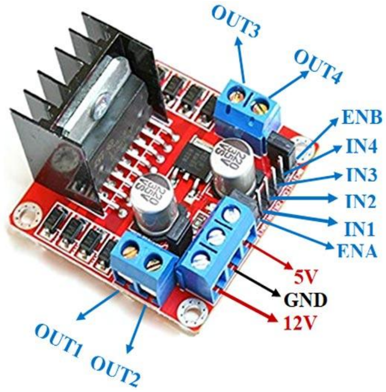


Figure1.6: Motor Driver

The L298 is a dual H-Bridge motor driver IC that allows control of two DC motors or one stepper motor simultaneously. It is widely used in robotics, automation, and motor control applications due to its ability to handle high currents and voltages.

Features:

- Dual H-Bridge design for controlling two DC motors independently
- Operating Voltage: 5V (logic) and up to 46V for motors
- Output Current: Up to 2A per channel (4A peak)
- PWM Speed Control supported
- Direction Control via logic signals (IN1, IN2, IN3, IN4)
- Built-in Thermal Shutdown Protection
- Can drive DC motors and stepper motor

Pin Configuration:

- VCC: Motor power supply (up to 46V)
- GND: Ground
- 5V: Logic power supply
- IN1, IN2, IN3, IN4: Control inputs for direction
- EN A, EN B: Enable pins for speed control (PWM)
- OUT1, OUT2, OUT3, OUT4: Motor outputs

LCD Display

An LCD (Liquid Crystal Display) is a flat-panel display technology commonly used in embedded systems, Arduino, ESP32 projects, IoT applications, and consumer electronics. It operates by controlling liquid crystals to modulate light and display characters, numbers, or graphics.

Types of LCD Displays:

1. Character LCDs (e.g., 16x2, 20x4) – Displays text characters only.
2. Graphic LCDs (e.g., 128x64, 240x128) – Can display images and custom graphics.
3. TFT LCDs (e.g., 2.4", 3.5") – Color displays with better resolution.
4. OLED Displays – Advanced technology with high contrast and power efficiency.

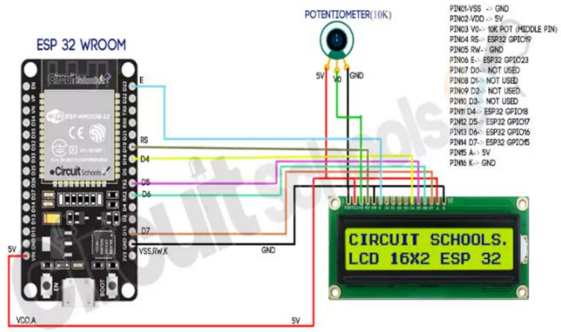


Figure1.7: LCD Display

Specifications (for Common 16x2 LCD Module):

- Display Type: Character LCD (16 columns × 2 rows)
- Interface: Parallel (4-bit or 8-bit mode), I2C with adapter
- Operating Voltage: 5V DC
- Backlight: LED with optional brightness control
- Character Size: 5x8 pixel matrix
- Controller: HD44780 or equivalent
- Viewing Angle: ~45°
- Power Consumption: Low

III. CONCLUSION

- Time-intensive steps waiting for material to come up to temperature, time for parts to queue, etc especially if an operator could be working on something else during this time

- Tasks that require multiple operators' Routine quality problems like a frequent need to scrap or rework, or areas of inconsistent quality between operators
- Points of wasted labor or labor that is better spent on "human-only" tasks installing delicate electrical wires or soldering tiny components
- Consistent bottlenecks and backups in production
- Work that utilizes heavy tools or parts - especially since these often cause workers to slow down as the shift progresses
- Rule-based operations (e.g. sorting, simple if-then logic)
- Tasks that don't rely on human senses to complete (e.g. process that can only begin once paint/adhesive is dry to the touch)
- Jobs or locations in your facility with a record of accidents or near misses
- Jobs employees complain about, dislike, or find challenging
- Areas with exposure to gases, dust, or byproducts of the manufacturing process
- Activities with repetitive motion and ergonomic problems, especially over time and repeated exposure
- Tasks requiring prolonged, intense focus or constantly shifting attention

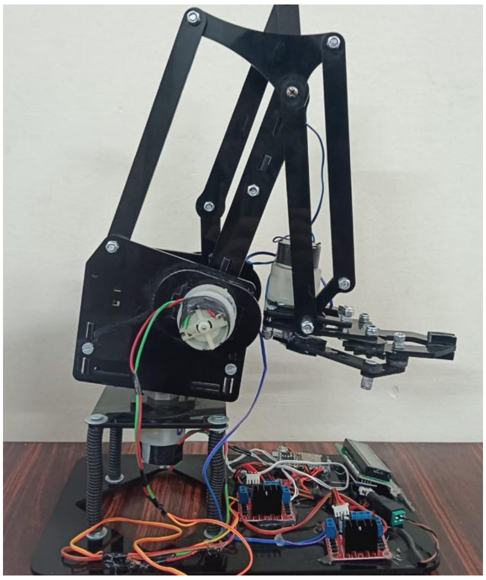
Future Scope

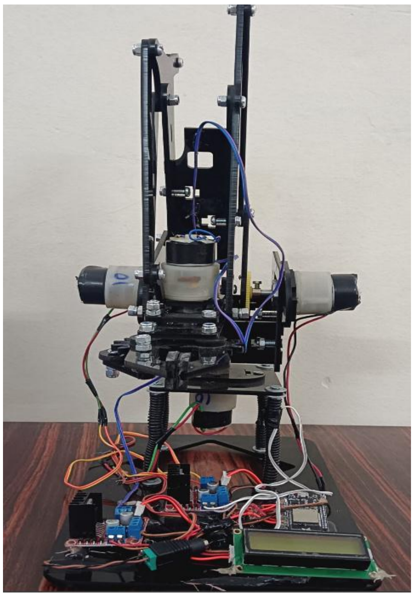
Future work includes completing fabrication and testing of the remaining wearable cobot. A minor redesign will be implemented to increase the rigidity of the system by adding a bearing to further support shafts A3 and A4. The bearing on shaft A4 will be replaced. The large capstan on shaft A3 will be remade to the precise specifications. Also, lightening of components and the addition of bearings at shafts A3 and A4 may reduce the start torque. Safety stops will also be designed and placed to protect the user and to prevent the device from exceeding its limits. The current design will employ the use of a 6-axis force transducer but alternative intent sensing measures at the CVT level must be investigated. The development of adjustable cobot arm length must also be investigated to accommodate a wide variety of users. A new mounting method using sleeves should be considered to allow greater flexibility in capstan mounting. The new all-metal-contact CVT will be implemented with the new powered cobot control algorithm.

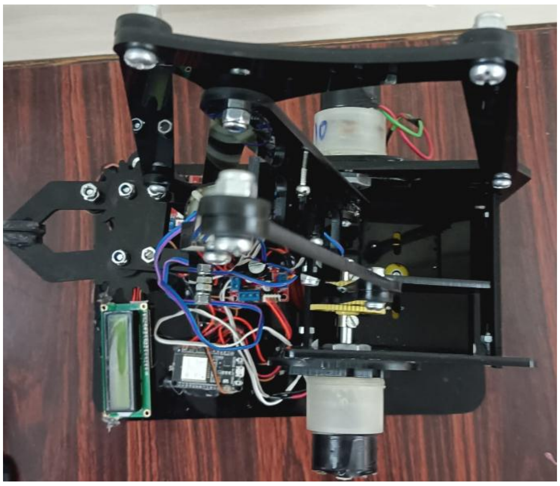
Application

- Pick and place (e.g. moving item from conveyor to tray)
- Machine tending (e.g. injection molding or CNC machines)
- Packaging and palletizing
- Process tasks, when equipped with end effector tools (e.g. gluing, drilling, welding)
- Finishing (sand, polish, deburr, trim)
- Quality inspection, when equipped with a vision camera
- Assembly
- Dispensing (e.g. adhesive, lubricant, sealant)
- Painting, coating, dipping

Model Photos







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