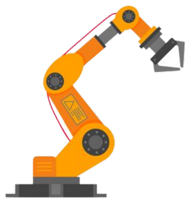
An-najah national University
Faculty of Engineering & Information Technology
Department of Computer Engineering

SEER
"Secure and Efficient Robotics for Hazardous Work Environments"



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A Hardware Graduation Project Presented in partial fulfillment of the requirements for Bachelor degree in computer engineering.

August, 2023

Acknowledgement

In the name of Allah, the Most Merciful, we are thankful for the blessings that guided us to complete this project. We express deep gratitude to the Almighty for granting us the strength, skills, and understanding needed for this achievement. We sincerely appreciate our supervisor, Dr. Muhannad Al-Jabi, whose steady guidance and unwavering support shaped this project's path. His expertise led us to a successful outcome we're proud to present. Thanks to the esteemed doctors of the Computer Engineering Department for their valuable insights that enriched our journey. We're grateful to Eng. Abdullah Alhinawi for generously aiding our project's progress and refining our methods. To our families and friends, your unwavering presence and support strengthened us at every step. Your belief in us means a lot. May our efforts and gained knowledge benefit our community and humanity.

Aya,Leen

Disclaimer

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Abstract

In the pursuit of human well-being and safety, technology has rapidly advanced, and the robotics industry has emerged as a vital component. Despite this progress, many robots lack real-time interaction with human input.

The 'Secure and Efficient Robotics for Hazardous Work Environments' (SEER) project addresses this gap by enabling human control of an arm robot with a gripper through a glove interface. This wireless glove-arm system utilizes defined movements and sensors for control.

By implementing this project, we aim to replace humans in performing risky tasks across sectors such as chemicals, laboratories, oil and gas, mining, nuclear, medical, laser, and x-ray industries.

The project prioritizes human safety by deploying robots in hazardous environments, reducing the risk of injuries or diseases. Moreover, it enhances productivity and accuracy, mitigates errors, and maintains work quality.

The SEER project not only enhances safety and efficiency but also offers potential cost savings by eliminating the need for specialized equipment and reducing maintenance expenses.

Chapter 1

Introduction

1.1 Problem Statement

The problem centers around balancing workplace safety and human interaction. It highlights the significance of human engagement in upholding workplace safety and continual improvement of security, while acknowledging the potential for accidents. Attention is also directed towards high-risk tasks involving hazardous materials, where human intervention remains essential, especially in dealing with toxic chemicals and radiation exposure. based on statistics The ILO also estimates that every day approximately 6,400 people die from occupational accidents or diseases and that 860,000 people are injured on the job. The main challenge lies in finding the equilibrium between automation and human judgment, emphasizing the limitations of solely relying on programmed actions and prioritizing worker safety in enhancing overall security [2].

1.2 Project Objectives

The Glove-Controlled Robotic Arm empowers users with full mastery over a robotic arm. Utilizing an ESP32-equipped glove, it captures hand movements and wirelessly communicates them to an ESP32-connected unit on the robotic arm. Equipped with responsive motors, the robotic arm mirrors user gestures precisely.

1. Innovative Control Solution: Develop a cutting-edge control mechanism, providing intuitive interaction between the user and the robotic arm.

2. Natural Hand Gesture Tracking: Utilize the glove to accurately track and translate the user's natural hand movements into corresponding robotic arm actions.

3. Wireless Communication: Establish seamless wireless communication between the glove and the robotic arm unit, ensuring real-time and fluid control.

4. Enhanced Workplace Safety: Enable the robotic arm to perform tasks in hazardous environments, addressing the need for safer work conditions and reduced human exposure to risks.

5. Technological Innovation: Pioneer the fusion of human intuition and robotics technology to achieve a harmonious interaction between human control and machine precision.

1.3 Project Scope

In this project, the focus will be on establishing a secure working environment within hazardous workplaces through an innovative control solution that synergizes the capabilities of both machines and humans. This integration recognizes the indispensable role of human expertise and proficiency alongside the capabilities of technology.

1.4 Project Significance

The significance of the project comes from its crucial role in redefining occupational safety in risky circumstances. This effort cleverly combines human experience with cutting-edge technology, which not only strengthens individual protection but also has the ability to redefine safety benchmarks across sectors.

1.5 Report Organization

- Introduction (Chapter 1): Sets the stage for the project by providing a background and context for the research.
- Constraints and Earlier Coursework (Chapter 2): Explains the project's limitations and challenges, as well as how these were overcome. It also discusses relevant coursework that contributed to the project's development.
- Literature Review (Chapter 3): Provides an overview of existing research related to your project, showcasing your understanding of the current landscape and any similar projects.
- Methodology (Chapter 4): Describes in detail how you approached solving the problem, including the systematic plan, development process, software tools used, and hardware equipment employed.
- Results and Analysis (Chapter 5): Presents the data collected during your project and discusses how you analyzed it, including any statistical treatment. This chapter also provides a platform for comparing your results to expectations or benchmarks.
- Conclusion and Future Work (Chapter 6): Summarizes the entire project, highlighting key takeaways and lessons learned. It concludes with suggestions for future improvements or additions to the project.

Chapter 2

Constraints & Earlier course work

2.1 Limitations & Constraints

2.1.1 Limited Time

Within the concise span of a two-month summer semester, the project's planning and execution are constrained. This timeframe includes learning new programming technologies, navigating intricate modules like ESP32,MPU-6050A and Flex sensor, all of which demand dedicated time. Moreover, the project coincides with other coursework, intensifying the need for effective time management to successfully balance these commitments.

2.1.2 Limited Resources

- Flex Sensor Size: We encountered difficulty sourcing flex sensors of suitable sizes for our project's needs, as the available sizes were often too small and incompatible.
- Limitations Due to Weight: car's performance was hindered by its capacity to manage weight restrictions, resulting in movements that were slower than initially envisioned. The structural design of the vehicle's foundation did not account for accommodating both the arm's dimensions and the added weights.
- Coordinating Arm and Base Movement: An additional challenge arose in effectively synchronizing the movements of both the arm and the mobile base.
- Securing the Right Arm: Sourcing an arm that aligned seamlessly with our objectives posed a challenge. Balancing considerations of suitability, cost-effectiveness, and availability proved to be a significant task.
- Purchasing Unsuitable Parts: Acquiring certain components that met our specific requirements proved difficult, leading to extra effort and resources needed to rectify the situation.
- Cost: Managing the project's financial aspects presented a challenge. Some required solutions carried a high cost, necessitating careful financial resource allocation.

2.2 Earlier coursework

The project leverages four years of education in the computer engineering department, complemented by insights from electrical engineering. Our journey began with fundamental programming in C language and progressed through courses such as Digital Circuits, microprocessors, electronics, computer architecture, and PIC microcontroller. These experiences provided us with a solid knowledge base. The Micro-Controllers course honed our hardware control skills, while CPU Lab improved our debugging abilities. Critical Thinking and Scientific Research enhanced our research capabilities and paper writing skills. The Microprocessor Lab translated theoretical concepts into practical applications, covering topics like I/O, serial communication, and motors. Furthermore, the Digital Circuits Lab equipped us to work with essential project components. This comprehensive educational journey has significantly contributed to shaping the capabilities of our project.

2.3 Standards

We have chosen the ESP32 microcontroller for our project due to its user-friendly design, affordability, and compatibility with various operating systems. The ESP32 software environment offers a gentle learning curve for beginners and the flexibility required by advanced users. Its open-source nature facilitates customization and expansion in both software and hardware aspects. The selection of the ESP32 was made to align with our project requirements.

The ESP32 offers a rich set of features, including numerous digital I/O pins, many of which can be configured for PWM outputs, and a range of analog inputs. We have followed software and electrical standards, developing our code using Arduino C with a strong focus on maintainability. By designing each function independently, we ensure reusability and smooth integration, consistent with our project's efficiency objectives.

Here are some reasons why you might prefer using ESP32 over Arduino:

1-Better Performance: ESP32 comes with a dual-core processor and more memory, making it better than Arduino for executing complex tasks and Wi-Fi/Bluetooth applications.

2-Built-in Wireless Connectivity: ESP32 has built-in wireless connectivity features, including Wi-Fi and Bluetooth, making it ideal for Internet of Things (IoT) projects and remote control applications.

3-Support for Voice Commands and Sensor Integration: ESP32 can handle audio and image applications due to its ability to connect to multiple sensors.

4-Multiple Programming Environments: You can program ESP32 using Arduino IDE and other languages like MicroPython and JavaScript.

Chapter 3

Literature Review

Simulating human hand movements through the utilization of a glove integrated with flex sensors and a balance sensor represents a pioneering leap in the field of robotics and human-machine interaction. This innovative approach holds the promise of bridging the gap between human dexterity and robotic precision, particularly in contexts where human intervention is restricted due to hazardous environments or intricate laboratory tasks.

The integration of flex sensors into gloves has been a subject of growing interest in recent years. Research has delved into various aspects of their design, calibration, and applications. Studies have explored the challenges of accurately capturing intricate hand movements, compensating for sensor drift, and establishing reliable real-time communication between the glove and the robotic system. These investigations contribute not only to improved hand gesture recognition but also to refining the overall performance and usability of such systems.

In parallel, balance sensors or accelerometers play a pivotal role in achieving seamless coordination between the glove-wearer's hand movements and the robotic arm's actions. Research in this area encompasses sensor calibration techniques, signal filtering algorithms, and fusion strategies for combining data from multiple sensors. The integration of balance sensors into the glove's design enhances the system's ability to accurately interpret a user's intentions and translate them into precise robotic movements.

Furthermore, the successful deployment of glove-based systems in hazardous environments and chemical laboratories offers multifaceted benefits. Research in this domain has explored scenarios where human presence would be perilous, such as nuclear facilities, toxic waste management, and explosive ordinance disposal. By employing glove-controlled robotic arms, operators can manipulate objects, conduct experiments, or perform tasks remotely, minimizing their exposure to potential risks.

Gesture recognition has emerged as a modern alternative to the conventional method of operating robots using buttons and other mechanisms, now replaced by control based on hand gestures[5]. Robots have dedicated their efforts to the creation of a "Human-Machine Interface Device," offering the potential to maneuver a robot through the concept of gesture recognition[6]. Leveraging the affordability and compact dimensions of accelerometers, they serve as optimal tools for detecting and identifying human movements[8].

”Traffic Police Gesture Recognition using Accelerometers”
This paper introduces an innovative traffic police gesture recognition system utilizing two 3-axis accelerometers positioned on the back of the hand to detect arm movement and hand positioning. Real-time gesture recognition is achieved through an algorithm executed on an MCU. The system's PC software emulates traffic lights. Remarkably, the system attains high recognition rates, even for non-standard gestures. Unlike vision-based systems, this on-body approach avoids occlusion and illumination issues.Notably, the proposed gesture recognition technique can be readily adapted for traffic police gestures in different countries [9].

”A Comparative Study for Telerobotic Surgery Using Free Hand Gestures”
This study discusses the use of a highly dexterous surgical robot by responds to human Gestures natural hand gestures employed by surgeons. The aim of the study is to explore the advantages and drawbacks of integrating touchless interfaces into surgical control. Performance metrics were gathered to evaluate user proficiency, learning rates, control stability, and interaction nature through experimental designs encompassing standardized surgical tasks. The results indicate that touchless interfaces offer comparable performance to touch-based interfaces for tasks of varying complexity. This study paves the way for evaluating and comparing these interface types within surgical contexts, contributing to the exploration of novel interaction methods to enhance human-robot interaction in the field of surgical robotics, with a focus on responds to human Gestures natural hand movements.[10].

”Utilizing Glove-Based Gestures and a Tactile Vest Display for Covert Communications and Robot Control”
The study involved maneuvering a robot through paths and obstacles using hand gestures. Sensor-equipped gloves with accelerometers in the fingers and additional sensors on the hand's back were used for control. The gloves improved signal detection compared to traditional methods, showing potential for effective and covert communication in military settings [7].

Chapter 4

Methodology

In order to successfully realize the core concept of the project, a series of necessary steps had to be undertaken. The initial step involved the collection of essential materials and the required technology.

4.1 Components

In this section, the design and tools used are described so as to show the full process of SEER development and its basis.

4.1.1 Sender Part

Tools were used in "Glove-Controlled Robotic arm" are as follows:

1.ESP 32:
The ESP32 is a versatile microcontroller module designed for IoT projects, featuring dual-core processing, built-in Wi-Fi and Bluetooth, ample memory, GPIO pins, and communication interfaces. It's widely used for wireless connectivity, sensor integration, and IoT applications [1].
In our project it was used for communication between the glove that was used for hand gesture movement mode and the onother ESP32 on the receiver part.

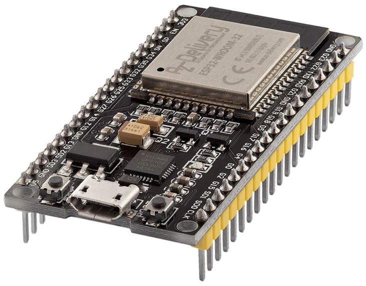

Figure 4.1: ESP32

2.Triple Axis Accelerometer & Gyro Breakout - MPU-6050A:
The MPU-6050 is a sensor chip that combines a gyroscope and an accelerometer.
It tracks rotation and acceleration in three dimensions each, providing 6 degrees of freedom (6DoF) data, it communicates digitally with microcontrollers and often includes a built-in processor for handling motion calculations [3].
In our project it was used to calculate the hand gesture movement.

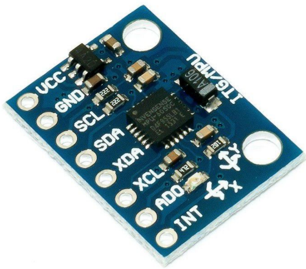

Figure 4.2: ESP32

3.Flex Sensors:
Flex sensor is a particular component that is used to calculate the motion or the bending of the motion. Most of the material is done with carbon and plastic, Due to the carbon's connection to the flex sensor, any motion of the sensor will cause a change in resistance. The moments of the robotic arms have become precise and meticulous, this also helps in acuteness. There are enormous types and uses of flex sensors for rehabilitation, security systems, intensity control and music interface. This is one of the most important aspects of the experiment[4].
In our project we used three flex sensors to measure and monitor the degree of bending and movement in the glove.

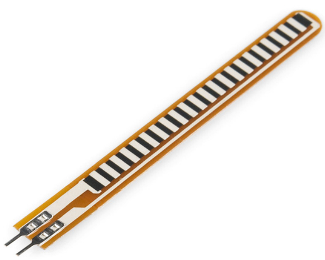

Figure 4.3: Flex Sensor

4.Lithium Batteries:
Lithium batteries were used because of the high current they provide.

NOTE: Please take care while using lithium batteries. When the batteries fail to operate safely or are damaged or a short circuit happens, they may present a fire or explosion hazard.

Figure 4.4: Lithium Batteries

4.1.2 Receiver Part

1.ESP 32:
The robotic arm's ESP32 acts as a receiver, decoding the transmitted data. This decoded information guides the arm to responds human hand gestures.

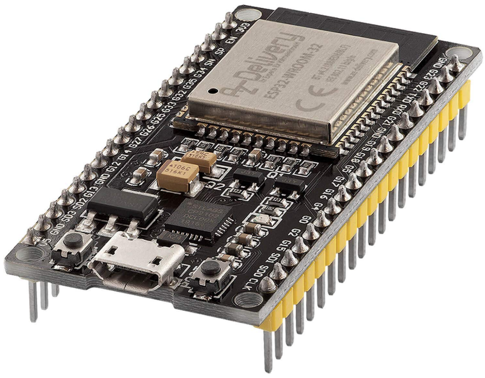

Figure 4.5: ESP32

2.3D Printed Robotic Arm:

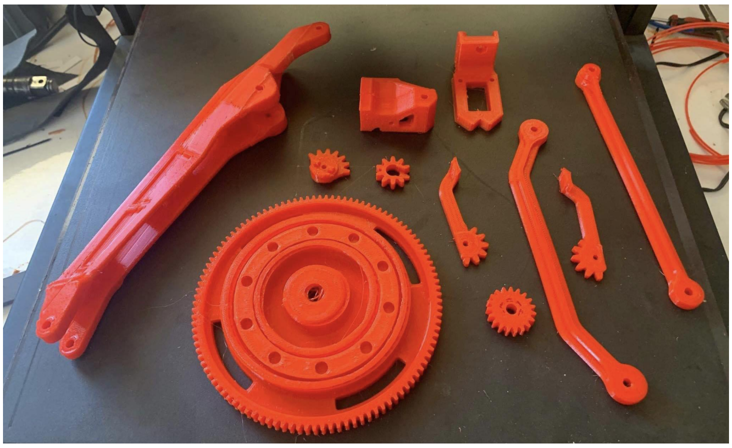

Figure 4.6: 3D Printed Robotic Arm

3.Stepper Motors:
Stepper motors provide value without compromising quality, with a 0.9° step for precision and minimized vibration. Customizable for various needs. NEMA sizes based on frame, following safety standards by the "National Electrical Manufacturers Association" (NEMA). Stepper motors move in fixed angles via energized coils, suitable for accurate control. They're essential in robotics, 3D printing, CNC, and more, offering precise and reliable motion control.

In our project the arm control system will incorporate three stepper motors in its design. Each motor will serve a specific function in controlling the arm's movements:

- The first stepper motor will enable vertical movement of the arm, allowing it to move up and down.
- The second stepper motor will facilitate a 360-degree rotation of the arm.
- The third stepper motor will control the forward and backward movement of the arm.

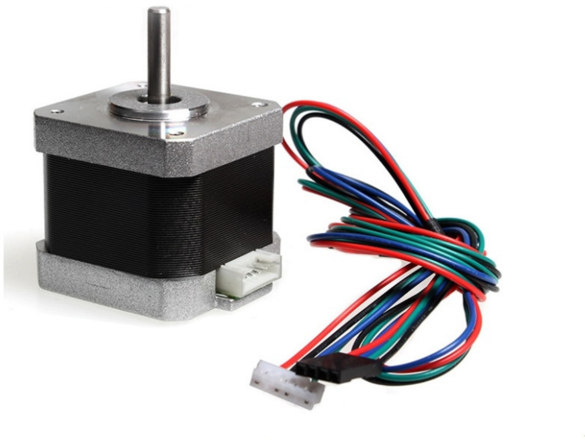

Figure 4.7: NEMA17 Stepper Motor

4.A4988 Driver:
The A4988 is a microstepping driver for controlling bipolar stepper motors which has built-in translator for easy operation. This means that we can control the stepper motor with just 2 pins from our controller, or one for controlling the rotation direction and the other for controlling the steps.

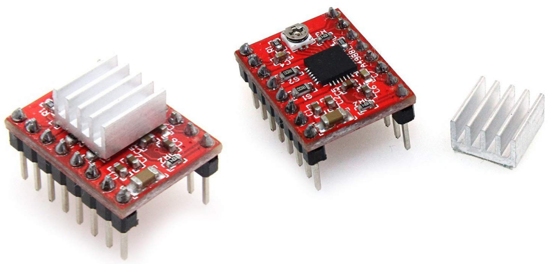

Figure 4.8: A4988 Driver

5.Servo Motor:
The SG90 servo motor is a compact and lightweight micro servo motor that finds widespread application in robotics, motorized vehicles, and robotic arms. With its impressive power output, this motor offers precise control over position and speed. It is capable of rotating approximately 180 degrees, 90 degrees in each direction. Operating at a voltage of +5V, it delivers a torque of 2.5kg/cm. Typically equipped with plastic gears, the SG90 servo motor utilizes pulse width modulation (PWM) signals to ensure accurate and efficient control of its position and speed.
In our project, we utilized the servo to control the gripper, enabling it to open and close.

Figure 4.9: Servo Motor

6.LM7805:
The LM7805 is a linear voltage regulator commonly used in electronic projects that require a regulated power supply for different devices.

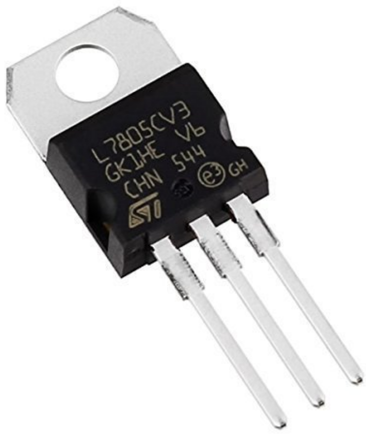

Figure 4.10: LM7805

7.DC Motors:
DC motors are widely used to power the wheels of cars. These motors typically consist of two leads - a positive and a negative. By directly connecting these leads to a battery, the motor initiates rotation. Interestingly, switching the leads results in the motor rotating in the opposite direction.

Figure 4.11: DC Motor

8.H-bridge:
An H-bridge is an electronic circuit that allows for the control of the direction in which a DC motor spins, without the need to change the connection of its leads. This circuit consists of four transistors arranged in a specific configuration that resembles the shape of an "H" on a schematic diagram. By utilizing an H-bridge, motors can be effectively driven in both forward and reverse directions. H-bridges have a wide range of applications, with one of the most common being their use in robotics to control motor movement.

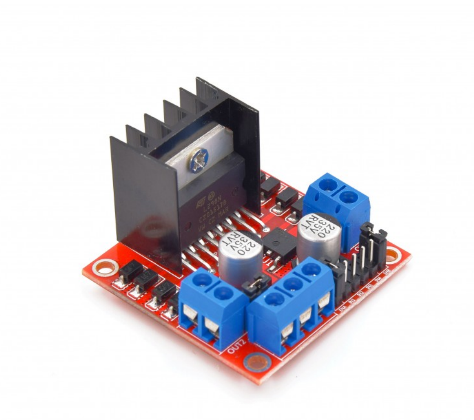

Figure 4.12: H-bridge L298N

4.2 Robot Assembly

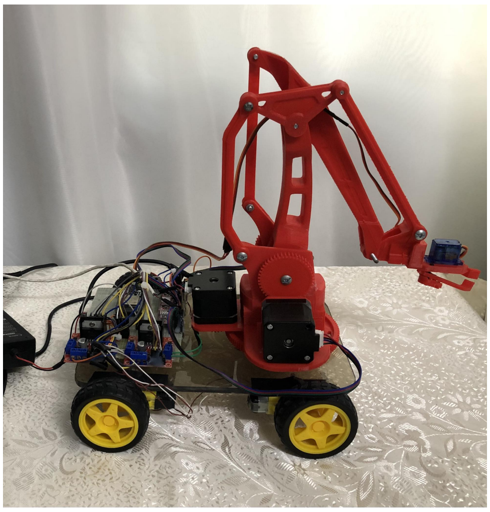

Figure 4.13: View for car base and arm robot Design

Figure 4.14: View for car glove Design

4.3 Overview of The System

In this project, we have developed an innovative robotic arm with a distinctive response to hand gestures, setting it apart from traditional mimicry systems. By harnessing the capabilities of the ESP32 microcontroller and establishing a serial communication link between them, we have created a pioneering system for interpreting hand gestures as actionable commands. This approach introduces a novel dimension to human-robot interaction.

When the user initiates movement while wearing a glove equipped with an MPU and flex sensor, the data is seamlessly transmitted to the robotic arm through an ESP connection. Every gesture and flexion of the glove guides the robotic arm to mimic human hand movements accurately. Once we have established all the necessary arm directions and precise positioning, this information is leveraged to control four Direct Current Motors (DC) responsible for the arm's mobility. Consequently, we gain the ability to manipulate the arm for grasping desired objects. This is facilitated by a servo motor that controls a gripper, allowing controlled opening and closing actions.

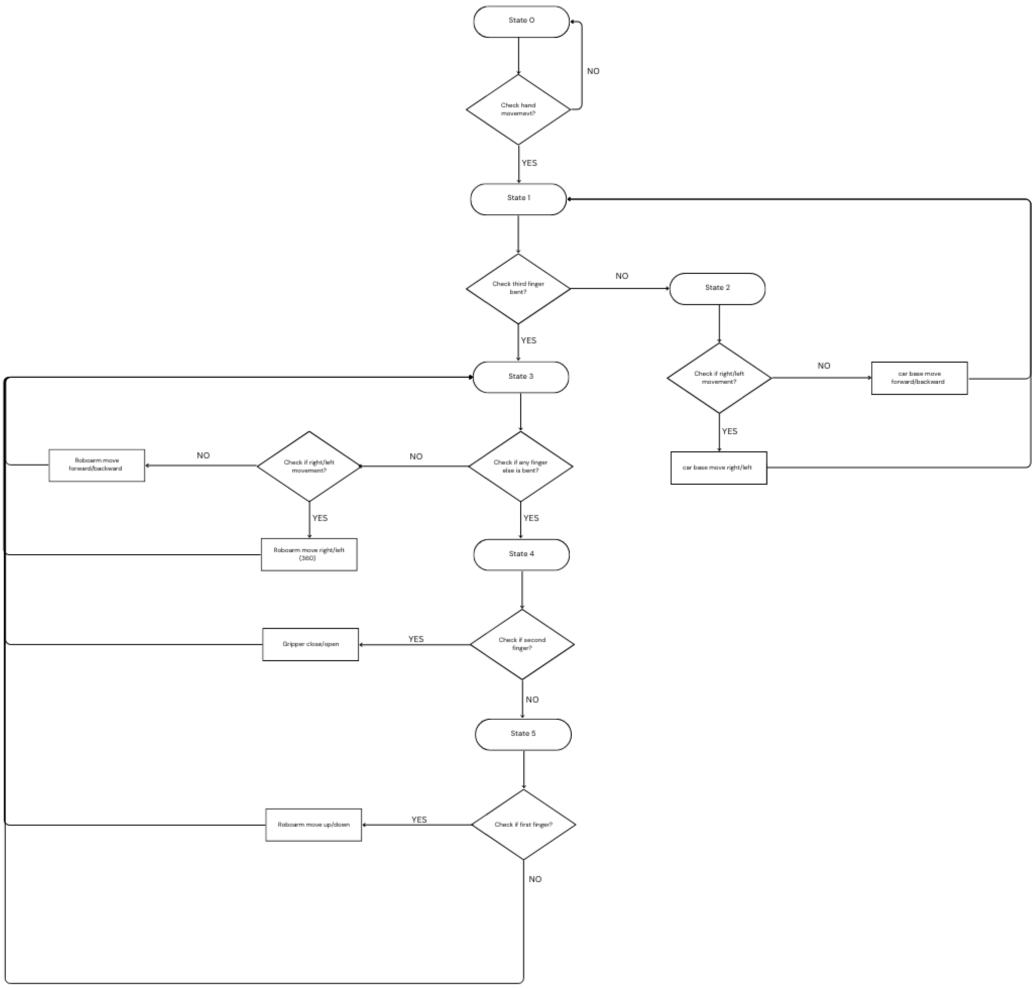

Figure 4.15: SEER UML Design

4.4 Implementation

4.4.1 Glove Part

In the design of our system, the measurement of finger movements was achieved using flex sensors. These sensors are adept at gauging the degree of deflection or bending. Typically, they are affixed to a surface, and their resistance is altered through the bending of this surface. This configuration proved to be highly effective in capturing the intricate movements of the fingers.

When considering the motions of the wrist and elbow, which predominantly occur along specific axes, we opted for the Triple Axis Accelerometer & Gyro Breakout - MPU-6050A. This choice was strategic.

As previously mentioned, our selected microcontroller is the ESP32, which comes equipped with ample capabilities, including a set of analog pins. This configuration allowed us to seamlessly integrate both the three flex sensors and the MPU 6050 into our system.

Here's a breakdown of how each component was integrated into the circuit:

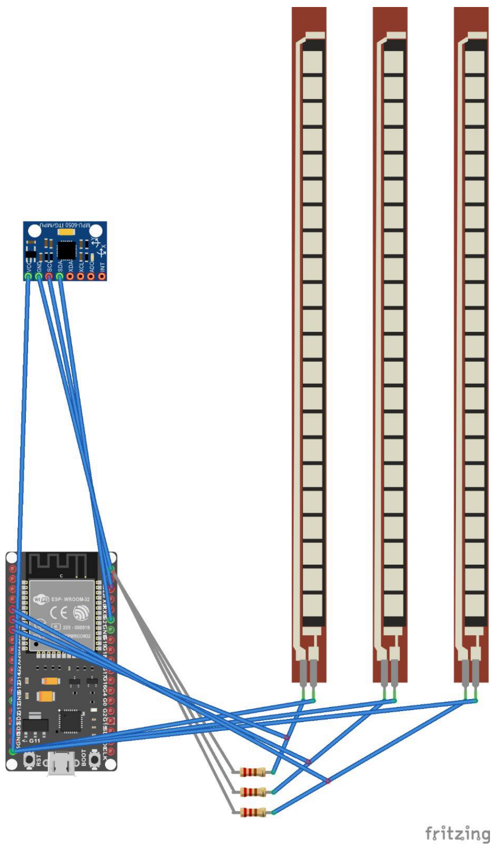

Figure 4.16: Sender Part Connection

4.4.2 Roboarm & Car Base Part

- Roboarm:

With its intricate design and meticulously crafted joints, the Roboarm possesses the ability to mimic the wide range of movements found in the human arm. Engineered to interpret hand gestures and replicate the articulation of human limbs, it offers a multitude of degrees of freedom (DOF) to perform diverse motions. Each joint is driven by three precise stepper motors which provide a range of movement from 0 to 360 degrees: the first controls vertical arm movement, the second enables a 360-degree rotation, and the last facilitates forward and backward arm motion. These stepper motors are managed by A4988 drivers. Additionally, a servo motor is employed to manipulate the gripper, and the LM7805 voltage regulator is utilized to ensure consistent operation of the servo motor by maintaining a steady 5-volt supply, which is essential for optimal servo performance. This regulator also effectively filters out electrical noise. As a result, the Roboarm seamlessly combines flexibility and accuracy, providing the agility needed to effectively engage with its surroundings.

- Car Base:

The Car Base, an integral counterpart to the Roboarm, is the locomotive force that propels our system across surfaces. Designed to prioritize stability and precise control, it incorporates a set of four DC motors, each connected to wheels and motorized mechanisms. These components work in tandem, allowing the platform to achieve omnidirectional movement effortlessly. The L298 H-bridge acts as the driver for these DC motors, ensuring seamless coordination and control. This dynamic mobility introduces an additional dimension of adaptability to its capabilities.

- Synchronization:

The synergy between the Roboarm and Car Base is a testament to the interconnectedness of our system's components. This harmonious collaboration ensures that the Roboarm's actions and the Car Base's locomotion are seamlessly coordinated, facilitating precise and agile interactions with the surrounding environment.

Here's a breakdown of how each component was integrated into the circuit:

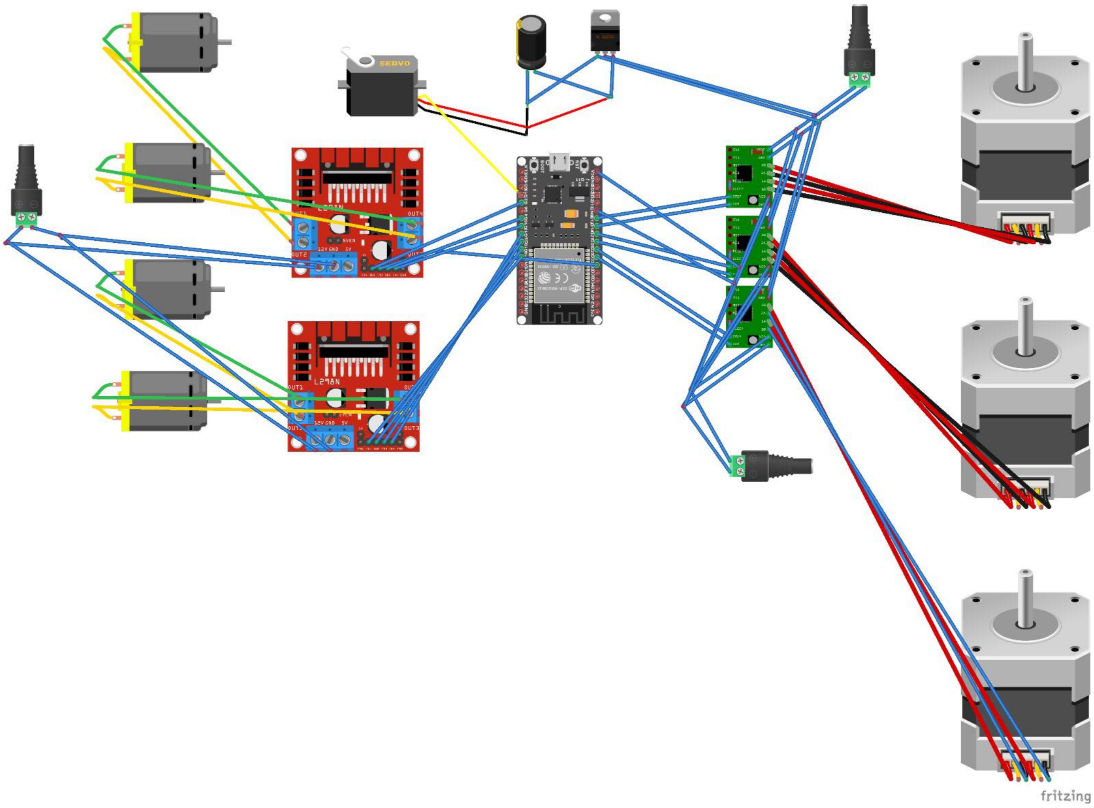

Figure 4.17: Receiver Part Connection

4.4.3 Wireless connection

Upon finalizing the design of the two components, our focus shifted to establishing seamless communication between them. Given our project's core objective of ensuring a safe distance between the glove and the robotic arm to mitigate potential hazards, we opted for wireless communication over traditional wired alternatives. The implementation of wired communication would have posed challenges, particularly in the space where the robotic arm operates.

In light of this, we adopted a wireless communication solution for the central circuit governing both components. To achieve this, we harnessed the power of the ESP32 module, known for its robust wireless capabilities. The ESP32's built-in Wi-Fi and Bluetooth functionalities enabled us to create a reliable and responsive communication channel between the glove and the robotic arm.

For data transmission and reception, we leveraged the ESP32's adaptability to the 2.4 GHz frequency, a widely accepted standard for engineering applications globally. This frequency band ensures efficient communication while minimizing interference. With a substantial range of up to 100 meters (200 feet), our system could seamlessly facilitate wireless remote control. This choice of technology empowers our project to overcome spatial constraints and optimize safety while maintaining a fluid and effective connection between the glove and the robotic arm.

Chapter 5

Results and Analysis

The implementation of our SEER project, which focuses on emulating human hand movements using a glove equipped with flex sensors and a balance sensor, has yielded notable results. Through rigorous testing and experimentation, we evaluated the efficacy and feasibility of this groundbreaking glove technology in controlling a robotic arm.

Balance Sensor Calibration: Integrating the balance sensor presented an additional challenge due to the requirement for precise calibration. Through iterative adjustments and calibration processes, we achieved a satisfactory level of accuracy in translating balance shifts into robotic arm movements.

Enhancing Safety in Hazardous Environments: The primary aim of our project was to enhance safety in hazardous environments, especially chemical laboratories dealing with hazardous substances. Our experiments demonstrated the glove's capability to manipulate the robotic arm with human-like precision, thereby reducing the risk of human exposure and potential accidents.

User-Friendly Interface: We found that the glove's interface was intuitive and user-friendly, even for individuals with limited technical expertise.

In conclusion, our project's results underscore the significant potential of innovative glove technology to revolutionize human-robot interaction, particularly in hazardous environments. The seamless translation of human hand movements into robotic actions offers improvements in both safety and efficiency, rendering it a promising solution for a range of applications.

Chapter 6

Conclusion and Future Work

6.1 Benefits & Gains

In the course of our project, we have realized several benefits and gains. These include:

- New Technical Skills: Our project exposed us to a range of new skills, such as effectively utilizing the ESP32WiFi.h library to establish data connections.
- Flex Sensor Implementation: We acquired expertise in setting up flex sensors on the ESP32 platform.
- MPU Module Usage: We learned how to use an MPU module with ESP32, including training it with hand motion commands.
- Motor Control: Understanding how to employ stepper and DC motors to address application requirements.
- Proficiency in Overleaf: Our use of Overleaf enhanced our proficiency in creating comprehensive project reports.
- Cultivation of Versatile Skills: The project contributed to the development of versatile skills, including problem-solving, hands-on experience with sensors and microcontrollers, and effective project management. These skills synergistically bridge theoretical knowledge with practical application."

6.2 Future Work

features for the future development of the SEER project:

- We are considering replacing the generator with batteries, as they provide optimal performance for the project. Furthermore, we will also incorporate a meticulously crafted printed glove. In conjunction with these improvements, we intend to redesign the car's base to properly accommodate the robot arm's dimensions ,This addition will enhance its durability t, allowing it to effectively manage the increased weight. Our ultimate goal is to elevate the overall performance of the SEER project.

- Advanced Hand Design: Explore the possibility of a five-fingered hand design, enhancing the robotic arm's natural interaction with objects and environments, moving beyond the current gripper design.
- Expanding Applications: Investigate the feasibility of applying this technology in diverse fields beyond hazardous environments, such as manufacturing, healthcare, and other sectors where human-robot interaction plays a pivotal role.
- Integrated AI Capabilities: Implement an AI system that actively monitors the robotic arm's surroundings, enabling real-time decisions for optimized interactions. This could encompass obstacle detection, object recognition, and predictive learning from user interactions.
- Comprehensive Muscle Control: Further develop the integration of EMG sensors, allowing the robotic arm to be guided not only by hand movements but also by the user's muscle activity. This advancement would introduce an additional layer of natural and intuitive control.

These proposed enhancements signify the project's evolution, amplifying its capabilities and potential applications. They also push the boundaries of human-robot interaction and control, underscoring the project's ongoing relevance and impact.

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