



GRADO EN INGENIERÍA EN TECNOLOGÍAS DE INDUSTRIALES

TRABAJO FIN DE GRADO BENCH PRESS SMART HELPER (HARDWARE)

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Madrid

Julio 2022

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Bench Press Smart Helper (hardware)

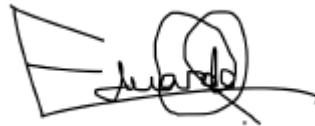
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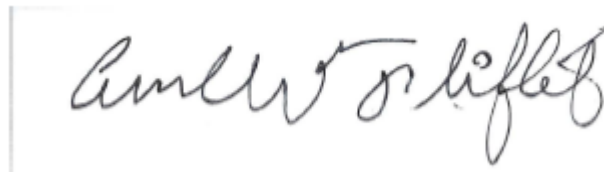


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TRABAJO FIN DE GRADO BENCH PRESS SMART HELPER (HARDWARE)

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Madrid

Julio 2022

ASISTENTE INTELIGENTE PRESS BANCA (HARDWARE)

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RESUMEN DEL PROYECTO

El objetivo de este Proyecto es crear una máquina automática que permita al usuario realizar el ejercicio de press banca de la forma más fructífera posible. La máquina se controla externamente. Esta se activa y ayuda al usuario solo durante las repeticiones que el/ella especifica previamente. Además, es capaz de detectar el fallo y ayudar al usuario antes de lo previsto para prevenir lesiones. Finalmente, aporta feedback sobre algunos aspectos del ejercicio, como el ángulo de inclinación de la barra o el tiempo que tarda el usuario en realizar cada una de ellas. En concreto, este proyecto se enfoca en el hardware del diseño. Esto incluye la investigación, el diseño y el informe sobre las diferentes partes del hardware del proyecto. Algunas de estas son las siguientes: el diseño completo de la placa de circuito impreso (PCB), la implementación del polipasto eléctrico, el circuito de control, la definición y conexión de los subsistemas del proyecto, la implementación de los debidos reguladores de voltaje, y la selección de los componentes necesarios.

Palabras clave: Hardware, Asistente Automático, Press Banca, PCB, Subsistemas

1. Introducción

El press banca es uno de los ejercicios más importantes en el mundo del fitness. La persona que realiza el ejercicio se tumba boca arriba en un banco y procede a levantar el peso hacia arriba y hacia abajo con sus brazos. El press banca involucra todos los músculos de la parte superior del cuerpo en cierta medida [FERR21]. Además, de acuerdo con estudios de electromiografía, el press banca con barra es el mejor ejercicio para activar todos los músculos del pecho [SUPP11]. No obstante, ejecutar este ejercicio sin ayuda puede resultar en lesiones o entrenamientos contraproducentes. El/la atleta tiende a trabajar con menos peso del que es capaz de levantar, o se acaba lesionando tratando de levantar lo máximo sin supervisión.

Con el objetivo de resolver este problema, la gente suele apoyarse en otra persona para realizar el ejercicio, a la que comúnmente se le llama “spotter”. Esta persona permite a la/al deportista levantar más peso del que podría levantar normalmente sin ayuda de forma segura. Sin embargo, no es siempre posible encontrar a otra persona disponible en el gimnasio que pueda ayudar a la/al deportista con la ejecución correcta del ejercicio. El/la atleta puede estar entrenando en solitario, o puede no sentirse cómodo/a apoyándose en una persona desconocida o pidiendo ayuda.

El objetivo de este proyecto es estudiar y construir el hardware de una máquina automática que permita al usuario realizar el ejercicio de press banca de la manera más productiva y segura posible, sin la necesidad de un “spotter”.

2. Objetivos:

Los objetivos de este proyecto son:

- Seguimiento del movimiento: El diseño debe ser capaz de seguir el movimiento de la barra durante toda la ejecución del ejercicio.
- Detección de fallo: El sistema debe detectar cuando el usuario está teniendo dificultad para levantar el peso, para poder activar el mecanismo de ayuda.
- Reducción de peso: La máquina debe ser capaz de ayudar al usuario levantado hasta 45 libras (20 kilogramos) de peso cuando sea necesario.
- Control del usuario: El usuario debe ser capaz de controlar externamente la máquina a través de un dispositivo como una pantalla o un teléfono móvil.
- Diseño compacto: El circuito del proyecto debe caber en una caja. Todo el diseño debe ser portátil, ajustable a distintas superficies, y no excesivamente pesado para que no sea difícil de trasladar.

3. Diseño del modelo

El diseño consiste en cinco subsistemas diferentes: el subsistema mecánico, el subsistema de control, el subsistema de potencia, el subsistema de sensores y el subsistema del usuario. En la Ilustración 1 se muestra el diagrama de bloques del diseño completo.

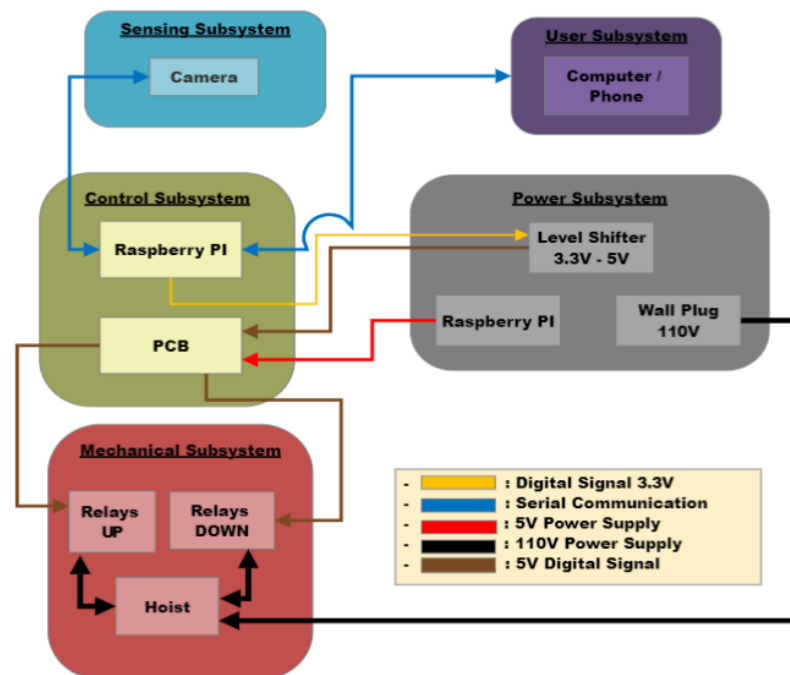


Ilustración 1 : Diagrama de Bloques

Subsistema mecánico: El subsistema mecánico consiste en un polipasto eléctrico capaz de levantar hasta 440 libras (200 kilogramos). El polipasto eléctrico elegido está controlado por un interruptor manual. Para los objetivos del proyecto, el interruptor manual ha sido sustituido por cuatro relés. Estos relés actúan en parejas, cuando dos de ellos son activados, se simula la pulsación del botón de “polipasto hacia arriba”, mientras que cuando la otra pareja de relés es activada, se simula la pulsación del botón de “polipasto hacia abajo”. Además, el polipasto está sujeto por una estructura diseñada para poder agarrarse a distintas superficies mediante el uso de abrazaderas

Subsistema de control: El diseño de la PCB y una Raspberry Pi son partes de este subsistema. La PCB trabaja con una ATmega328. Tiene dos entradas digitales accesibles para las señales “polipasto hacia arriba” y “polipasto hacia abajo” que vienen de la Raspberry Pi; y dos salidas digitales accesibles también que controlan el sistema de relés que activa el polipasto. También tiene pines extra accesibles en caso de que sean necesarias entradas o salidas analógicas o digitales. La Ilustración 2 y la Ilustración 3 muestran el esquema y la disposición de la PCB.

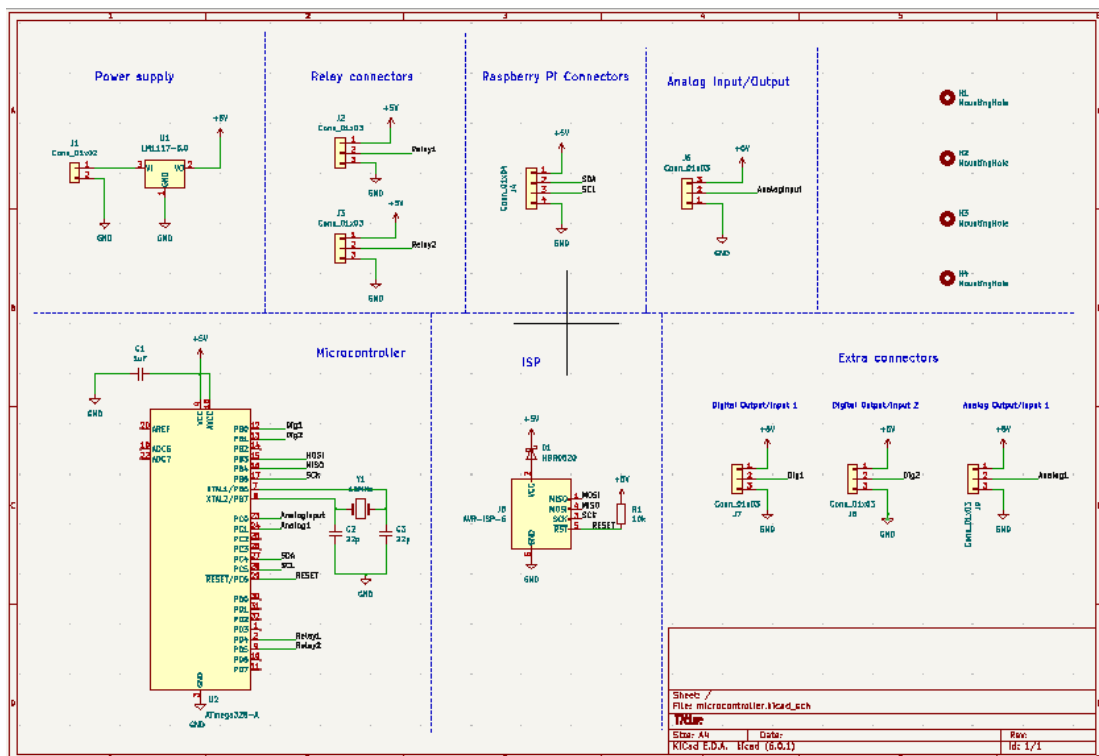


Ilustración 2: Esquema PCB

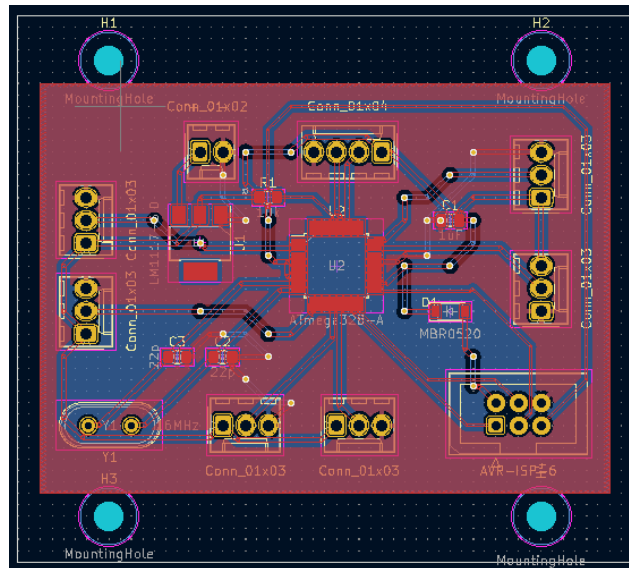


Ilustración 3: Disposición PCB

Debido a que el diseño usa un programa de Computer Vision, se usa una Raspberry Pi para procesar la información proveniente de una cámara que sigue el movimiento de la barra. La Raspberry Pi trabaja con dos señales digitales: “polipasto hacia arriba” y “polipasto hacia abajo”, que se establecen a nivel alto cuando el programa detecta que el polipasto debe activarse. Estas señales son enviadas a la PCB que se comunica con los relés permitiendo el movimiento del polipasto.

Subsistema de potencia: Este subsistema esencialmente consiste en el cargador de la Raspberry Pi, el enchufe de la pared y un elevador de nivel lógico (logic level shifter). La RPI trabaja con señales digitales de 3.3V, y el ATmega328 trabaja con señales digitales de 5V. Por este motivo, la salida de la RPI se debe conectar al level shifter para que las entradas de la PCB sean señales digitales de 5V. Asimismo, la RPI tiene pines que proporcionan voltaje de 5V, por ello el microcontrolador se alimenta directamente de esta.

Subsistema de sensores: La cámara es el único componente de este subsistema. Es una cámara especial que se conecta fácilmente a la RPI, así esta puede trabajar con el entorno capturado por la cámara usando Computer Vision.

Subsistema del usuario: Este subsistema permite al usuario colocar el gancho del polipasto en la posición deseada, introducir el número de repeticiones que se desea hacer sin y con ayuda, y ver el feedback que el programa genera sobre la ejecución del ejercicio. Se puede usar una pantalla conectada vía HDMI o un móvil conectado vía Wi-Fi a la RPI.

4. Resultados

Es importante recalcar que, a pesar de las complicaciones y los retos que este proyecto ha supuesto, los objetivos se han logrado con éxito. El diseño funciona como se esperaba.

Subsistema mecánico: La estructura de soporte es portátil y se puede agarrar a distintas superficies mediante el uso de abrazaderas. El polipasto está sujeto por esta estructura. El sistema de relés funciona correctamente. En la Ilustración 4 se muestra el subsistema mecánico de la máquina.

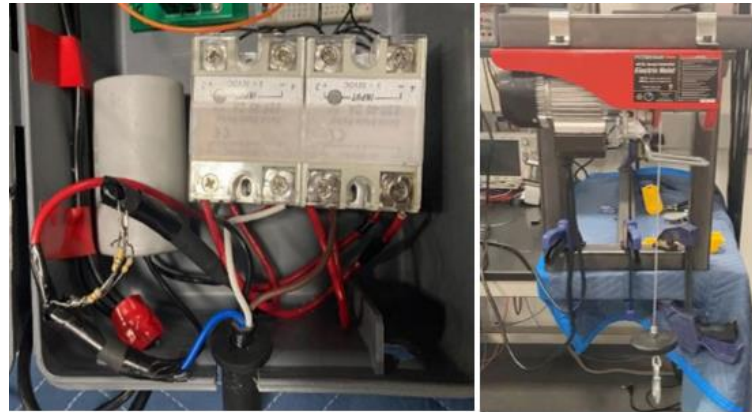


Ilustración 4: Subsistema Mecánico

Subsistema de control: La PCB funciona como se esperaba, está bien diseñada. La PCB y la RPI se comunican correctamente, las conexiones están bien hechas. Hay también dos LEDs en este subsistema para comprobar que la señal “polipasto hacia arriba” o “polipasto hacia abajo” está siendo enviada a los relés. Es útil para comprobarlo cuando el polipasto no está alimentado. La Ilustración 5 enseña una foto del subsistema de control.

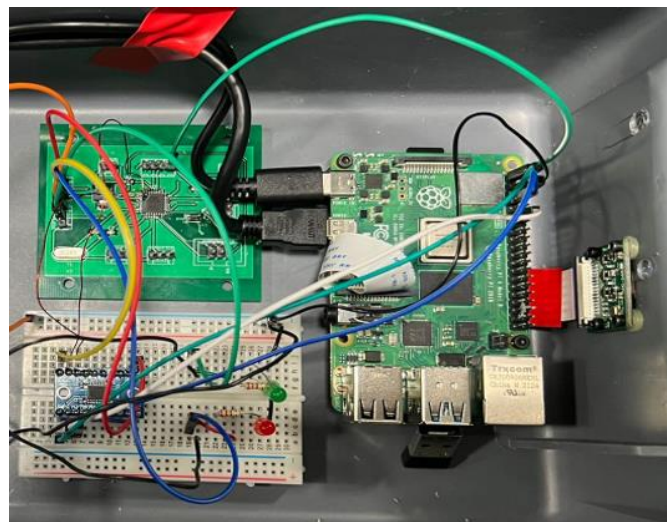


Ilustración 5: Subsistema de control

Subsistema de potencia: El level shifter de este subsistema puede apreciarse en la Ilustración 5 en el tablero de circuitos. También se puede ver la conexión directa entre PCB y RPI que es la señal de 5V que alimenta la PCB.

Subsistema de sensores: La cámara conectada directamente a la RPI es el único componente. En la Ilustración 6 se puede ver atornillada a la caja. También se puede ver lo que la cámara graba, en la manera en la que se le muestra al usuario

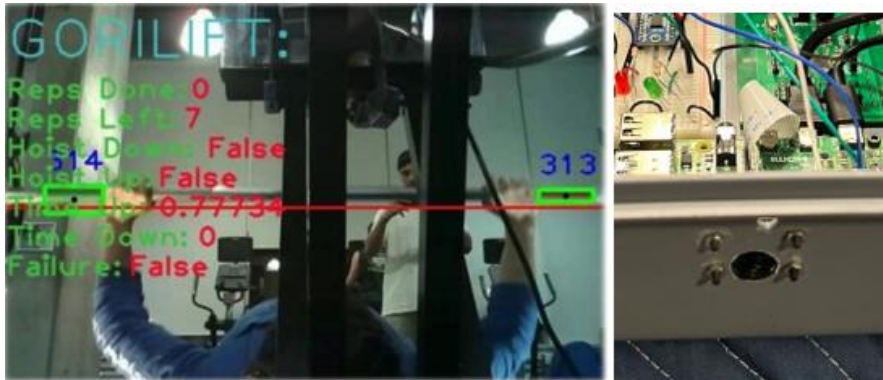


Ilustración 6: Subsistema de Sensores

Subsistema del usuario: El subsistema del usuario puede ser una pantalla o un móvil conectado a la RPI. La Ilustración 7 muestra como se ve la RPI en una pantalla o un móvil, y como puede ser controlado por el usuario.



Ilustración 7: Subsistema del Usuario

El circuito del diseño cabe en una caja cumpliendo así uno de los objetivos principales (diseño compacto). En la Ilustración 8 se puede observar el circuito dentro de la caja (en ella se conectan el subsistema mecánico con el de control y el de sensores).

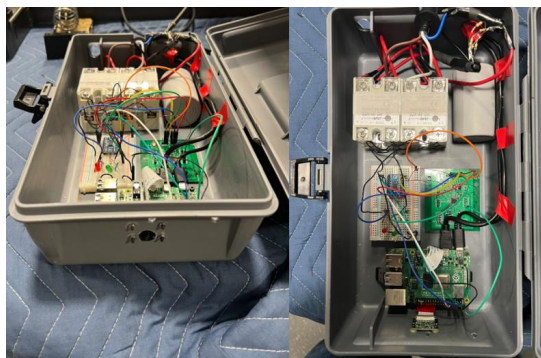


Ilustración 8: Implementación Subsistemas Mecánico, de Control y de Sensores

Una vez probada la máquina con una barra de madera, se decidió probarla en un gimnasio de verdad con mayor peso. La prueba se hizo con 95 libras (43 kilogramos) y fue un éxito. La máquina fue capaz de levantar la barra cuando era necesario sin que el usuario aportara esfuerzo. La Ilustración 9 muestra la prueba hecha en el gimnasio.



Ilustración 9: Prueba del Asistente Automático para Press Banca en Gimnasio

5. Conclusiones

Incluir asistencia automática en el mundo del fitness no es solo una posibilidad, sino también un gran avance. Los beneficios que este proyecto puede aportar en el campo del levantamiento de pesas son de un amplio rango y muy significativos. Entre estos se encuentran: la reducción de lesiones, la mejora de la ejecución del ejercicio por parte de los deportistas, el aumento de la efectividad del ejercicio y el incremento de los ingresos económicos de los gimnasios comerciales. Este diseño acaba con la necesidad del “spotter”, mientras que proporciona una ayuda más segura y consistente. Asimismo, puede ser fácilmente ajustable para ser utilizado en otros ejercicios.

6. Referencias

- [FERR21] Ferraro, Kathleen. “Bench Presses Are the Multi-Muscle Workout You've Been Missing.” Byrdie. Byrdie, October 28, 2021. Accessed May 20, 2022. [Online]. Available: <https://www.byrdie.com/bench-press-guide-5112654#:~:text=%E2%80%9CThe%20bench%20press%20involves%20virtually,to%20fitness%20instructor%20Jenny%20Leigh.>
- [SUPP11] “Suppversity EMG Series - Musculus Pectoralis Major: The Very Best Exercises for a Chiseled Chest.” SuppVersity. July 12, 2011. Accessed June 6, 2022. [Online]. Available: [https://suppversity.blogspot.com/2011/07/suppversity-emg-series-musculus.html.](https://suppversity.blogspot.com/2011/07/suppversity-emg-series-musculus.html)

BENCH PRESS SMART HELPER (HARDWARE)

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Supervisor: Fliflet, Arne.

Collaborating Entity: University of Illinois Urbana-Champaign

ABSTRACT

The aim of this project is to create an automated machine that enables the user to perform the bench press exercise in the most fruitful way possible. The machine is externally controlled, and it activates and helps the user only during the repetitions in which he/she specifies beforehand. Besides, it is able to detect failure and help the user before the expected repetition to prevent injuries. Finally, it provides feedback about some aspects of the exercise like the tilt angle of the barbell, or the time each repetition takes. Specifically, this project focuses on the hardware of the design. It includes researching, designing, and reporting on the specific hardware parts of the project. Some of them are the following: the design of the complete PCB, the implementation of the electric hoist, the control circuit, the definition and connection of the subsystems of the project, the implementation of proper voltage regulators, and the selection of the right components.

Keywords: Hardware, Automated Assistant, Bench Press, PCB, Subsystems

1. Introduction

The bench press is one of the most important exercises in the world of fitness. The person performing this exercise lies on a bench face up and proceeds to lift a weight up and down with his/her arms. The bench press engages virtually every upper body muscle to some extent [FERR21]. In addition, according to electromyography studies, the barbell bench press is the best exercise to activate all the muscles in the chest [SUPP11]. Nonetheless, executing this exercise without help may result in injuries or unproductive trainings. The lifter tends to work with less weight than he/she is capable of lifting, or he/she ends up getting injured for trying to maximize the weight without oversight.

Aiming to solve this problem, people tend to rely upon another person to perform the exercise, which is commonly called “spotter”. This person allows the weightlifter to lift more weight than they could normally do safely. However, it is not always possible to find another person available at the gym that can help the athlete execute the exercise correctly. The athlete may be training alone, or he/she might not feel confident relying on a stranger or asking a stranger for help at all.

This project aims to study and build the hardware of an automated machine that enables the user to perform the bench press exercise in the most productive way possible, without the need of a “spotter”.

2. Main goals

The high-level requirements of this project are:

- Motion Tracking: The design must be able to follow the motion of the barbell during the performance.
- Failure Detection: The system must detect when the user struggles to lift the barbell and it must activate in order to help him/her.
- Weight Reduction: The machine must be able to help the user by lifting up to 45 pounds when specified.
- User Control: The control design must be selected so that the user is able to control it through an external device (phone, computer, etc.).
- Compact Design: The circuit part of the project must fit within a box. The whole project must be portable, adjustable to different surfaces, and not too heavy so it can be easily portable.

3. Model Design

The design consists of five different subsystems that are connected to each other. The first one is the mechanical subsystem. The second one is the control subsystem, which is composed of a designed Printed Circuit Board and a Single-Board Computer. The third subsystem is the power subsystem. Then, there is the sensing subsystem and finally, the user subsystem. Fig. 1 shows the block diagram of the design.

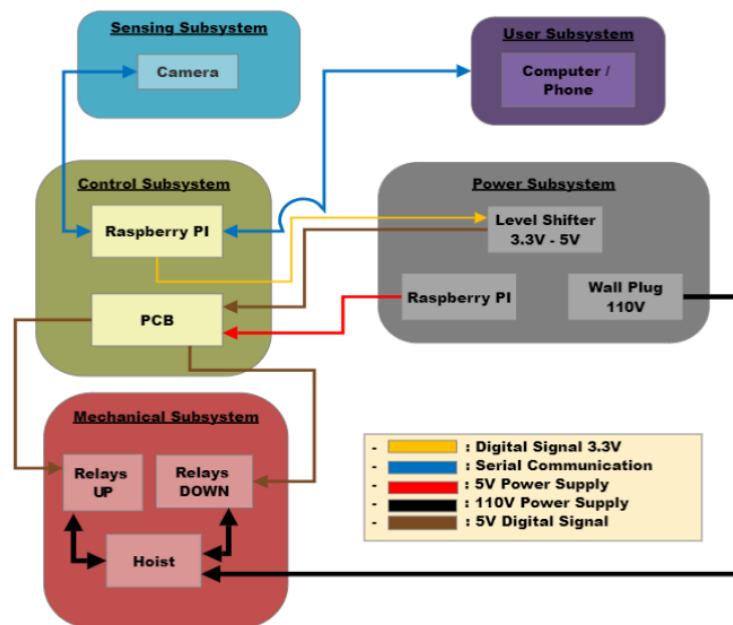


Fig. 1: Block Diagram

Mechanical subsystem: The mechanical subsystem consists of an electric hoist that can lift up to 440 pounds (200 kilograms). The electric hoist chosen is controlled by a

manual switch. For the purposes of this project, the manual switch has been replaced for four relays. This relays act in pairs, when two of them are activated, the “hoist up” button of the switch is simulated to be pressed; when the other two are activated, the “hoist down” button of the switch is simulated to be pressed. In addition, the electric hoist is held by a mounting frame designed to be attached to different surfaces by using clamps.

Control subsystem: The designed PCB and a Raspberry Pi are the parts of this subsystem. The PCB works with an ATmega328, and it has two digital inputs available for the signals “hoist up” and “hoist down” that come from the Raspberry Pi; and two digital outputs available that control the relays system that activates the hoist. In addition, it has extra pins available in case digital or analog inputs or outputs are needed. Fig. 2 and Fig. 3 show the PCB schematics and the PCB layout respectively.

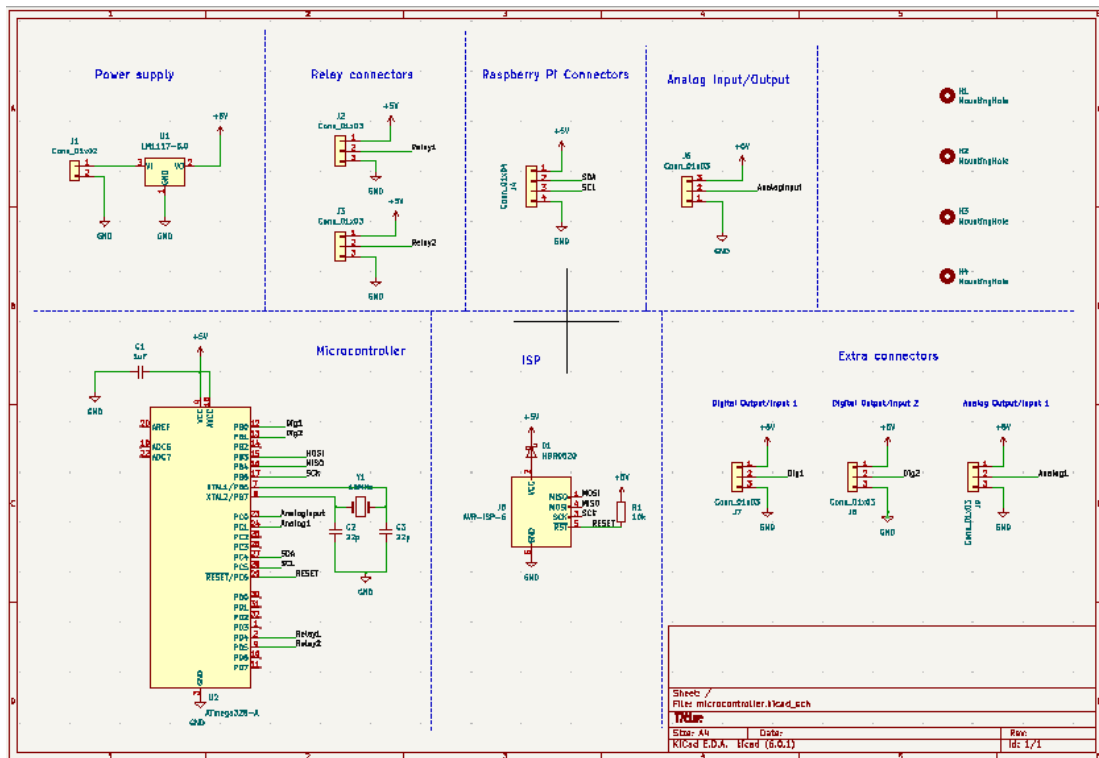


Fig. 2: PCB Schematics

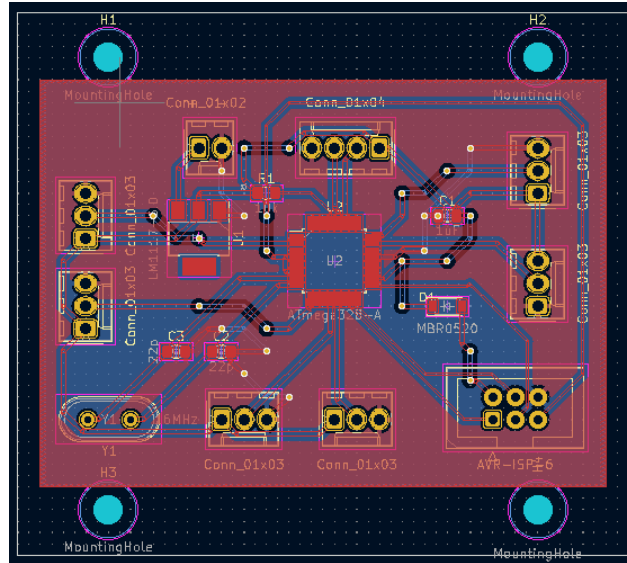


Fig. 3: PCB Layout

Since the design uses a Computer Vision program, a Raspberry Pi is used to process the information coming from a camera that tracks the movement of the barbell. The Raspberry Pi works with two signals “hoist up” and “hoist down”, that are set two high when the program detects that the hoist must be activated. These signals are sent to the PCB, that communicates with the relays system allowing the movement of the hoist.

Power subsystem: This subsystem essentially consists of the charger of the Raspberry Pi, the wall plug where the hoist is connected, and a logic level shifter. The RPI works with 3.3V digital signals, and the ATmega328 works with 5V digital signals. Therefore, the output of the RPI must be connected to the level shifter so the inputs of the PCB are 5V digital signals. Moreover, the RPI has 5V DC voltage pins, thus the microcontroller of the PCB is powered by it.

Sensing subsystem: The camera is the only component of this subsystem. It is a special camera that is easily connected to the RPI so it can work with the environment by using Computer Vision.

User Subsystem: The user interface allows the user to set the desired hoist position, input the number of repetitions to be performed with and without help, and see the visual feedback the program generates about the performance of the exercise. The device used for this subsystem can either be a screen connected through an HDMI to the RPI, or a phone connected through Wi-Fi to the RPI.

4. Results

It is important to outline that, despite the complications and challenges this project supposed, the objectives have been successfully achieved. The machine works as expected.

Mechanical subsystem: The mounting frame is portable, and it can be attached to many surfaces by using clamps. The hoist is held by this mounting frame. The relays system works correctly. In Fig. 4 there is a picture of the mechanical subsystem.

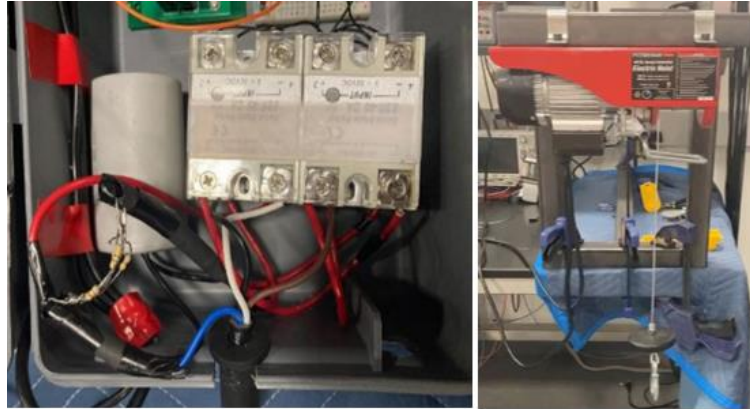


Fig. 4: Mechanical Subsystem

Control Subsystem: The PCB works as expected, it was well designed. The PCB and the RPI communicate properly, the connections are done correctly. There are also two LEDs in this subsystem to check whether the signal “hoist up” or “hoist down” is being sent to the relays. It is useful to check that the design is working when the hoist is not connected. Fig. 5 shows a picture of the control subsystem.

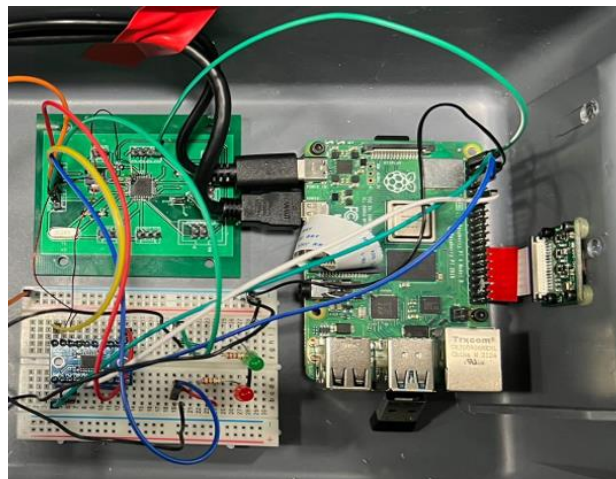


Fig. 5: Control Subsystem

Power subsystem: The logic level shifter of this subsystem can be seen in Fig. 5 in the breadboard. Moreover, the direct connection between PCB and RPI that can be seen in Fig. 5 as well is the 5V signal that powers the PCB.

Sensing subsystem: The camera directly connected to the RPI is the only component. In Fig. 6 it can be seen attached to the box. Besides, it is shown the display of what it is recording during the execution of the exercise.

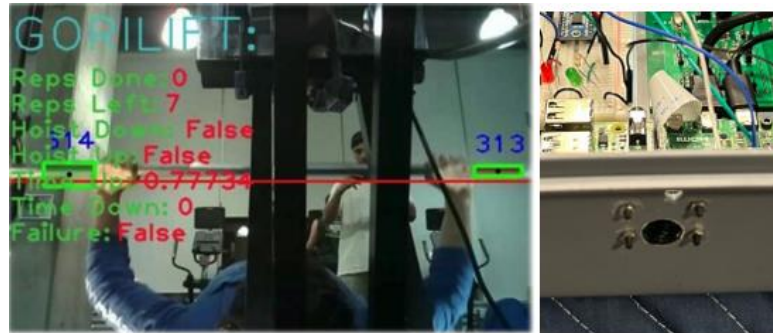


Fig. 6: Sensing Subsystem

User subsystem: The user subsystem can be either a screen or a phone connected to the RPI. In Fig. 7 there is a picture of how the RPI looks like on the screen of a computer and on the screen of a phone, and how it can be controlled by the user.



Fig. 7: User Subsystem

The circuit of the design fits in a box, which was one of the main goals of the objectives (compact design). Fig. 8 shows the implementation of the mechanical, control, and sensing subsystem fitting in the box.

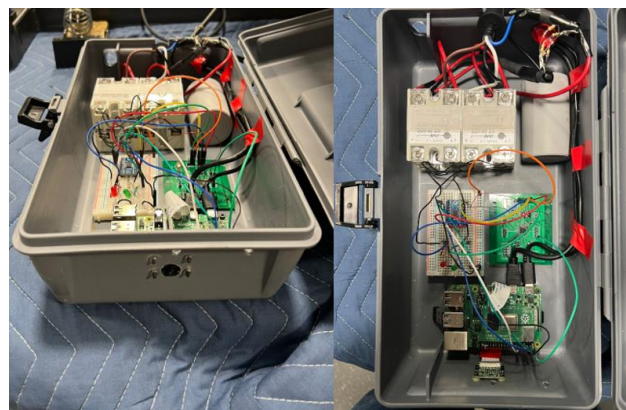


Fig. 8: Mechanical, Control, and Sensing Subsystem implementation

Once the machine was tried with a wooden barbell, it was decided to test it in a real gym with real weights. The test was done with 95 pounds, and it was a success, the machine was able to lift the barbell when required while the user was not making any effort. Fig. 9 shows the test done in the real gym.



Fig. 9: Bench Press Smart Helper in Real Gym Test

5. Conclusions

Including automated assistance in the world of fitness is not only a possibility, but also a major breakthrough. The benefits this project can provide to the powerlifting field are wide ranging and significant. Reducing injuries, improving athletes' performances, enhancing exercise effectivity, increasing economic income of commercial gyms are among these benefits. This project ends with the need of a "spotter", while it provides a safer and solid help. Furthermore, it can be easily adjusted to be used in many other exercises.

6. References

- [FERR21] Ferraro, Kathleen. "Bench Presses Are the Multi-Muscle Workout You've Been Missing." Byrdie. Byrdie, October 28, 2021. Accessed May 20, 2022. [Online]. Available: <https://www.byrdie.com/bench-press-guide-5112654#:~:text=%E2%80%9CThe%20bench%20press%20involves%20virtually,to%20fitness%20instructor%20Jenny%20Leigh.>
- [SUPP11] "Suppversity EMG Series - Musculus Pectoralis Major: The Very Best Exercises for a Chiseled Chest." SuppVersity. July 12, 2011. Accessed June 6, 2022. [Online]. Available: [https://suppversity.blogspot.com/2011/07/suppversity-emg-series-musculus.html.](https://suppversity.blogspot.com/2011/07/suppversity-emg-series-musculus.html)

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Acronyms

AC	Alternating Current
DC	Direct Current
ECEB	Electrical and Computer Engineering Building
GPIO	General Purpose Input/Output
ICAI	Instituto Católico de Artes e Industrias
PCB	Printed Circuit Board
RPI	Raspberry Pi
UIUC	Univerity of Illinois at Urbana-Champaign

PART I: PROJECT REPORT

CHAPTER 1. INTRODUCTION

In this chapter a general description of the project is given. First, the problem that the project aims to solve is explained, followed by the necessity of this problem to be solved. An explanation about how the bench press is executed is provided. Facts about the benefits of this exercise will be stated. This chapter explains what the problem is with this gym exercise. Once stated the problem with this matter, it will be easier to understand the purposes of the project. Besides, in this chapter a definition of the word “spotter” is given, which is crucial to understand the function of the design. As a matter of fact, the name of the design could be bench press smart spotter (hardware) rather than bench press smart helper (hardware).

The bench press is one of the most important exercises in the world of fitness. The person performing this exercise lies on a bench face up and proceeds to lift a weight up and down with his/her arms. Refer to Figure 1 to obtain a better understanding of the exercise.

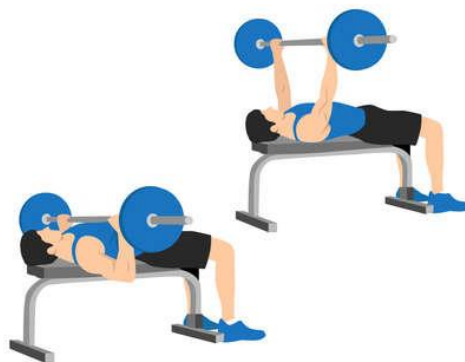


Figure 1: Barbell Bench Press [PUTR22]

The bench press engages virtually every upper body muscle to some extent [FERR21]. In addition, according to electromyography studies, the bench press with barbell (BPBB) is

the best exercise to activate all the muscles in the chest. As shown in Figure 2, no exercise can reach the effectiveness of the bench press with barbell.

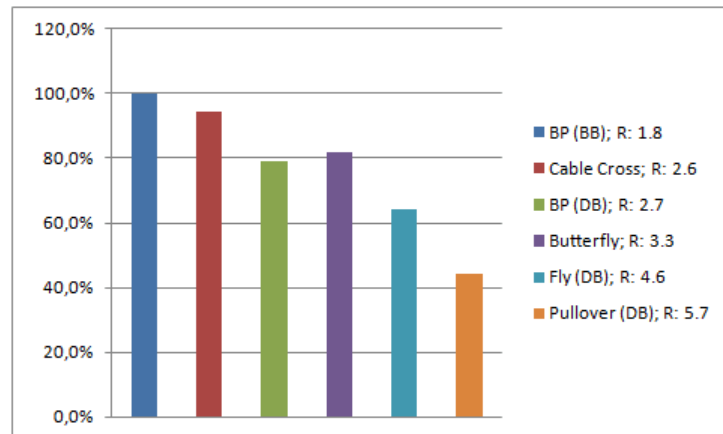


Figure 2: Degree of muscle activation compared to reference exercise barbell bench press [SUPP11]

Furthermore, the barbell bench press is one of the three exercises that are performed during a powerlifting competition, along with the squat and the deadlift [IPF_22].

1.1 PROBLEM

Performing the bench press without external help may be counterproductive and harmful for the bodybuilder. Without external help, the performer will not be able to lift the maximum weight in a safe and secure way. For this reason, the answer of the athlete to this problem will be a less productive and intense training, or a more dangerous execution of the exercise, in case he/she does not count on external help. Doing this exercise without supervision might result in many injuries. As a matter of fact, a recent study conducted over sub-elite to elite powerlifters showed that up to 46 % of their injuries were caused by the bench press [BENG2022], accounting for almost half in some athletes.

In order to solve this problem, as stated before, people tend to rely upon another person. This person is commonly called a “spotter”. A spotter is a person who supports another person during an exercise, shown in Figure 3. This person allows the weightlifter to lift more weight than they could normally do safely. However, it is not always possible to find another person available at the gym that can help the athlete execute the exercise correctly. The weightlifter may not feel comfortable asking a stranger for help, or he/she might be training completely alone. On the other hand, the person asked may not be an expert and might provide useless help while “spotting”. For many reasons, using a person as a spotter may not be the best option, or may not be an option at all.



Figure 3: Spotter for Barbell Bench Press [MCKA21]

This project consists of creating an automated machine that enables the user to perform the bench press exercise in the most fruitful way possible. The machine is externally controlled. It activates and helps the user only during the repetitions in which he/she specifies beforehand. Besides, it can detect failure and help the user before the expected repetition to prevent injuries. Finally, it provides feedback about some aspects of the exercise like the amount of weight the tilt angle of the barbell, or the time each repetition takes.

The machine has an electric hoist that lifts the barbell when specified, and a webcam that tracks the movement of the barbell. A sketch of the design is shown in Figure 4.

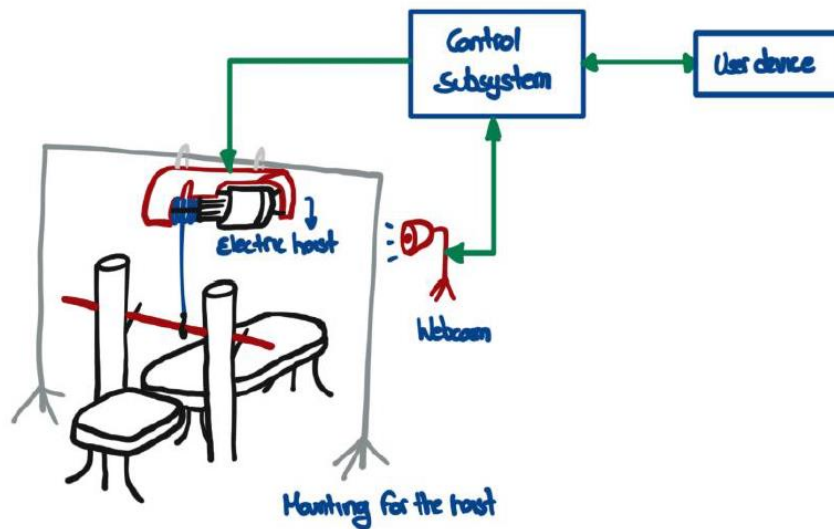


Figure 4: Physical Design

This project is focused on the hardware of the device. It includes researching, designing, and reporting on the specific hardware parts of the project. Some of them are the following: the design of the complete Printed Circuit Board (PCB), the implementation of the electric hoist, the control circuit, the definition and connection of the subsystems of the project, the design and implementation of proper voltage converters and regulators, and the selection of the right components.

CHAPTER 2. STATE OF THE ART

Today not being able to execute the barbell bench press without help is still a problem. There have been some designs that have tried to give a solution to this concern, but they are not ideal.

2.1 BENCH PRESS FEET SPOTTER

This machine, shown in Figure 5, enables the user to lift part of the weight by using his/her legs in case he/she is not able to lift it with his/her arms. The idea is similar to what this project wants to achieve. However, this “feet spotting” mechanism does not allow the user to have complete stability to perform the exercise. Moreover, it forces the user to be constantly focused on the force he is making with his/her legs, decreasing his/her possibilities of performing the exercise in the most fruitful and effective way. In addition, the user relies on himself/herself. If his/her legs fail to act as the device expects, he/she may get harmed and injured.



Figure 5: The Spotter Bench Press Self Spotting Free Weight Machine [SPOT22]

2.2 THE SMITH MACHINE

The Smith machine bench press is a machine-based movement targeting the chest. The Smith machine mimics a barbell but provides more stability. This helps because it decreases the possibility of getting injured. However, doing the exercise with this structure does not allow the user to fulfil its full muscle potential. "The Smith machine offers poor results when compared to a free-weight barbell. It is an inadequate use of stabiliser muscles and gives poor muscle recruitment." [MAJE22].

The Smith Machine also decreases the freedom of movement that the common barbell bench press provides. This can make the lifter perform the exercise in a more harmful and unnatural way. Besides, this can also make the lifter feel uncomfortable and encourage him/her to lift less weight. Figure 6 shows the Smith Machine.



Figure 6: The Smith Machine for Bench Press [DREA22]

CHAPTER 3. PROJECT DEFINITION

In this chapter, the reasons why this project has been developed are mentioned, followed by the enumeration of the different objectives of the design. Then, the work methodology followed during the process of creating the device is stated. Finally, the resources used to create the machine are listed

3.1 MOTIVATION

Since automation and smart technologies are becoming popular in different fields, the aim of this project is to bring a useful engineering application to the world of fitness. This field has become very popular in the last decades. Many people decide to choose the gym as a lifestyle. Some others decide to work out to keep in shape or in order to relieve stress. One way or another, the popularity of the world of fitness and bodybuilding is increasing rapidly.

There are many exercises at the gym that are very mechanical. Moreover, people who go to the gym want to reach effective and efficient results. For this reason, automation and smart devices can be created and adapted to obtain better results when working out. Seeking for maximizing gains and optimizing time and effort, this project aims to develop a machine that can be used for a better performance of the barbell bench press.

The bench press is an exercise where big muscles are involved. Thus, it is an activity that may result in many injuries. For this reason, bodybuilders and powerlifters usually depend on another person to help them during its execution. As mentioned before, this person is called “spotter”. The spotter helps the powerlifter to do the exercise tracking the movement of the barbell and helping him to lift it in case of failure.

The main purpose of this project is to simulate the role of the ‘spotter’ in a more sophisticated and complete way. However, unlike a real “spotter”, this system will be able

to accurately activate when the person struggles to lift the weights, follow the movement of the user, and provide feedback about different aspects of the performance. Besides, this technology allows the weightlifter to execute the exercise without relying on other person, giving him/her the opportunity to lift the weights safely and efficiently.

As this project consists of the hardware of the machine, the most effective and powerful way to accomplish this has been studied. The choice of a mechanism or tool that helps fulfil the objectives efficiently and completely has been made. A PCB with the choice of the microcontroller that better fits the specifications has been designed, and the different components needed for its proper function have been selected. It has been made the choice of the different components and their connections needed for the signals to be sent and processed correctly by using techniques such as soldering. These are some of the parts that are covered in this project, which explains all the hardware of the design.

3.2 OBJECTIVES

There are five main objectives that this project covers:

- **Motion Tracking:** The system must be able to follow the motion of the barbell within a 60 cm range and successfully track repetitions performed by the lifter. It must also be able to track and to analyze the inclination of the barbell up to a 45° degree angle.
- **Failure Detection:** The system must detect when the user is struggling to lift the weights and it must provide full help to him, lifting the barbell avoiding injuries or harmful scenarios.
- **Weight Reduction:** The design must be able to help the lifter by lifting up to 45 pounds, at least, from the barbell for him to complete the exercise successfully. The repetitions on which the lifter receives external help must be specified prior to the execution of the exercise.
- **User Control:** The system must be externally controlled. The lifter inputs the number of repetitions he wants to perform, and then he specifies on which of

those repetitions he wants help. The user must also be given feedback after the execution of the exercise.

- **Compact design:** The circuit part of the project must fit within a box. The whole project must be portable, adjustable to different surfaces, and not too heavy so it can be easily moved.

3.3 WORK METHODOLOGY

The work methodology of this project focused on finding an optimized and doable way of accomplishing the problem. Finding an option to lift the weights without interfering with the user’s performance was very important. It had to suit the budget given by the University of Illinois at Urbana-Champaign. Besides, a PCB that met the requirements was designed and used to create the product. Furthermore, the choice of the proper different components for the PCB, and any other external components were studied, analyzed, and correctly done so the functioning of the product was guaranteed. All the soldering of the PCB and any other components were done using the materials provided by the University. Once finished the soldering and debugging of the PCB and getting all the different parts of the product, the procedure was to check separately the functioning of each of them to make sure that results were as expected. Finally, the integration of the different subsystems was done, wiring the components in the proper way, and connecting the different parts together. The schedule followed during the process is shown in Table 1.

Table 1: Schedule

01/24/2022 – 02/21/2022	Analysis and study of the best way to build the product
02/21/2022 – 03/14/2022	PCB design
03/21/2022 – 04/04/2022	Getting the components and PCB soldering
03/21/2022 – 04/11/2022	Testing PCB and components
04/11/2022 – 04/25/2022	Integrating different subsystems
04/25/2022 – 05/04/2022	Preparing for final presentation

3.4 RESOURCES

- **Machine Shop:** The Machine Shop of the Electrical and Computer Engineering Building (ECEB) built the mechanical design. A sketch of the mechanical parts needed for the project was given. They constructed the mounting frame to hold the electric hoist with enough height. Thanks to that, the exercise can be done comfortably. They also elaborated a box where all the electronic hardware of the circuit is storage. They made holes in the box for the wires that need to be connected to other parts or plugs outside.
- **PCB design resources:** The software resource for the design of the PCB was KiCad. Besides, PCBWay received the design of the PCB, and they manufactured it and sent it to the UIUC.
- **ECEB Laboratory:** The Laboratory of the Electrical and Computer Engineering was available 24 hours every day of the week. There were different materials such as soldering machines, wires, computers, and heat guns.
- **Electronic component shops:** Shops that sell any type of electronic components such as Digi-key or Mouser Electronics and The ECEB Supply Centre, that had basic components and wires of different types.

CHAPTER 4. ETHICS AND SAFETY

As stated in the IEEE Code of Ethics I.1: “to hold paramount, the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to promptly disclose factors that might endanger the public or the environment” [IEEE22]. One of the main objectives of this design is to reduce the risk of injury during the exercise. Therefore, the development of a secure and safe design was a priority in the project.

According to the ACM Code of Ethics and Professional Conduct 1.3: “Honesty is an essential component of trustworthiness. A computing professional should be transparent and provide full disclosure of all pertinent system capabilities, limitations, and potential problems to the appropriate parties” [ACM_22]. Since this project involves the user’s physical integrity, there is awareness of the need to warn and report about the limitations of the product. False statements about the capabilities of the system are not consented. More specifically, information is given to the user about the maximum weight the machine can lift safely, including and considering a safety coefficient.

Finally, regarding group members and other students’ safety, the rules of the laboratory were strictly followed while working there. We always wore the required protective gear was always worn. The work was done dutifully and responsibly. Lab policies were never questioned and activities such as working alone or taking food or drinks into the lab space were never condoned.

CHAPTER 5. DECISION-MAKING

In this chapter, the different alternatives that were studied for the different parts of the project are discussed. An explanation of them is given, and an explanation on why they were discarded. First, it is stated one of the major decisions that were made, which was how to lift the barbell. Different potential alternatives were taken into consideration. Secondly, the mounting frame to hold the device that was going to lift the barbell. Thirdly, the decision of the sensors that were needed to approach the project. Then, the decision of the control subsystem that was going to be used. After that, the selection of a microcontroller that could meet all the specifications required. Finally, the possibility of creating the power converters needed for the project.

In this chapter there are only explanations of the decision-making process and the options that were ruled out. Full explanation of the decisions that were finally made and the different parts that were chosen for the project are described in Chapter 6.

5.1 BARBELL LIFTING

This was one of the hardest decisions of the project. A good choice here was important to make the product efficient, comfortable, and economically affordable. Since the demonstration at the beginning of the project was going to be with only an Olympic barbell that weighs 45 pounds, a device that were able to lift at least 45 pounds was needed.

5.1.1 PNEUMATIC SYSTEM

The first idea to solve this problem was to use a pneumatic cylinder system. The force upon the barbell would be exerted by two pneumatic cylinders, one on each end. This subsystem would be in charge of exerting the physical force on the barbell and be able to move it upwards. The decision of using this mechanism was based on a study of the

Milwaukee School of Engineering [NGO_21] Its requirements were:

- **Pneumatic Cylinders:** most commercially available pneumatic cylinders are equipped with a 20 mm bore diameter, which was more than enough for the project purposes. The one that would fit the needs of the design the most would be Double Acting Style H Cylinders.
- **Compressed Air Supply:** it would power the pneumatic cylinders. To achieve the desired force of 45 Pound-Force (which is the weight of an Olympic barbell), the pneumatic piston needs to operate under a pressure of 0.637 MPa. Most cylinders available can operate under up to 1 MPa.
- **4/3 Directional Control Valve:** in order to be able to expand, retract and keep the cylinders at a stationary position, a 4/3 Electrical Controlled DCV would meet our requirements.

The system would look something like in figure 7.

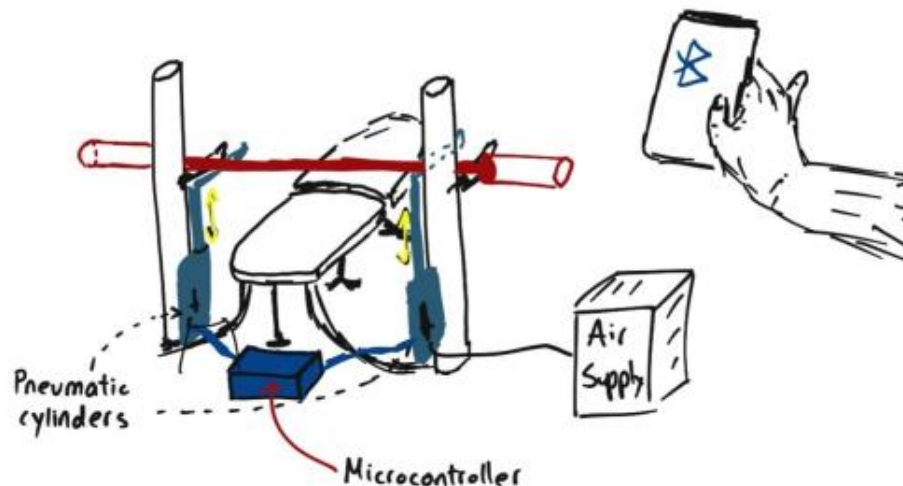


Figure 7: Physical Design with Pneumatic Cylinders

However, the thermodynamics of this device were too complex, and this design would not have been possible to be built within the time that was given by the UIUC.

Furthermore, the budget that the UIUC provided for the project was roughly 200\$. The whole system was by far out of budget, so the final decision was to discard this idea.

5.1.2 MOUNTING FRAME

A structure was needed to hold the device that was going to be used to lift the barbell. As it is explained in Chapter 6, the final decision to approach the barbell lifting issue was using an electric hoist. The structure needed to be able to hold the device and the weight of the barbell, therefore a big and solid structure was needed. The structure needed the approval of the ECEB Machine Shop since they were going to be building it.

The first idea was to use a big mounting frame with two columns, the electric hoist at the bottom of the structure, and a pulley system that could lift the barbell picking it from the two ends. Figure 8 shows a draft the first mounting frame idea.

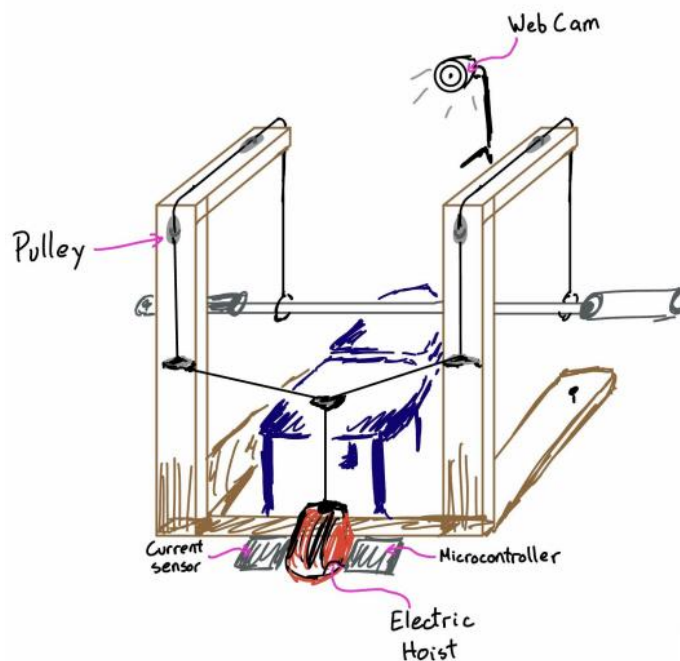


Figure 8: Mounting Frame First Approach

After having the first sketch of the structure that was intended to be built, more specifications were added to the design. Please refer to Figure 9 to see the first mounting frame that was intended to be built.

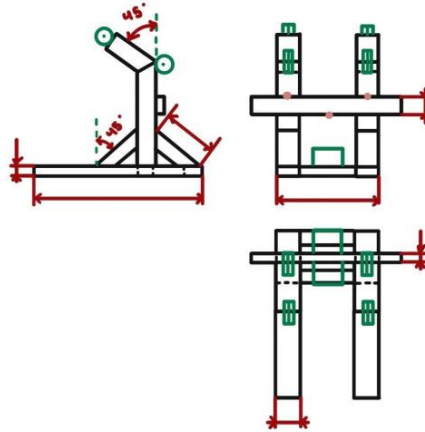


Figure 9: Mounting Frame First Approach Second Sketch

Nevertheless, this mounting frame was too big for the Machine Shop. It was too expensive too. The project was going to be developed in the ECEB Laboratory, so the structure could not be too big because it would not fit into the Lab, and it would have been impossible to work on it. Furthermore, one of the objectives of the project was to provide feedback to the user. One of the aspects that were going to be commented after the performance of the exercise was the tilt angle of the barbell. In order to provide this kind of information, the design needed to hold the barbell by the middle of it. If the barbell was held by the ends of it there would be no inclination, thus no useful information for the user about it.

5.2 SENSORS

The sensors needed to be able to serve for the purposes of the project. It was important that the microcontroller could know somehow where the barbell was. It should know if it was moving or not and if the system was supposed to help the user too.

One of the first ideas was to use distance sensors to detect where the barbell was and if it was moving. An option for this was the Sharp GP2Y0A710YK0F Long Range IR Distance Sensor shown in Figure 10. It has a working range of 100 centimeters to 550 centimeters. Since the range of movement of the barbell does not go far beyond 70 centimeters, this sensor seemed to work for the project.



Figure 10: Sharp GP2Y0A710YK0F Long Range IR Distance Sensor [SHAR06]

However, this sensor could not provide all the information that the project wanted the microcontroller to use. It could not precisely track the movement of the barbell. It was decided to rule out this option and use a camera with Computer Vision instead, which is explained in Chapter 6.

At the beginning of the project, it was also considered using a force sensor. Nonetheless, it was discarded because the force sensed by this kind of sensor would be changing much through each repetition and it would not be very useful as feedback for the user. The main purpose of this project is to help the user during the exercise by giving him/her a little bit of extra help when he/she struggles.

5.3 CONTROL SUBSYSTEM AND MICROCONTROLLER

One of the parts of this project is to be able to design a Printed Circuit Board that can be used in the demonstration of the design. For this reason, it was mandatory to include an original PCB designed and soldered for the main purposes of the project.

In order to choose the microcontroller properly, it was important to know the kind of sensors that were going to be used.

The first idea was to use the ATTiny85 since it was simple and easy to program. The only problem was that it does not have many pins as it can be seen in Figure 11, so it was discarded soon.

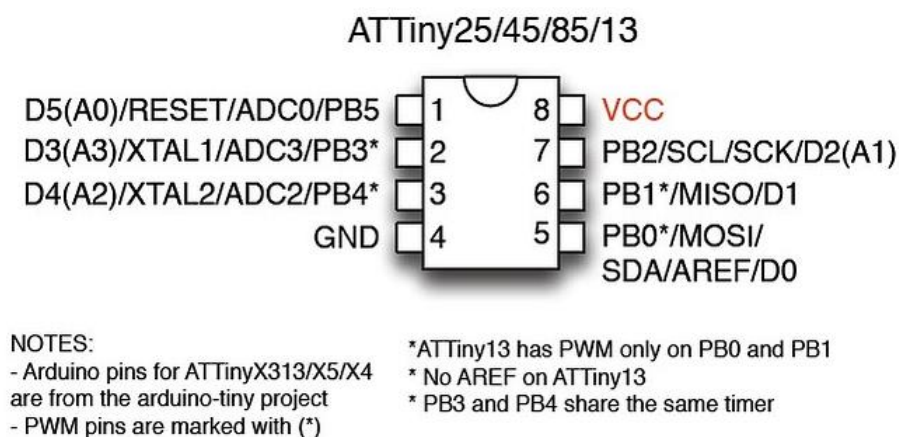


Figure 11: ATTiny pinout [ARDU13]

The second option that was discussed was the ATmega328 which is the microcontroller commonly used in Arduino. More information about this microcontroller is given in Chapter 6.

Even though the microcontroller was chosen, it was not able to work with Computer Vision. For this reason, it was important to find a way of processing the information given by a camera that was going to be tracking the barbell during the exercise. After researching, it was concluded that using Computer Vision in Python was the most effective way of approaching this. In order to use this library and this programming language, it was decided that a Single-Board Computer was needed. In Chapter 6 this is explained in more detail.

5.4 POWER CONVERTER

The ATmega328 works with 5V. Because of this, it was intended to create a power converter for the purposes of the project. The power converter would be an AC to DC converter that will have an input of 110V AC from the wall plug and an output of 5V DC to supply power to the PCB.

The 110V AC coming from the wall plug would go through a transformer that would turn them into approximately 11V AC. After this, this 11V AC signal would go through a rectifier giving a DC signal. This DC signal would go through a voltage regulator, connected properly to two 0.1 μ F. The output signal of the AC to DC converter would be 5V. There is a screenshot of the schematics of the AC to DC converter in Figure 12.

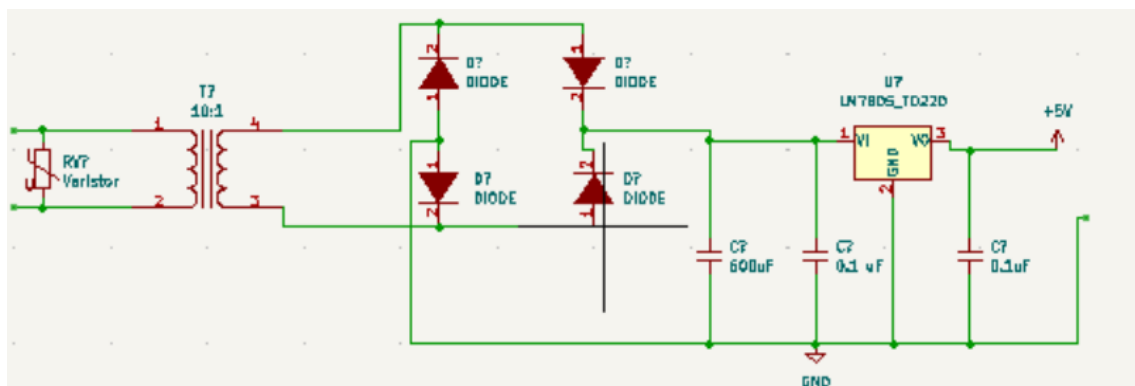


Figure 12: AC to DC Converter Schematics

Once the converter was designed, it was important to know if it was given the expected results. In order to check if the circuit was properly designed, a simulation in LTSpice was done.

Figure 13 shows the circuit in LTSpice, and Figure 14 shows the results of the simulation. The 110V AC input signal is not provided in the plot to make the other signals easier to read. However, the output of the transformer is plotted, which is the green signal. It is also plotted the output of the rectifier which is the purple signal. Finally, the 5V DC

voltage of the output of the complete AC to DC converter is plotted as well and it is the red signal.

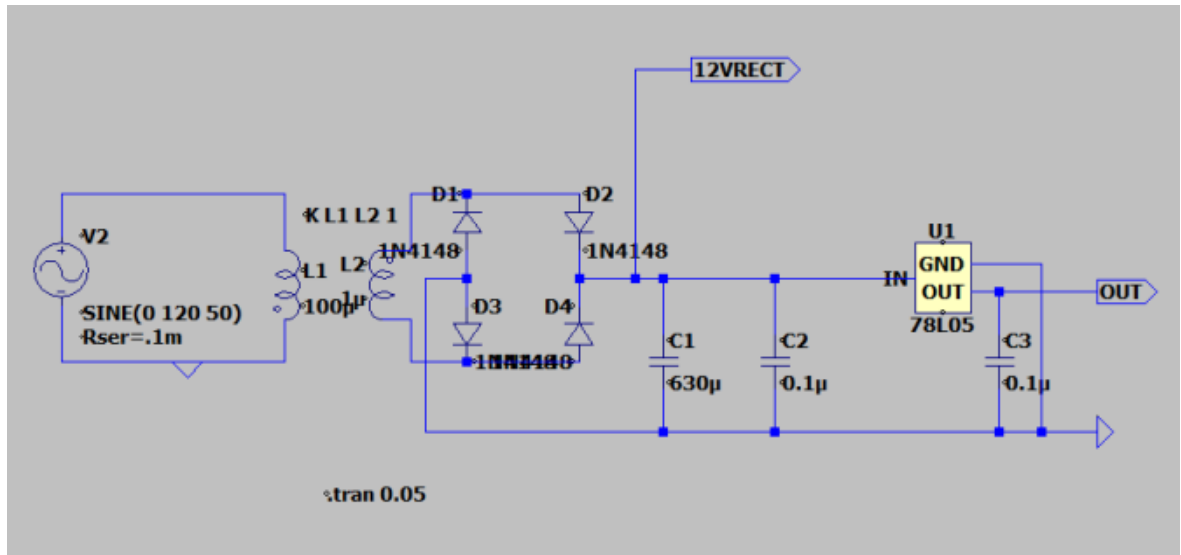


Figure 13: AC to DC Converter LTSpice Schematics

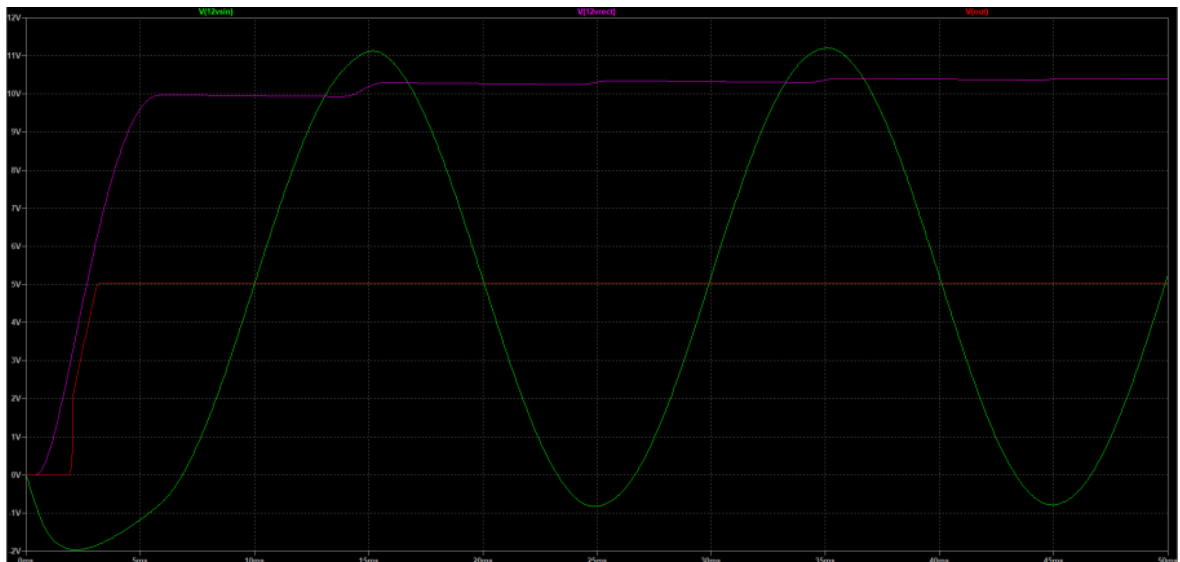


Figure 14: AC to DC Converter Simulation Results

Despite the intention of physically building the AC to DC converter, it was suggested not to do so since it was going to make the project cost more expensive, and more importantly, because the time for the project was limited.

CHAPTER 6. HARDWARE DESIGN

In this chapter every different subsystem of the project is explained. Every part and every component that was used in the design is mentioned. The function each part performs is described and the reason why each component was chosen is given.

The design consists of five different subsystems that communicate with each other. The first one is the mechanical subsystem which involves all the mechanical parts of the project. The mechanical subsystem consists of an electric hoist that is capable of lifting the weight in case of failure; a mounting frame that holds the electric hoist; and a relay system that allows the connection between the electric hoist and the control subsystem. The second one is the control subsystem that takes care of the logic of the machine. This subsystem is in charge of getting the information, processing it, and giving an answer to other subsystems. This subsystem consists of the PCB designed specifically for this project; and a Single-Board Computer that was needed to run the Computer Vision program, more specifically, a Raspberry Pi. The third one is the power subsystem. This subsystem, as its name suggests, provides power to the different parts of the different subsystems of the project. In this subsystem is included the wall plug that provides 110V that power the electric hoist and the Raspberry Pi; the Raspberry Pi since some of its pins provide a 5V signal that is used to power the microcontroller of the PCB; and a level shifter that connects the outputs of the Raspberry Pi to the inputs of the microcontroller. Then, there is the sensing subsystem, which gets the information from the environment, and it sends it to the control subsystem so it can be processed. This subsystem consists of a camera that is directly connected to the Raspberry Pi. Finally, there is the user subsystem, that is the one the user can control to set the kind of help he/she wants and to get the feedback from the control subsystem. It allows the communication between user and the automated assistant. This user subsystem can either be a computer, a screen with a mouse and a keyboard, or a smartphone.

Figure 15 shows the block diagram of the projects. The different subsystems with their different parts are displayed. The subsystems are displayed in different colors so they can be easily identified. Moreover, the connections between the subsystems are represented with arrows. The arrows represent electric signals. The kind of signal each color represents can be seen in the legend.

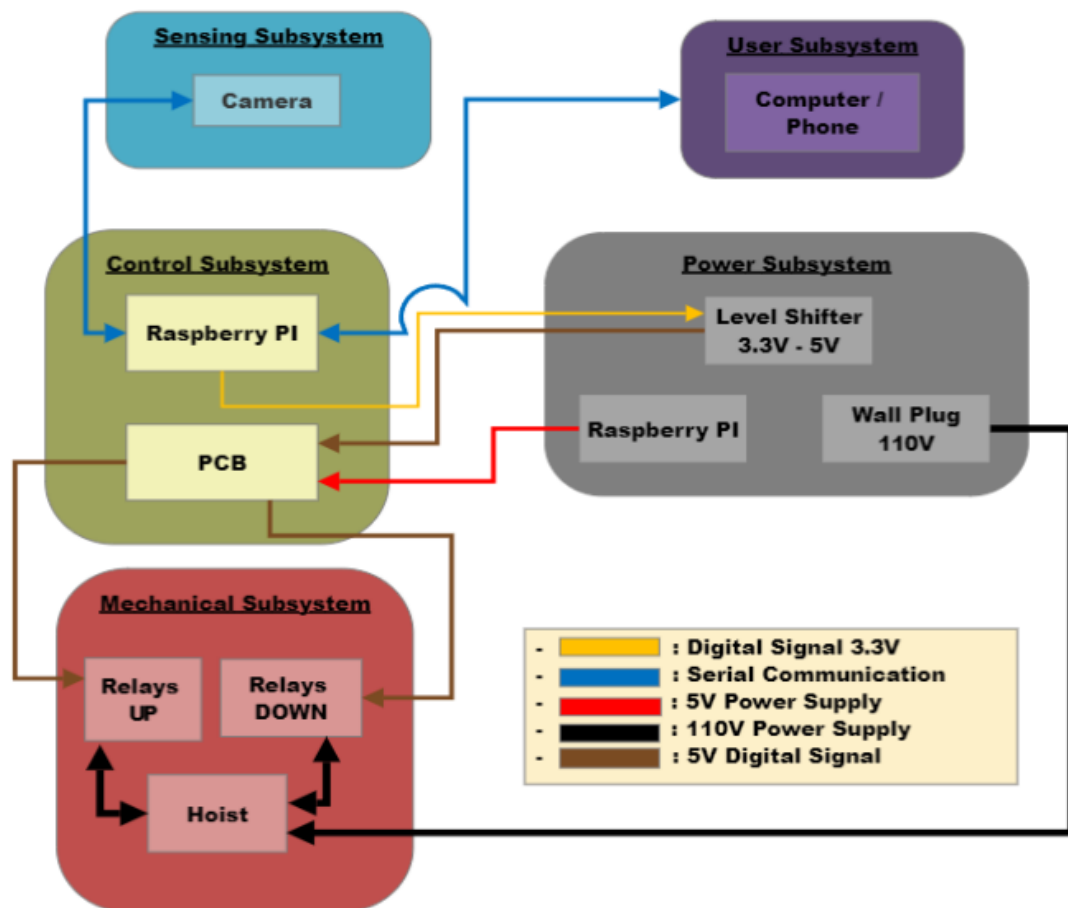


Figure 15: Block Diagram

6.1 MECHANICAL SUBSYSTEM

The decisions related to this subsystem were some of the most important ones of the project. A device capable of lifting a good amount of weight vertically without interfering with the user's performance was needed. Besides, a mounting frame that was not too big was necessary so demonstrations could be done in the Lab.

The first thought was a pneumatic system, as mentioned in Chapter 5. However, this pneumatic system was out of the budget by far, so this idea was ruled out. After this, another alternative came up. It was decided that a motor with enough power to lift the barbell was a feasible option. After researching for a while, it was settled that an electric hoist could fulfil the requirements needed to achieve the project goals.

Another further point for this subsystem was the choice of a proper mounting frame that could hold the weight of the barbell and the electric hoist. The first idea was too big, and the Machine Shop suggested not to go for it. Finally, a smaller and less heavy mounting frame was selected.

6.1.1 ELECTRIC HOIST

An electric hoist is a type of equipment that is powered by a motor and positioned overhead. This equipment usually has a hook to grab the product that is going to be moved. The movement of the hook powered by the motor is either an upward movement or a downward movement. This had great potential for the project since it was able to lift heavy things up and down.

Since the budget was limited, the final decision was to use the 440Lb Electric Hoist with Remote Control from Pittsburgh Automotive. This electric hoist is able to lift up to 440 pounds (200 kilograms) if it is connected in double line, and it is able to lift up to 220 pounds (100 kilograms) if it is connected in single line. At the beginning, the design was supposed to be able to lift at least 45 pounds which is the weight of an Olympic barbell without additional weights. The hoist is able not only to lift the weight of an Olympic

barbell, but to lift the amount of weight that an average elite powerlifter can lift if it is connected in double line, as shown in Figure 16.

Strength Level	Weight
Beginner	103 lb
Novice	154 lb
Intermediate	217 lb
Advanced	291 lb
Elite	372 lb

Figure 16: Male Bench Press Standards [STRE22]

This electric hoist was more than suitable for the purposes of the project. It provided better results than the ones expected at the beginning. The 440Lb Electric Hoist with Remote Control from Pittsburgh Automotive is shown in Figure 17.

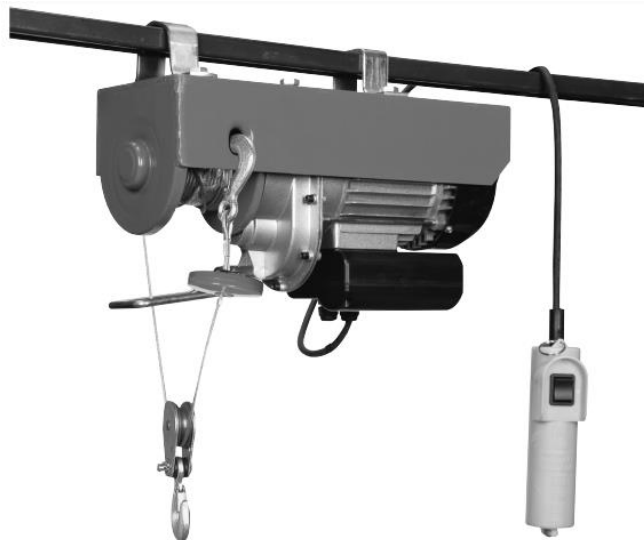


Figure 17: 440Lb Electric Hoist with Remote Control from Pittsburgh Automotive [HARB22]

The specifications of the electric hoist are shown in Table 2.

Table 2: Electric Hoist specifications

Electrical Rating	120VAC / 60Hz / 4.5A
Rated Capacity	440 lb. double line / 220 lb. single line
Lifting Speed	26 FPM (single); 13 FPM (double)
Cable Length	39'
Cable Diameter	0.12''(3mm)
Duty Cycle	20%

The electric hoist is controlled by a remote control that can be seen in the picture. It has a switch that can be pressed up, which makes the hoist move the hook upwards; or down, which make the hoist move the hook downwards. For the purposes of the project, the remote control needed to be removed. The aim of this system was to control the movement of the hoist with a microcontroller. It had to be turned into an automated electric hoist. In order to do that, it was important to know the connections of the manual switch. Having this information, the manual switch could be substituted by a relays system or a contactors system. The connections of the switch are presented in Figure 18.

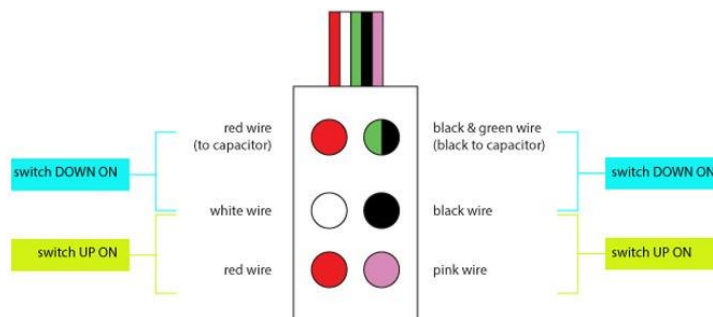


Figure 18: Manual Switch Connections [CHUC17a]

Once knowing the wire connections that made the hoist move up and down, the connections were simulated by a relays system. This could be easily controlled with the microcontroller.

6.1.2 SOLID STATE RELAYS SYSTEM

The relays that were used for this project were the Solid-State Relays SSR-40 DA, shown in Figure 19. These relays have a control voltage of 24-380V AC and an input voltage of 3-32V DC. The output digital signals of the ATmega328 provide 5V DC voltage, therefore these relays were suitable for the microcontroller. Moreover, the electric hoist works with 120V AC, which is within the control voltage of the relays, so they were appropriate for it as well.



Figure 19: Solid-State Relay SSR-40 DA [OPEN22]

So as to change the manual switch for the relays system, it was important to notice that there was a capacitor connected to the electric hoist that was inside the manual switch case. It was a 60uF capacitor, so it was important for it to be discharged before changing the direction of the movement of the electric hoist. When it was connected to the manual switch, the capacitor was discharged by the contact with the switch button. Nonetheless, it needed a resistor to be discharged without the manual switch. This resistor was connected in parallel with the capacitor creating a RC circuit. Once the hoist was disconnected from the wall plug, the capacitor would start discharging through the resistor. A 200k Ω resistor was used at first. A schematic of the circuit with the resistor in parallel with the capacitor, the connections between the relays and the wires of the hoist, and the connections between

the relays and the microcontroller are shown in Figure 20. The blue wire and the yellow wire are connected to two digital output pins of the ATmega328. Although the manual switch is displayed in the schematics, it was completely removed for the final design since it served no purpose.

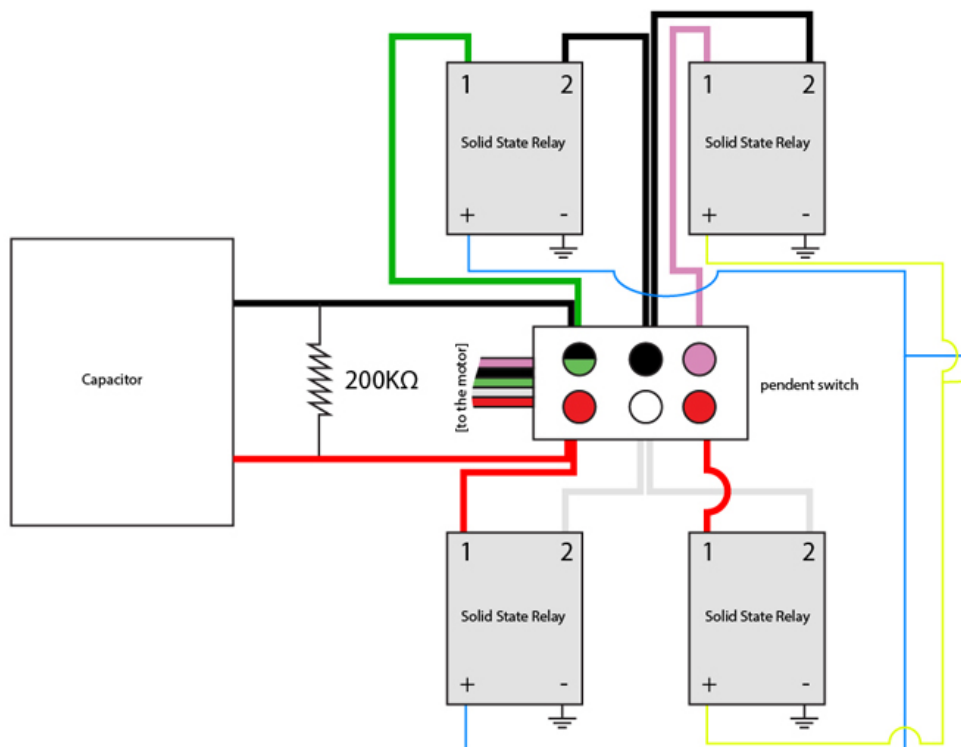


Figure 20: Relays System Circuit [CHUC17b]

The connections between the relays system and the motor wires were done by soldering wires and following the schematics. Given that there was not a 200kΩ resistor, two 100kΩ resistors were placed in series, in parallel with the capacitor. It was proved that the relays system was properly working by running a simple code that sent a digital 5V DC signal to the two relays that were supposed to move the hoist up. Then another signal was sent to the other two relays, that were supposed to move the hoist down. This was done without powering the electric hoist, so it could be proved that the relays were connected as they should. Each Solid-State Relay has an LED that turns on when it is receiving power. After testing the relays system, the electric hoist was powered. The code was supposed to

move down the hook of the hoist for 2 seconds, then wait 2 seconds, and move it up for 2 seconds again. A problem was encountered while doing the test; the hoist was not able to change the direction. Another test was run with a waiting time of 8 seconds, and it worked. It was noticed that the problem was coming from the capacitor discharge, it was not fast enough, therefore it did not let the motor change the direction that fast. One of the objectives of the project was to allow the user to execute several repetitions with the help of the hoist along the performance. With a view to do so, the waiting time needed to be reduced from 8 seconds to 1.5 seconds, which is the time a person waits before starting a new repetition. The solution to this matter was to add three 100k Ω resistors in series, so the equivalent resistor of the RC circuit was smaller, and therefore the time constant was not too big either. When running the test with a waiting time of 1 second, the hoist was able to change its direction with no issue. The relays system connections and the resistors in parallel with the capacitor (gray cylinder) are shown in Figure 21.

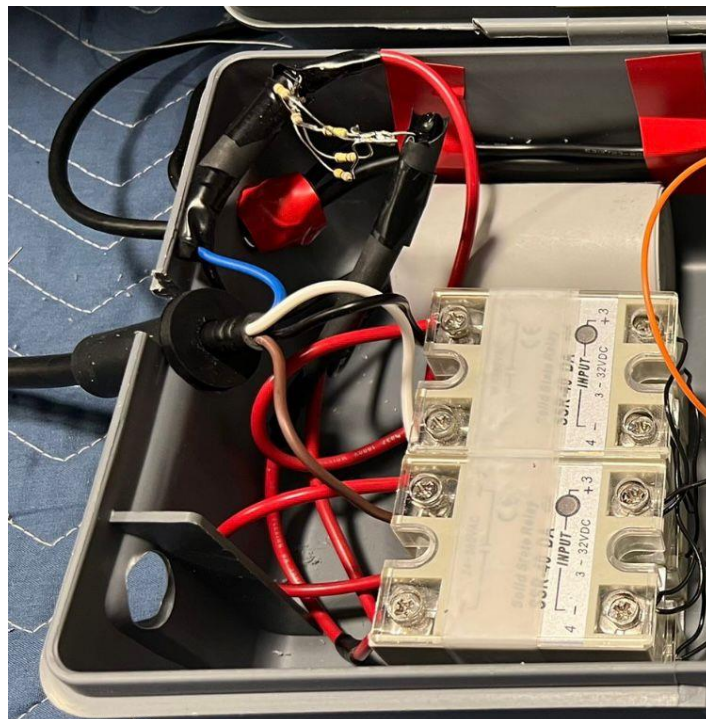


Figure 21: Relays System connections

6.1.3 MOUNTING FRAME

The mounting frame was built by the ECEB Machine Shop. A few ideas were ruled out by the Machine Shop due to lack of space in the ECEB Lab, as mentioned in Chapter 5. It was decided finally to create a structure that could be attached to the Lab desks, holding the hoist from above and allowing a person to test the prototype lying on the floor or on a short bench. This structure could be portable so it could be taken to a normal gym for a further demonstration. The sketch of the mounting frame in Autodesk Fusion 360 is provided in Figure 22.

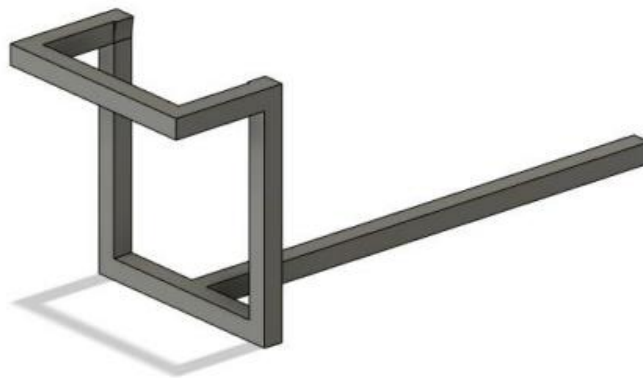


Figure 22: Mounting Frame CAD Design

6.2 CONTROL SUBSYSTEM

The control subsystem was the most important part of the project. Designing a PCB specifically for this project was compulsory. In order to do so, a microcontroller that met all the requirements was needed. After discarding some options, it was decided that the most effective microcontroller for the purposes of the project was the ATmega328. It is one of the most documented microcontrollers in the market. Besides, due to the lack of microcontrollers in stock, it was a good option because it is the one used in many Arduinos. In case it was not found in stock, it was possible to unsolder it from an Arduino

and solder it to the PCB. It also has many output and input pins so it can work with many different signals.

Another important decision taken regarding this subsystem was the need of a Single-Board Computer. The software of the project was mostly going to be programmed in Python, using Computer Vision libraries. This was a very hard task for the PCB, many microcontrollers could not run this type of programs, while a Single-Board Computer could work with it easily. Furthermore, the Single-Board Computer could take the information given by the camera, process it, and send answers to the PCB, so the PCB could communicate with the electric hoist. The Single-Board Computer selected was the Raspberry Pi. It is one of the most common Single-Board Computers. As a matter of fact, it is very common to work with it when doing projects with Computer Vision. In addition to this, it could easily communicate with the ATmega328. Therefore, it was ideal for this project.

6.2.1 PRINTED CIRCUIT BOARD (PCB)

As mentioned before, one of the biggest challenges of the project was to learn how to design a PCB. The PCB was designed by using KiCad. The first significant decision was the choice of the microcontroller. As stated earlier, the microcontroller chosen was the ATmega328 due to its properties and amount of information on the Internet. The ATmega328 works with 5V, which was important for the choice of voltage regulators. Providing greater voltage to the microcontroller would have burnt it and it would have been necessary to replace it. It was important to study the different pins of the microcontroller, so it was possible to make accessible the ones that were going to be used.

It was significant to know all the pins that needed to be connected to different components such as resistors, capacitors, or oscillators. Moreover, it was necessary to be aware of the pins that were used to power the microcontroller or to connect the ground of it. It was also essential to be informed about the pins that were going to be used to burn the bootloader and run the program on the PCB. Furthermore, it was necessary to know the

pins that were going to be used as digital outputs or inputs for the purposes of the project. The ATmega328 pinout is displayed in Figure 23.

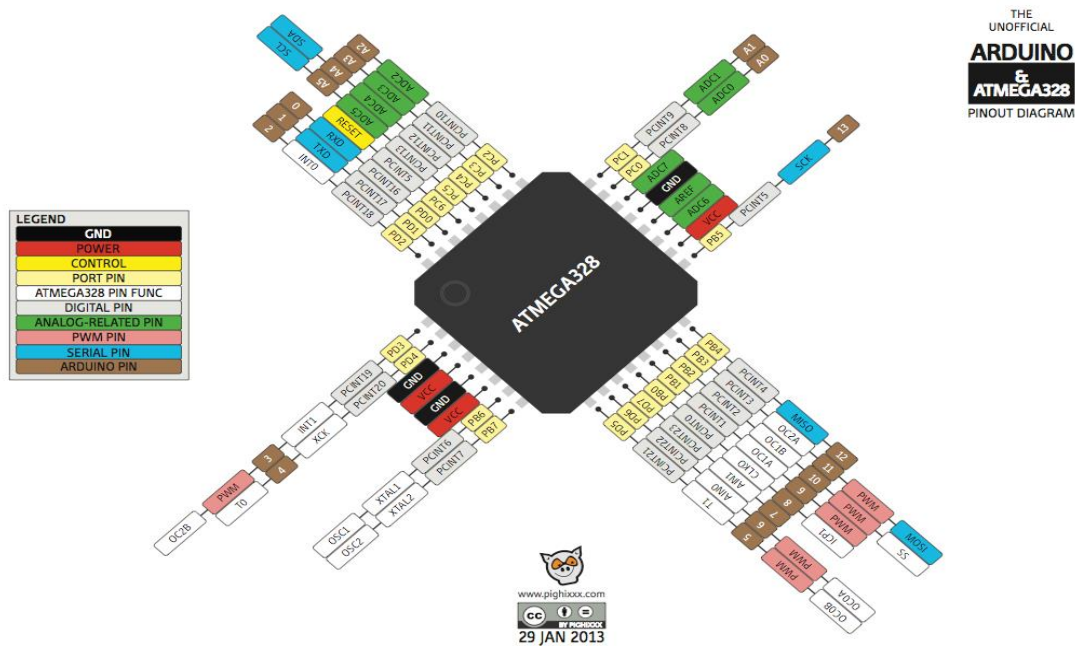


Figure 23: ATMega328 Pinout [ZENS18]

6.2.1.1 PCB Schematics

The first designed part of the PCB was the microcontroller. The first thing that needed to be done was to choose a proper model of ATmega328. The ATmega328-A was chosen for this design. After this, the microcontroller Vcc pin was connected to a 5V label. This would be the power pin of the microcontroller. Moreover, the ground pin of the ATmega328 was connected to the ground label. The XTAL1 and XTAL2 pins were connected to the 16MHz external oscillator, that was at the same time connected to two 22pF capacitors in parallel. This oscillator provides a clock signal to the microcontroller. In order to program the microcontroller, an ISP Programmer was used. It was crucial to label the pins of the ATmega328 that were going to be used for this function. The PB3 pin is the MOSI (Master Output Slave Input) which sends the information from the microcontroller to the programmer. The PB4 pin is the MISO (Master Input Slave Output) which receives information from the programmer. The PB5 is the SCK (Serial Clock)

which sets the speed each bit is transmitted. The last pin that had to be connected to the ISP Programmer was the PC6 that is the RESET pin.

A display in the PCB was necessary to connect the ISP Programmer. Furthermore, it needed to be connected to the labels that were connected to the microcontroller pins. The ISP programmer has six pins: MOSI, MISO, SCK, RESET, Ground, and 5V. The RESET pin was connected to a 5V signal through a 10kΩ pull up resistor. The schematics of the microcontroller and the ISP are provided in Figure 24.

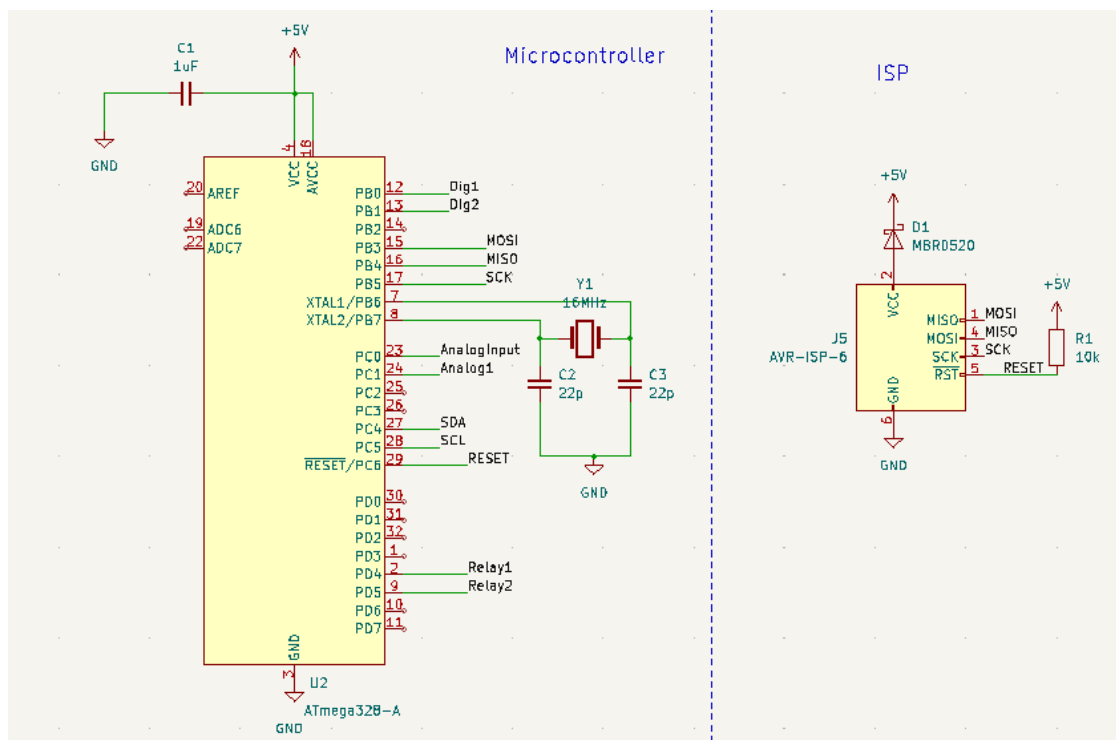


Figure 24: PCB ATmega328 and ISP Schematics

To power the PCB a voltage regulator was used since the Lab provided a 12V power unit that, connected to the wall plug, provided a 12V DC voltage. The ATmega328 works with 5V DC, therefore this 12V signal had to be regulated to 5V. A LM1117-5.0 voltage regulator was used for this aim.

Further to this, some pins that were useful for receiving the input signals and providing the proper output signals had to be on the schematics of the PCB too. It was

critical to have two pins as outputs for the relays system. One of the outputs would activate two of the relays, that would simulate pressing the up button of the manual switch, and it would move the hoist upwards. On the other hand, the other output would activate the other two relays, so the hoist would move downwards. These two outputs are digital signals. They provide a 5V DC signals when they are True and 0V if they are False. The pins used for this matter were the PD4 and PD5. Besides, there was the need of having two digital inputs displayed on the PCB schematics so the microcontroller could know when the Raspberry Pi was sending the information that the hoist needed to move either up or down, depending on the information taken by the camera and processed by the Computer Vision program. The pins that were used were the SCL and SDA pins, in case I2C communication with the Raspberry Pi was needed. All the input/output pins were accompanied by a 5V pin and a ground pin, in case they were needed for the relays, the Raspberry Pi, or any other component. The regulator, the two digital output pins for the relays, and the two digital input pins for the Raspberry Pi are shown in Figure 25.

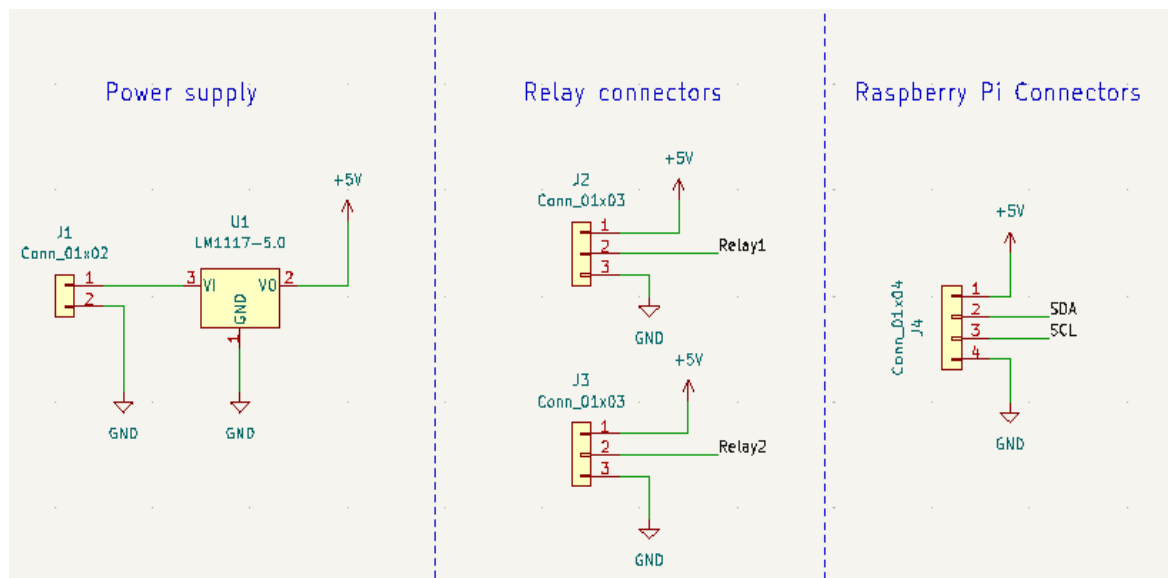


Figure 25: PCB Power Supply and Input/Output Pins Schematics

Finally, to complete the design of the PCB, some extra pins were made accessible in case it was necessary to use them in the future. Two analog output/input pins and two

digital output/input pins were labelled. In addition, four mounting holes were added so it could be screwed later. The extra pins and the mounting holes are shown in Figure 26.

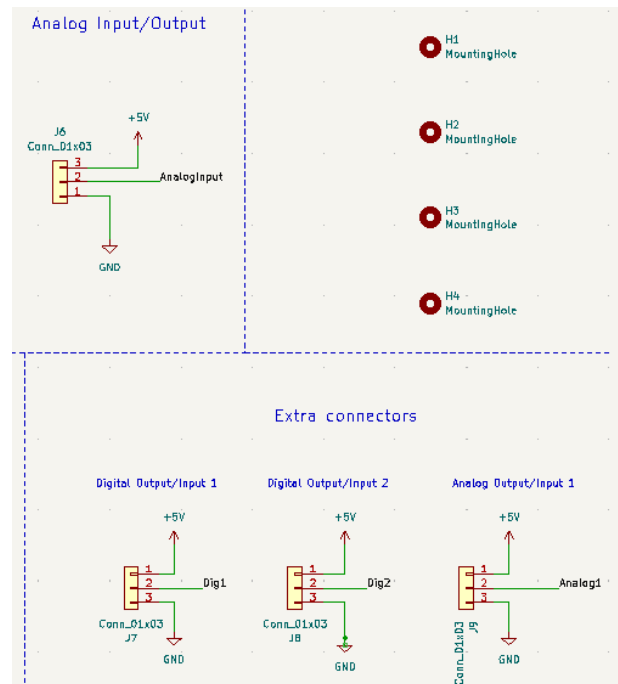


Figure 26: PCB Extra Pins and Mounting Holes Schematics

6.2.1.2 PCB Layout

Once having all the schematics of the PCB designed, it was time to associate PCB footprints to schematics symbols. This was required to continue with the layout of the PCB. The display of the different components of the PCB was important in order to have an efficient and clear layout. It was a good idea to have the microcontroller in the middle since it was the one with more connections. Then, placing the different components close to the pins of the ATmega328 to which they were connected would avoid having too many crossed wires. The manufacturer (PCB) only allowed the students to design two layer PCB, thus only two wires could be crossed at a time. For this reason, it was important to have a very clear and efficient distribution of the components before wiring. It was also possible to create one layer for the ground. However, this only connected the pins that went all the way through the board (holes); the other ground pins such the ones connected to the

capacitors, resistors, regulators, or the microcontroller needed to be wired as any other pin. The PCB layout designed for this project is presented in Figure 27.

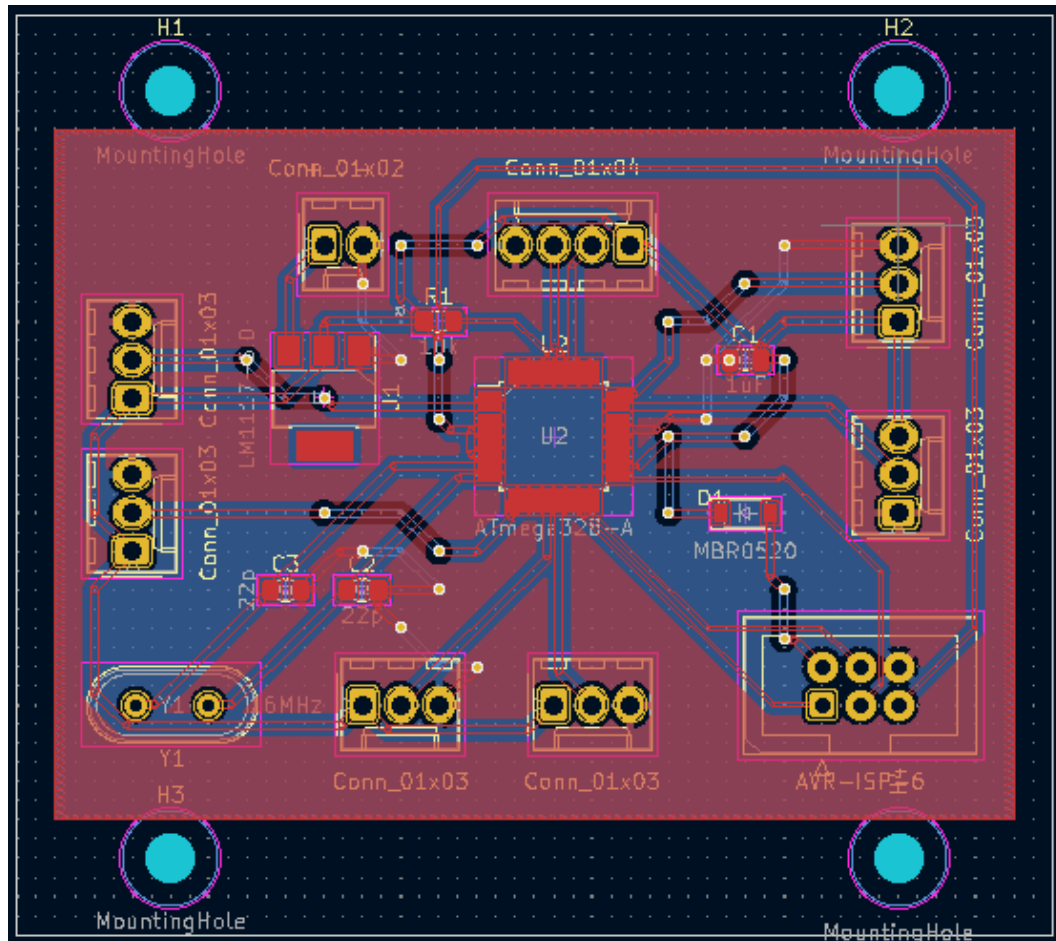


Figure 27: PCB Layout

6.2.1.3 PCB Soldering

As mentioned before, the files of the PCB from KiCad were sent to PCBWay so a supervisor could check if everything was okay and send it to the manufacturer in China. The PCB was manufactured by this company, and it was sent to the ECEB Lab. Once the PCB was being manufactured, the different components needed (specified in the schematics) were ordered so they could be soldered as soon as the PCB arrived. Figure 28 shows a picture of the PCB when it arrived to the ECEB Lab before soldering any

component. On the other hand, Figure 29 shows a picture of the PCB almost completely soldered, without the two 22pF capacitors and the six-pin header that was used for connecting the PCB to the ISP Programmer.

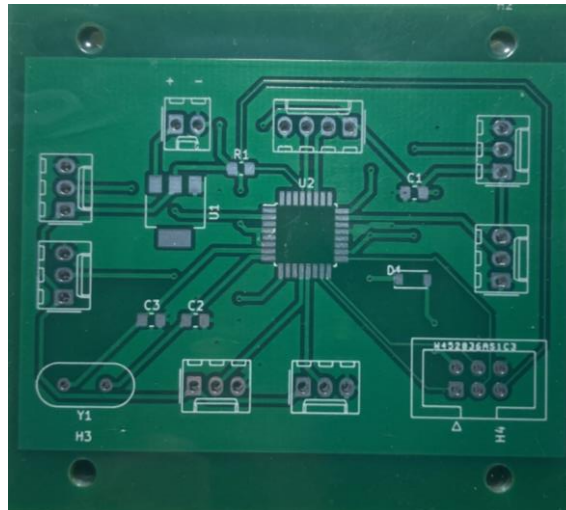


Figure 28: PCB Before Soldering

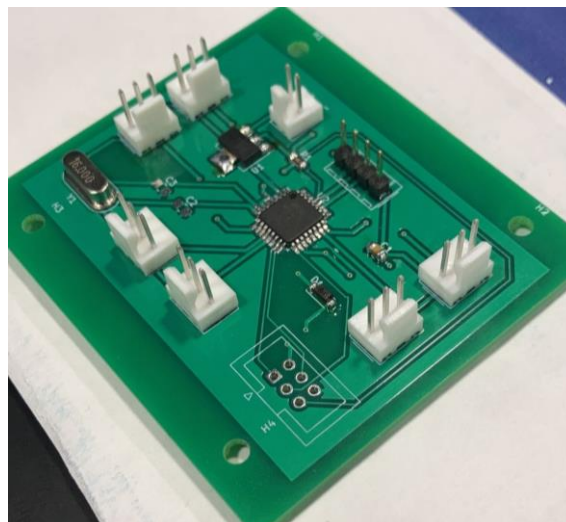


Figure 29: PCB Soldered

6.2.2 RASPBERRY PI

As mentioned earlier in the paper, the best way to accomplish the goals of the project was developing a program in Python by using Computer Vision. Therefore, using a Single-Board Computer that could communicate with the PCB was a feasible solution. The decision was to use a Raspberry Pi since it is very well documented and there are many applications where Computer Vision is used nowadays. The Raspberry Pi is a Single-Board Computer that runs Python. It also provides a set of GPIO (general purpose input/output) pins, allowing the user to control electronic components for multiple purposes. The Raspberry Pi would receive information about the position of the barbell thanks to the camera and it would process it. Depending on the specifications, it would send a digital signal to the PCB to make the microcontroller send a signal to the hoist to move the hook up or down.

The only model that was found in Stock when the project was being designed was the Raspberry Pi Model 4B 2GB, which was more than enough for the aim of this project. It was also ordered the RPI USB-C power supply to connect the Raspberry Pi, and a 16GB SD card so the libraries needed could be downloaded and the program could be run properly. The Raspberry Pi Model 4B 2GB appears in Figure 30.



Figure 30: Raspberry Pi Model 4B 2GB [SOSE22]

6.3 POWER SUBSYSTEM

As previously noted, the idea of creating specific AC/DC converter was not possible due to lack of time and budget. Moreover, the Lab provided 12V power supply adapter chargers that could easily be converted into 5V DC voltage suppliers by using the voltage regulator of the PCB. As a matter of fact, the RPI has some 5V outlets so the PCB can be powered by the RPI. Since the power supply for the RPI is a USB-C and it was purchased, there was no need to use the 12V power supply adapter charger. The other thing left to power was the electric hoist, that can be directly connected to the wall plug. For this reason, it was inefficient to create any type of power converters.

However, there was one important detail left to be covered. The RPI is a Single-Board Computer with many GPIO. Nonetheless, unlike the ATmega328, the digital inputs and digital outputs of the RPI are 3.3V signals. This was a problem because the ATmega328 usually reads as high signals that are higher than 3.5V. Even though the 3.3V signal might be taken by the microcontroller as a high input, it was a risk that could be avoided. In order to do so, the RPI was connected to the PCB through a logic level shifter. A logic level shifter is a device that gets an input of a specific voltage and provides an output of another one. These devices are usually bidirectional, so they can get an input of smaller voltage than the output. Each side of the level shifter is connected to a voltage that works as a reference; in this case it would be 3.3V for the outputs of the RPI, and 5V for the inputs of the PCB. A bidirectional logic level shifter can be seen in Figure 31 with its schematics.

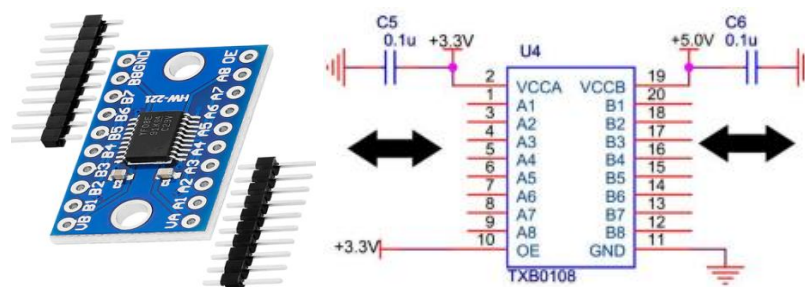


Figure 31: Logic Level Shifter 3.3V to 5V

6.4 SENSING SUBSYSTEM

This subsystem is simple. It only consists of the camera of the RPI that tracks the movement of the barbell and sends the information to the Computer Vision program so it can be processed.

6.4.1 CAMERA

The camera used was the Arducam 5MP Camera for Raspberry Pi, 1080P HD OV5647 Camera Module V1, shown in Figure 32. This camera is sold separately as the default Raspberry Pi 4B camera module.



Figure 32: RPI Camera [ARDU22]

6.5 USER SUBSYSTEM

The user interface allows the user to set the desired hoist position, input the number of repetitions to be performed with and without help, and see the visual feedback the program generates about the performance of the exercise.

6.5.1 NUMBER OF REPETITIONS

The user is asked to input the number of repetitions he/she will attempt to perform without and with help. If a person inputs ‘3’ in ‘repetitions without help’ and ‘2’ in ‘repetitions with help’, the hoist will start moving at the beginning of the fourth repetition and will continue to do so until the end of the fifth repetition. Figure 33 shows how the

user is asked to input the number of repetitions he/she wants to perform with and without help.

```
pi@raspberrypi:~/Documents/gorilift $ python3 gorilift.py
How many repetitions will you attempt to perform without help? 3
How many repetitions will you perform with help? 1
```

Figure 33: User Interface Number of Repetitions

6.5.2 ELECTRIC HOIST ADJUSTMENT

The user is free to adjust the starting position of the hoist prior to performing the exercise. There is a built-in function where the lifter is asked in what direction he/she wants to move the hoist, and for how many seconds. Figure 34 shows this.

```
pi@raspberrypi:~/Documents/gorilift $ python3 move_hoist.py
In which direction do you want the hoist to move? down
For how many seconds? 2
```

Figure 34: User Interface Hoist Adjustment

6.5.3 FEEDBACK

After completing all the repetitions, the user can see a chart with the time it took to complete each repetition and a graph with the inclination of the barbell through time, as demonstrated in Figure 35. It will help him/her improve the performance of the exercise.

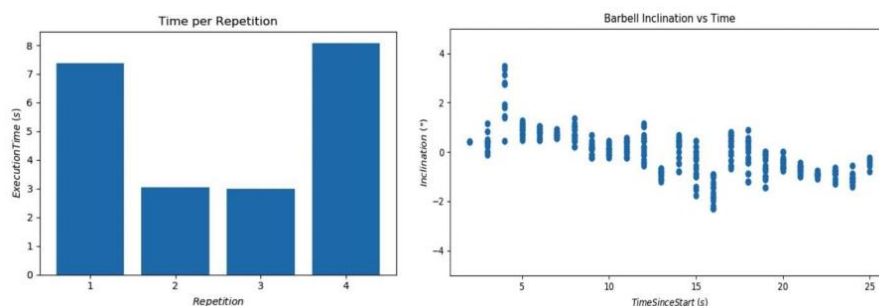


Figure 35: Feedback

CHAPTER 7. PROJECT LOGIC

This part of the project consists of a brief explanation of the logic that is implemented in the machine. The main purpose of this project is to describe the hardware of the device. Nevertheless, it is crucial to know how the logic of the project works in order to understand which signals are sent to what devices and get a better understanding of the invention as a whole.

First, it is essential to remember some of the objectives this project wanted to accomplish. This project aimed to track the movement of the barbell through the execution of the exercise. As a means to do so, two colored adhesive tape were attached to the ends of a wooden barbell that was used for the demonstration (refer to Figure 36 for better understanding). The Computer Vision program tracked these two colors through the whole exercise; thus, the program knew at every time where the barbell was placed.

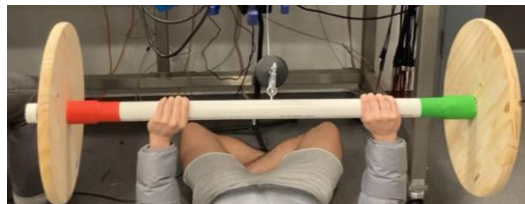


Figure 36: Barbell with Colored Tape

The RPI program works with two main variables, that are set to high or low depending on the position of the barbell. One variable is “hoist down” variable and the other one is the “hoist up” variable. These variables provide 5V through a GPIO pin of the RPI when they are set to high, and 0V when they are set to low. The hoist down signal is activated when the “hoist down” variable is set to high. It is a 3.3V digital signal that works as an output coming from a GPIO of the RPI. This 3.3V signal is connected to the logic level shifter, that is connected on the other side to the PCB, which provides 5V signals. This other side is connected to one input digital pin of the microcontroller. The microcontroller processes it and provides a 5V digital output that is connected to the relays system and to a

red LED that works as an indicator used to test the connections without connecting the hoist to the wall plug. It is connected to the two relays that make the function of the down button of the manual switch. The signal sent to move the hoist up follows the same process. An output 3.3V signal coming from one GPIO of the RPI is sent when the “hoist up” variable is set to high in the Computer Vision program. This signal is converted to a 5V signal through the logic level shifter. This is an input of one of the digital pins of the ATmega328 that is processed. It sets another digital pin of the microcontroller to high, that sends a 5V output to the other two relays of the relays system. These two relays simulate the hoist up button of the manual switch. This output signal of the microcontroller is also connected to a green LED that is used to test the program and the connections without powering the hoist.

At the beginning of the exercise, the user has to unrack the barbell, which means lifting it up until the arms of the user are fully extended. In this position, the program understands that the barbell is the highest it is going to be through the whole performance, so the “hoist down” signal is set to high. When the barbell stops moving down, which means that the barbell has reached the chest of the user, the signal of the hoist down deactivates. In this position, the hoist is not moving up or down either. However, since the wire of the hook of the hoist is not rigid, the user is able to move the barbell up and down as if it was not attached to the hoist.

One important function of the project is to allow the user to choose how many repetitions he/she wants to do with help and how many without it. Continuing with the example given in Chapter 6. The performer tells the device he/she wants to do three repetitions without help, and two repetitions with help. The “hoist down” signal activates when he/she unracks the barbell. It is set to low when the barbell stops moving down. Then the user can do three repetitions with the hoist deactivated. Once the Computer Vision program has counted that the barbell has passed through certain height three times, which means that the user has completed three repetitions, the “hoist up” variable is set to high. Therefore, the hoist assists the user to lift the barbell. Once the barbell reaches the maximum height set at the beginning of the performance based on the unracking position,

the “hoist up” variable is set to low, and the hoist stops moving up. This means that the user has completed the fourth repetition (first repetition with help). Immediately after this, the “hoist down” variable is set to high, and the hoist starts moving down, so the user can move the barbell down and start the fifth and last repetition (second repetition with help). Once the barbell stops moving down, the “hoist down” variable is set to low, and the hoist stops moving down. Right after this, the “hoist up” variable is set to high, therefore the hoist starts moving up and the user is able to finish the last repetition with help. Once the barbell reaches again the height set at the beginning, the “hoist up” variable is set to low, and the hoist stops moving. The exercise is over, and feedback is provided to the user through the user interface (computer or phone). The security time between the “hoist up” / “hoist down” deactivation and the “hoist down” / “hoist up” activation is 1.5 seconds, which allows the capacitor to discharge. Moreover, it is long enough for the user to be prepared to change the direction of the motion of the barbell.

One of the major aspects of the project was to develop a model capable of recognizing failure and helping the user in this scenario. If failure is detected, which means that the barbell is stuck in the same position (not taking into account the maximum height position) for 3 seconds, the “hoist up” signal activates, and the hoist helps the user to lift the barbell. In case the user wants to do three repetitions without help and two with help, but he/she is not able to do more than one without help and gets stuck trying to perform the second one, the system helps him/her with that repetition, and it also helps the user perform the second one he/she wants to do with help too. To clarify this, it is convenient to think about another example. Imagining the user wants to do eight repetitions, but he/she does not want help. However, he/she wants the system to be prepared in case of failure, but in this case, he/she does not want to continue. In other words, the user wants to do eight repetitions without help, but if he/she fails before the repetition number eight, he/she wants the system to help him lift the barbell and finish the exercise. In this case the hoist activates when it detects failure, and it helps the user to lift the barbell. Then, the hoist deactivates and the exercise is considered to be finished.

One additional feature the system provided is the option of adjusting the hoist before starting the exercise, as mentioned in Chapter 6. If the person that did the exercise before had longer or shorter arms than the next performer, it is likely that the position of the hook of the hoist is not adequate for the next user. In order to solve this, the system asks the user if he/she wants the hoist to move up or down and for how much time. The user could use this feature as many times as he/she wants, until the hoist is properly adjusted.

To get a general idea of how the logic of the project works, a flowchart is provided in Figure 37. In this flowchart there are no specifications whether the hoist is moving up or down because it has been specified earlier in this chapter. Nonetheless, it helps the reader to get a better understanding of how the project has been programmed.

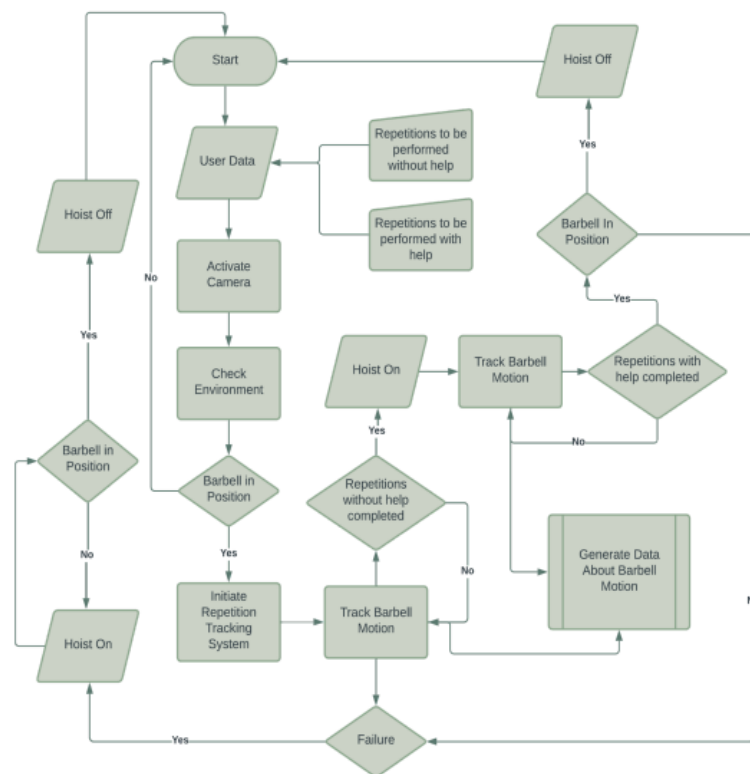


Figure 37: Program Flowchart

CHAPTER 8. RESULTS

In this part of the document, the results of the design are explained. It is important to outline that, despite the complications and challenges this project has supposed, the objectives have been successfully achieved. Pictures of the different parts of the system are provided in this section, in order to complete the descriptions given earlier in this paper.

8.1 MECHANICAL SUBSYSTEM

The hoist, the mounting frame and the relays system are the parts that make up this subsystem. The mounting frame is portable, and it can be attached to many surfaces by using clamps. The hoist is held by this mounting frame. In Figure 38 there is a picture of the mechanical subsystem.

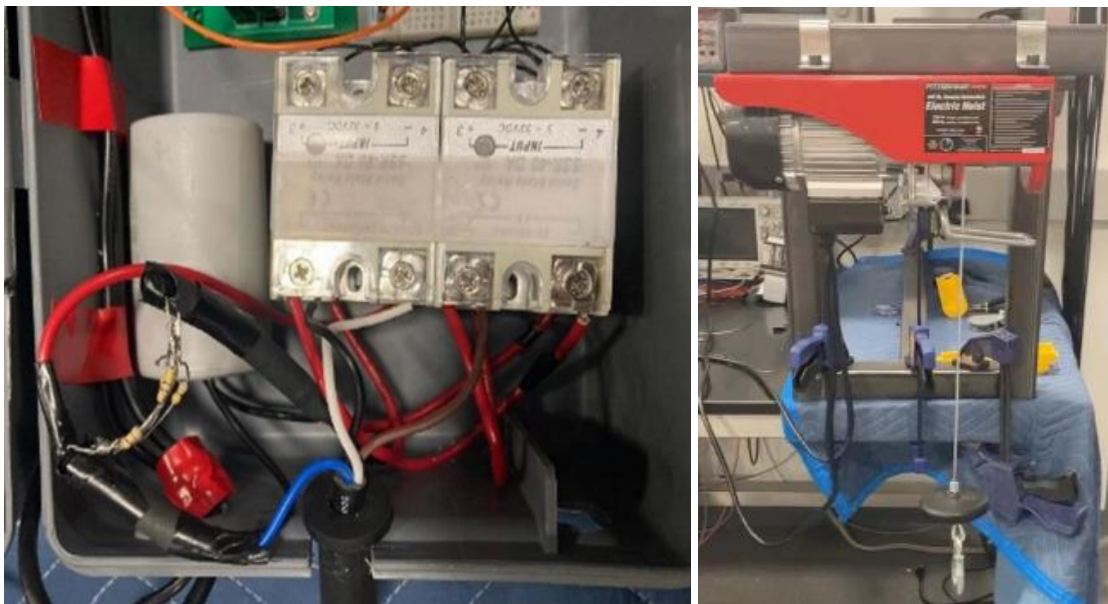


Figure 38: Mechanical Subsystem Results

8.2 CONTROL SUBSYSTEM

This subsystem consists of the PCB and the Raspberry Pi. It also includes a breadboard where two LEDs with their respective resistors are connected for the testing. As it has already been explained, the digital output signals of the RPI go as digital input signals of the PCB through a logic level shifter. Figure 39 shows the control subsystem.

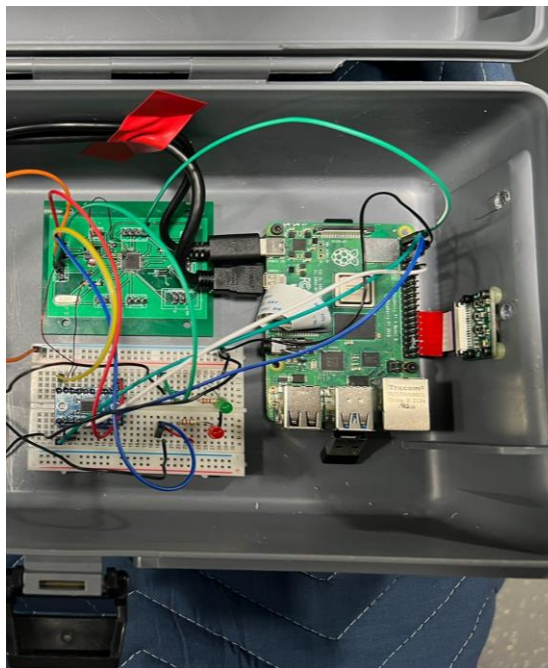


Figure 39: Control Subsystem Results

8.3 POWER SUBSYSTEM

This subsystem consists of the logic level shifter that can be seen as well in the breadboard in Figure 39. In addition to this, the power subsystem includes the RPI as well, since it provides 5V to the PCB (there is a green wire that connects the RPI directly to the PCB in Figure 39, which is sending a 5V signal). It also includes the charger of the RPI, and the wall plug where the electric hoist is connected.

8.4 SENSING SUBSYSTEM

The only component of this subsystem is the camera, that is directly connected to the RPI. In Figure 40, the display of the what the camera is recording can be seen.

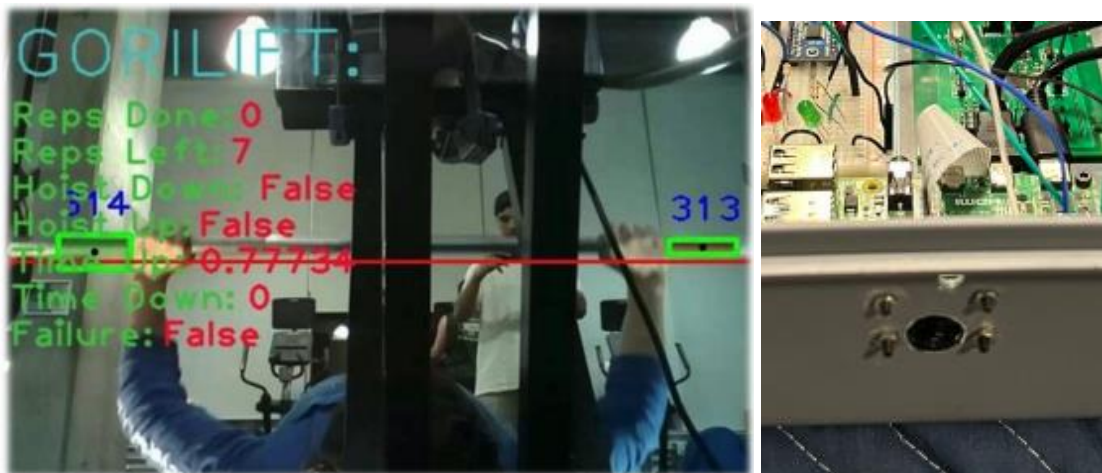


Figure 40: Camera (Repetition Tracking)

8.5 USER SUBSYSTEM

The user subsystem can be either a screen connected to the RPI, or a phone connected to the RPI. In Figure 41 there is a picture of how the RPI looks like on a screen and on a phone screen, and how it can be controlled by the user.



Figure 41: User Interface

8.6 SUBSYSTEMS IMPLEMENTATION

Once all the subsystems were connected separately, there were some connections between them that were crucial. One of them was the connection between the mechanical and the control subsystem through the relays system, which schematics were shown in Figure 20. In Figure 42 the results of this connections through the breadboard can be seen.

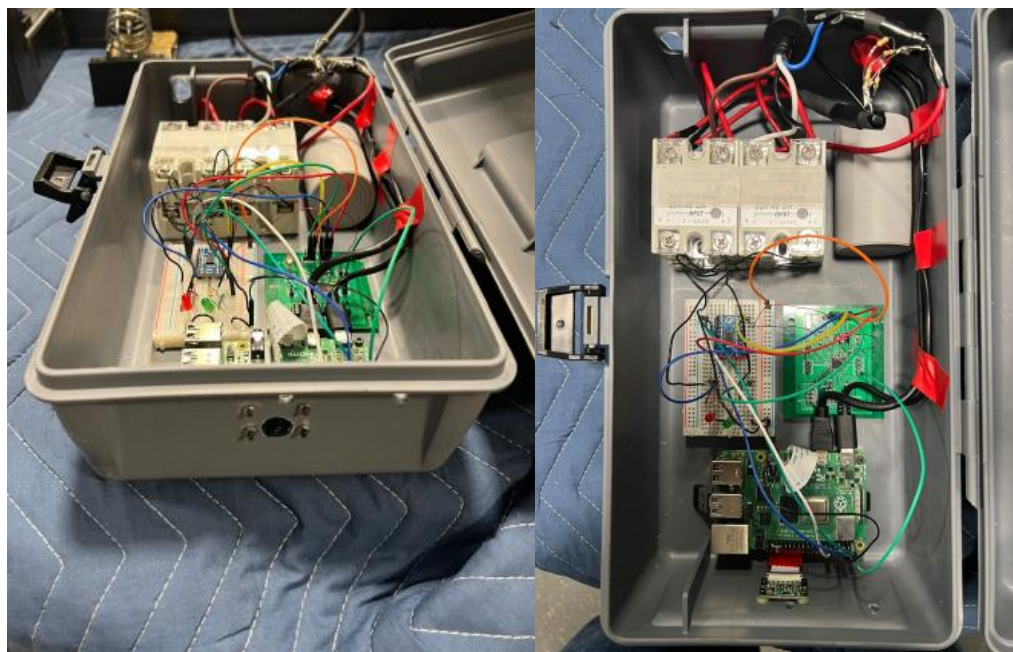


Figure 42: Mechanical and Control Subsystem Implementation

The connection between the control subsystem and the sensing subsystem was a simple connection between the camera and the RPI. The connection between the power subsystem and the control subsystem was basically connecting both sides of the level shifter, one to the PCB and the other one to the microcontroller. Moreover, connecting the hoist to the wall plug, and the RPI through its charger to the wall plug as well. Finally, the connection between the user subsystem and the control subsystem was through an HDMI connected to the RPI in case it was a screen, or through Wi-Fi connected to the RPI too, in case it was a phone.

Once all the different subsystems were integrated, the whole designed is reduced into a box (shown in Figure 42), the mounting frame, and the electric hoist. The box can be opened since it is a toolbox. However, there is no need for this since it has two holes for the only to wires needed: the charger for the RPI that needs to be connected to the wall plug, and the thick wire that controls the direction of the hoist, that consists of different wires connected to the relays system that are inside the box. It has a whole for the camera as shown in Figure 40. The mounting frame can be connected to different structures by using clamps, and it is not too heavy. The hoist is attached to the mounting frame. Therefore, to place the design at another place it is only necessary to have a strong structure where the mounting frame can be held by the clamps, and a floor where the box with the camera can be placed to track the movement of the barbell. Since the hoist is able to lift 220 pounds connected in single line, it was decided to take it into a real gym and test it with a real barbell, adding more weight on the sides. It was a successful test since it lifted more than 90 pounds (40 kilograms). Figure 43 shows the Bench Press Smart Helper taken into a real gym.



Figure 43: Bench Press Smart Helper in Real Gym

The electric hoist was covered with a white paper because its color was very similar to the color of the adhesive red tape. The camera was placed on a big box at the beginning. However, while doing the experiment it was decided that placing it on the floor provided

better results. Figure 44 shows one of the tests with 95 pounds, the camera is now placed on the floor.



Figure 44: Bench Press Smart Helper in Real Gym Test

On the next example, it can be seen how the camera detects failure. Thus, the “hoist up” signal is on, the “hoist down” signal is off and both sides of the barbell are being correctly tracked. Refer to Figure 45 to see this.

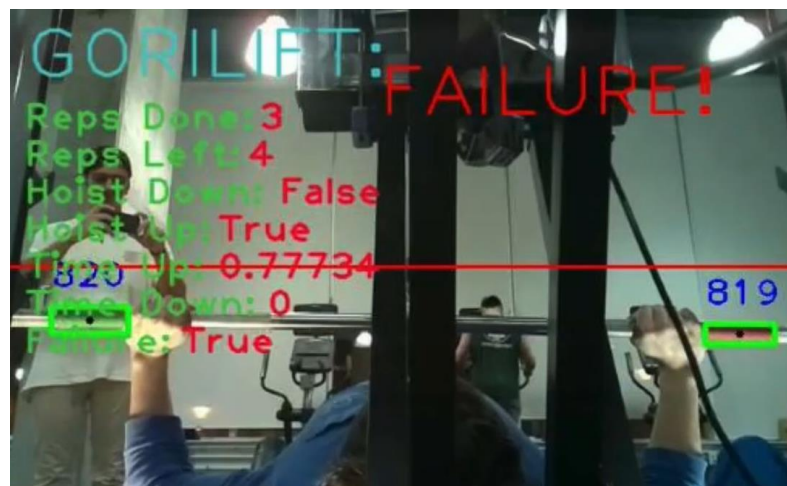


Figure 45: Real Gym Testing (Failure Detection)

To see the list of requirements and verifications that were used to check different features during the development of this project, please refer to Appendix A.

CHAPTER 9. PROJECT BUDGET

Table 3 shows the cost of the parts that were purchased for the project. It is convenient to stress that some of the components used for this project were part of the material of the Lab, so these components do not figure in the list of purchased ones.

Table 3: Project Budget

Part	Manufacturer	Cost/unit (\$)	Quantity	Total Cost (\$)
ATMega328	Atmel	10.12	1	10.12
Breadboard	Pololu	5	1	5
Electric Hoist	Pittsburgh Automotive	119.99	1	119.99
Logic Level Shifter	Texas Instruments	2.5	1	2.5
Raspberry Pi Camera Arducam5	CanaKit	13.49	1	13.49
Raspberry Pi Model 4B 2GB	Raspberry Pi Foundation	50	1	50
RPI USB-C Power Supply	CanaKit	8.8	1	8.8
SD Card 16GB	Raspberry Pi Foundation	9.28	1	9.28
Solid State Relays	Omega	9.95	4	39.80
22pF Capacitor	Kemet	0.36	2	0.72
Total				259.7

CHAPTER 10. CONCLUSION

As it has been discussed throughout this document, including automated assistance in the world of fitness is not only a possibility, but also a major breakthrough. The benefits this project can provide to the powerlifting field are wide ranging and significant. Reducing injuries, improving athletes' performances, enhancing exercise effectivity, increasing economic income of commercial gyms are among these benefits.

10.1 CONCLUSIONS

In Chapter 8 it is demonstrated how this design is capable of lifting heavy weights. As a matter of fact, it is shown how it can properly work on a real gym with weights people usually lift.

Regarding the state of the art earlier discussed on this document, this is a new and innovative design that clearly ends with the matters that concerned the two options that are in the market today. This invention ends with the lack of freedom that The Smith Machine has, and it adds the option of continuing the repetition in case of failure. The Smith Machine gives the option of leaving the barbell at the height it is when the user is not able to lift it anymore. Furthermore, it ends with the necessity of the performer to spot himself while doing the exercise like it does the Bench Press Feet Spotting Machine. All in all, it allows the athlete to execute the barbell bench press in a safer and more effective way than with any other kind of help.

This system is efficient since it only need the RPI to be powered when it is being used. In addition, the relays system allows the electric hoist not to be consuming power if the hoist is not moving up or down, which is a little portion of the time it is place in the gym. This is because the relays system works as an open circuit when they are not receiving the signal from the microcontroller. It will only be consuming when the "hoist up" or "hoist down" signal are set to high, which usually is for a short period of time.

Finally, the system is compact and easy to carry. It can be placed in many structures that gyms already have like big bench press racks. On the other hand, a solid structure can be easily built to hold the hoist in case a gym does not have a big structure. In conclusion, it is a very commercial product with great projection in the future of technology applied to fitness.

10.2-PERSONAL AND TECHNICAL ACCOMPLISHMENTS

This project teaches many things in the engineering field (technical skills) and in the professional area (personal skills). The process of this design develops many technical skills. First, it teaches how to design a PCB. It also shows how to solder small components to the PCB, and how to unsolder them. It teaches how to solder two or three different wires to make them longer, and how to isolate them later. Moreover, it shows how to read datasheets and how to find proper components for specific purposes. It shows how to order them too. Finally, it is great to learn how to implement different subsystems and how to take theory into practice. As for the personal side, this project shows many abilities too. It teaches finding a way of accomplishing a problem knowing what needed to be done, but not having a clue about how to do it. It teaches the importance of teamwork, the importance of talking to colleagues letting them know different points of view in an assertive way. It has been very important to be communicative and feel confident and comfortable talking about every different aspect of the project. This has avoided many complications. Furthermore, it teaches how to deal with frustration. This project involves making mistakes and not figuring them out at the first time, but after thinking and working on them being able to solve them. Finally, it shows the potential someone can have when he/she is pushed to the limits and out of his/her comfort zone. This teaches the importance of not giving up and the fact that everyone is capable of doing more than he/she thinks.

10.3 FUTURE DIRECTION

This field is yet to be exploited. There are many aspects of the world of fitness that could be complemented with technology and automated assistance. However, this part of the document is focused on how this specific application could be improved, and what other closely similar applications could be developed.

As it has been stated before, there is the possibility of creating this product by using a pneumatic system. It would be very interesting to go deeper into this idea. It could provide a more controlled force to lift the weights and the whole system could probably be smaller and lighter. This could be a very sophisticated option to accomplish this problem. Nevertheless, as an economic and profitable product, it would probably be unsuccessful. The cost of a system of this type could go over a thousand, which would probably be an excessively expensive cost.

On the other hand, this product could be sold as part of a bench press rack, increasing the price of the rack to compensate for the cost of the electric hoist and the different components. However, this would avoid creating a mounting frame and it would decrease the cost of production.

Another further point is that this product is specifically designed to meet the requirements of a bench press spotter. Nevertheless, it can be very easily adapted to be used in many other exercises. For example, the automated mechanism only needs to be placed higher so it can be used to assist a squat performance. The movement of the barbell during the squat is up and down, like during the bench press. Moreover, it can be used for barbell biceps curl, which follows the same motion, and some other exercises. As a matter of fact, it was decided to be built for the barbell bench press because it is the exercise with the greatest risk of injury. It was the exercise where a spotter is found more useful. Notwithstanding this fact, it can be helpful for other exercises too.

Finally, it would be ideal to patent the idea, so it can be sold in the market under the name of Gorilift. The hardware and the software created for this project would be

inspirational. Other ways of accomplishing the matter would be studied regarding different budgets and the amount of money a commercial gym would be willing to pay for the product.

BIBLIOGRAPHY

- [ACM_22] “The Code Affirms an Obligation of Computing Professionals to Use Their Skills for the Benefit of Society.” Code of Ethics. Accessed May 25, 2022. Available: <https://www.acm.org/code-of-ethics>.
- [ARDU13] Peter_I. “Attiny Pinout Leaves Me Confused. How to Call the Pins?” Arduino Forum, March 8, 2013. [Online]. Available: <https://forum.arduino.cc/t/attiny-pinout-leaves-me-confused-how-to-call-the-pins/149354>.
- [ARDU22] “Arducam for Raspberry Pi Camera Module with Case, 5MP ... - Amazon.com.” Accessed March 20, 2022. [Online]. Available: <https://www.amazon.com/Arducam-Raspberry-Camera-Module-1080P/dp/B07RWCGX5K>.
- [BENG22] Bengtsson, V., Berglund, L. and Aasa, U., 2022. “Narrative review of injuries in powerlifting with special reference to their association to the squat, bench press and deadlift.” Accessed May 17, 2022. Available: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6059276/#:~:text=Earlier%20studies%20that%20have%20reported,12%25%E2%80%9331%25%20to%20the>
- [CHUC17a] Ameliechucky, and Instructables. “How to Hack an Electric Hoist (AC Motor).” Instructables. Instructables, October 25, 2017. [Online]. Accessed March 25, 2022. Available: <https://www.instructables.com/How-to-hack-an-Electric-Hoist-AC-motor/>.
- [CHUC17b] Ameliechucky, and Instructables. “How to Hack an Electric Hoist (AC Motor).” Instructables. Instructables, October 25, 2017. [Online]. Accessed March 25, 2022. Available: <https://content.instructables.com/ORIG/FFA/VKL0/HCB8QBZA/FFAVKL0HCB8QBZA.jpg>
- [DREA22] Dreamstime. 2022. [Online]. Accessed May 17, 2022. Available: <https://www.dreamstime.com/stock-illustration-exercising-incline-smith-machine-bench-press-bodybuilding-target-muscles-marked-red-initial-final-steps-image66935692>
- [FERR21] Ferraro, Kathleen. “Bench Presses Are the Multi-Muscle Workout You've Been Missing.” Byrdie. Byrdie, October 28, 2021. Accessed May 20, 2022. [Online]. Available: <https://www.byrdie.com/bench-press-guide->

[5112654#:~:text=%E2%80%9CThe%20bench%20press%20involves%20virtually,to%20fitness%20instructor%20Jenny%20Leigh.](#)

- [HARB22] “Owner’s Manual & Safety Instructions - Harbor Freight.” Accessed June 5, 2022. Available: <https://manuals.harborfreight.com/manuals/60000-60999/60346-193175339461.pdf>.
- [IEEE22] “IEEE Code of Ethics.” IEEE. Accessed March 25, 2022. Available: <https://www.ieee.org/about/corporate/governance/p7-8.html>.
- [IPF_22] “The Basics of Powerlifting.” IPF - International Powerlifting Federation. Accessed May 23, 2022. Available: <https://www.powerlifting.sport/about-ipf/disciplines>.
- [MAJE22] Majewski, L., 2022. The one machine in the gym you should never use. [Online]. Accessed April 28, 2022. Available: <https://coach.nine.com.au/fitness/the-one-machine-in-the-gym-you-should-never-use/535f4123-8244-4f18-bcf2-73e651014611>
- [MCKA21] McKay, Brett & Kate. “How to Spot Someone on the Bench Press.” The Art of Manliness, August 19, 2021. Accessed May 25, 2022. Available: <https://www.artofmanliness.com/health-fitness/fitness/how-to-spot-someone-on-the-bench-press/>.
- [NGO_21] Ngo, Winnie. "Experimental Modeling and Control of Pneumatic Cylinders for Robotic Applications." 2021. Accessed January 28, 2022. Available: <http://msoe.s3.amazonaws.com/files/resources/winnie-final-report.pdf>
- [OPEN22] “SFCOM13015 Solid State Relay - 40A (3-32V DC Input).” OpenHacks. Accessed June 5, 2022. Available: <https://www.openhacks.com/page/productos/id/1185/title/Solid-State-Relay--40A-%283-32V-DC-Input%29#.YqrVIHQBzIV>.
- [PUTR22] Putra, Lio. STOCKLIB. Accessed May 20, 2022. [Online]. Available: <https://www.stocklib.es/media-157886718/man-doing-barbell-bench-press-chest-press-flat-vector-illustration-isolated-on-different-layers.html?keyword=bulking>.
- [SOSE22] electronic, SOS. “Raspberry Pi 4 Model B 2GB (RPI4-MODBP-2GB): Raspberry Pi.” Componentes electrónicos SOS electronic. Accessed March 10, 2022. [Online]. Available: <https://www.soselectronic.es/products/raspberry-pi/raspberry-pi-4-model-b-2gb-rpi4-modbp-2gb-318898?vat=1>.

- [SHAR06] “Sensor Reflector Sharp GP2Y0A710K0F.” Sensor reflector Sharp GP2Y0A710K0F | RS Components. Accessed February 4, 2022. [Online] Available: https://es.rs-online.com/web/p/sensores-opticos-reflectantes/6666577?cm_mmc=ES-PLA-DS3A--google--CSS_ES_ES_Displays_y_Optoelectronica_Whoop--%28ES%3AWhoop%21%29%2BSensores%2B%C3%93pticos%2BReflectantes%2B%28%29--6666577&matchtype=&pla-392765138567&gclid=EA1aIQobChMIyrGbtu-p-AIVgeh3Ch3hDAgYEAQYASABEgLxrPD_BwE&gelsrc=aw.ds.
- [SPOT22] The Spotter Inc, 2022. [Online]. Accessed April 28, 2022. Available: <https://www.youtube.com/watch?v=1brSCbzMDmc>
- [STRE22] “Bench Press Standards for Men and Women (LB).” Strength Level. [Online] Accessed June 5, 2022. Available: <https://strengthlevel.com/strength-standards/bench-press/lb>.
- [SUPP11] “Suppversity EMG Series - Musculus Pectoralis Major: The Very Best Exercises for a Chiseled Chest.” SuppVersity. July 12, 2011. Accessed June 6, 2022. [Online]. Available: <https://suppversity.blogspot.com/2011/07/suppversity-emg-series-musculus.html>.
- [ZENS18] Zenseidk. “Atmega328-Au.” Arduino Forum, October 13, 2018. Accessed February 25, 2022. Available: <https://forum.arduino.cc/t/atmega328-au/550838>.

PART II: APPENDICES

APPENDIX A. VERIFICATIONS

Control subsystem

Table 4: Control Subsystem Hardware Requirements and Verifications

Requirement	Verification
<p>1. The 3.3V to 5V and 5V to 3.3V level shifter will have a tolerance of 15%. The output of the Raspberry Pi pins must be between 2.97V and 3.63V. At the same time, the output voltage of the level shifter must be between 4.25 V and 5.75V.</p>	<p>1.a. Place probes in the output signal of the Raspberry Pi and ground to check that 3.3 V are coming out.</p> <p>1.b Check the other side of the level shifter while having it connected properly to a 5V source and the ground. There should be 5V+15%.</p>
<p>2. The voltage at PCB microcontrollerpins should be 5V +0.3V.</p>	<p>2.a Place probes on PCB ground while providing voltage to the input of the PCB and connecting it to ground as well. Voltage coming in the Microcontroller must be 5V+15%.</p> <p>2.b Create an easy programming test that sets one of the pins used as an output digital high.</p> <p>2.c Make sure that the output is 5V+15% by using the probes between the header pin of the output pin and the header pin of the ground of the PCB</p>
<p>3. Relays should be capable of moving the electric hoist wire up and down according to the signals “hoist up” and “hoist down”.</p>	<p>3.a Create a program that sets two output digital pins of the microcontroller. One will be the one that activates the hoist down and the other one activates up.</p> <p>3.b By using a delay of 2 seconds turn the down signal off and on consequently (so it does not hit the floor)</p> <p>3.c Connect the two signals to two relays each a</p>

4. The microcontroller is able to establish a direct connection with the hoist and activate it when desired	4.a. Simple code setting the pin connected to the microcontroller to high. 4.b. The electric hoist should start working.
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Sensing subsystem

Table 5: Sensing Subsystem Requirements and Verifications

Requirements	Verifications
1. The webcam should be able to capture the barbell from end to end horizontally and follow along the movement vertically.	1. Run the code and check the color is tracked correctly by moving the barbell.

Mechanical Subsystem

Table 6: Mechanical Subsystem Requirements and Verifications

Requirements	Verifications
1. The Mounting Frame is able to hold a 20-pound barbell without tilting nor obstructing the lifter's performance. Calculated with a 1.5 security coefficient.	1. Holding a 20-pound barbell in the hoist hook and running a code that moves up and down the barbell.
2. The electric hoist must be able to lift the weight accurately without disturbing the user's performance.	2. Prepare for doing the exercise.

APPENDIX B. PCB SCHEMATICS

PCB Schematics

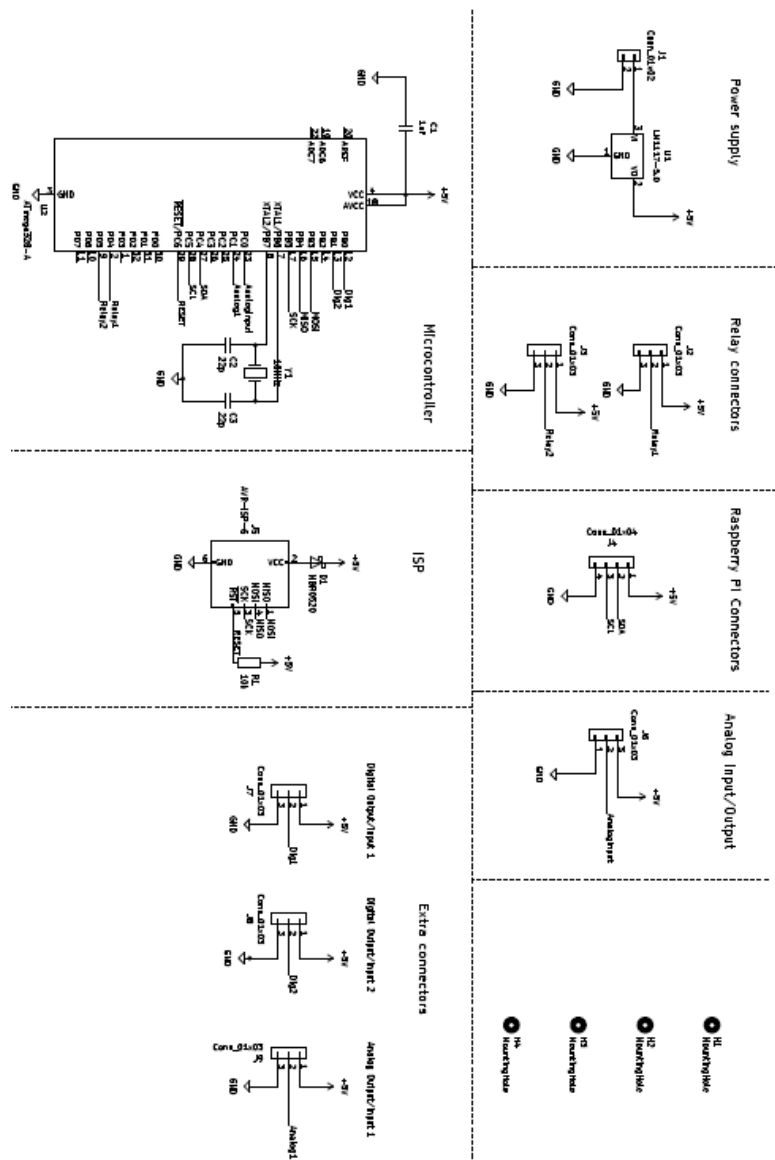


Figure 46: PCB Schematics

PCB Layout

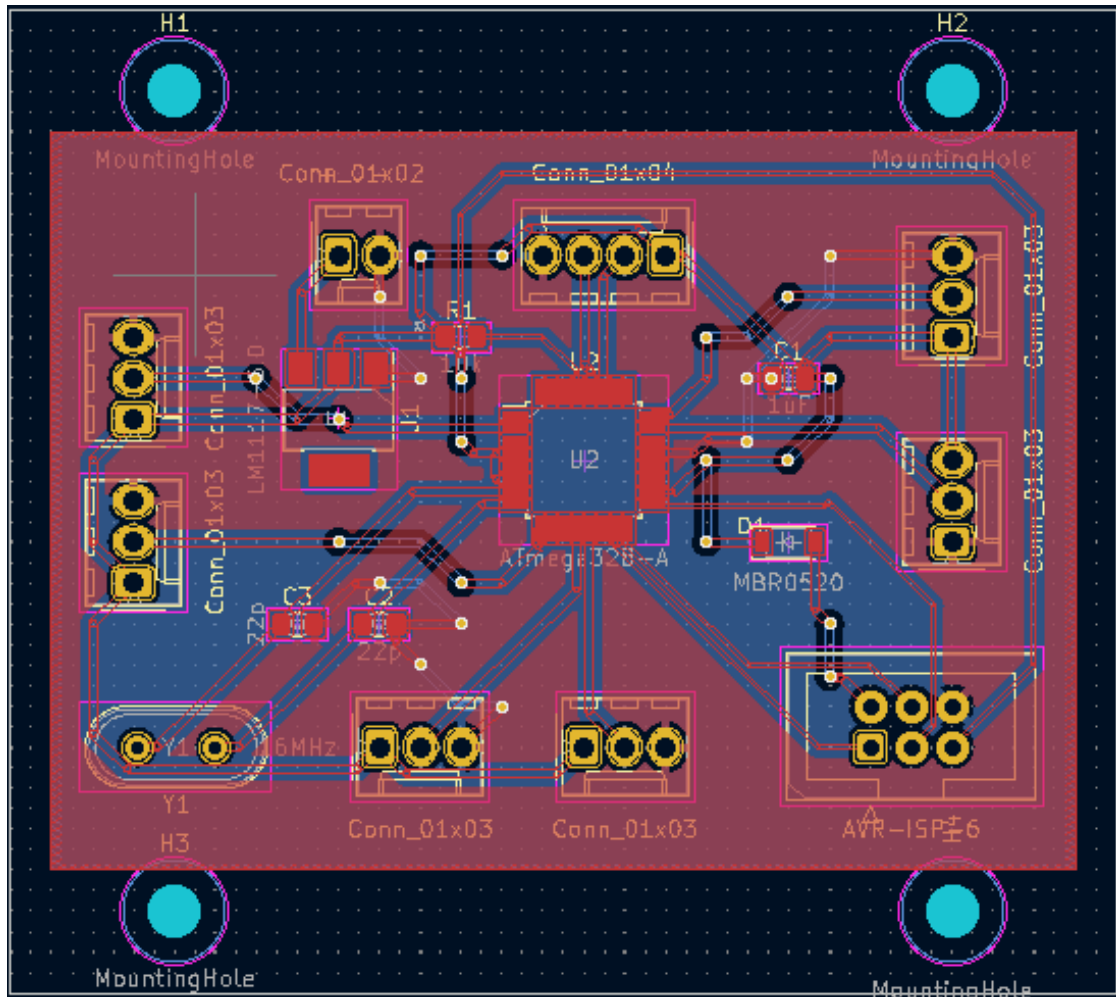


Figure 47: PCB Layout

APPENDIX C. SDG

Sustainable development goals

This project is committed to the next sustainable development goals:

- **Health:** This project is aligned with number 3 of the sustainable development goals: good health and well-being. The product features enable people that are already interested in gym to perform this exercise safely, minimizing the risk of injury and maximizing the benefits that the bench press provides. Furthermore, it will encourage people who do not usually do this exercise to try it because it will be easier and safer for them to get started in the fitness world.
- **Education:** This project is also aligned with number 4 of the sustainable development goals: quality education. This product will probably open new possibilities to the world of fitness. It is an engineering solution to a non-engineering problem. There will be many more people interested on automating and introducing AI into fitness centres. Besides, it will catch the attention of the users, that may or may not be interested in engineering, and it might encourage them to study similar things.