BarPro

ECE 445 Design Document Check

Kevin Mienta (kmient2), Patrick Fejkiel (pfejki2), Greg Gruba (ggruba2)

Group 28

TA: Anthony Schroeder

October 1, 2020

Table of Contents

1 Introduction

1.1 Objective

A common issue among weightlifters, regardless of experience, is bad form when doing exercises. This occurs from a beginning lifter not understanding the correct motion or an experienced lifter wearing out when reaching the end of his or her set. Muscles begin to fatigue and when exercises are performed with two hands (bench press, squats, deadlifts, for example), the stronger hand compensates for the other and the bar can become unlevel; this leads to asymmetrical strain on the body. Mitigation of this issue is possible if the user is doing a workout on a Smith machine or is partnered with a spotter; but these machines have their drawbacks, causing different muscle activation than a free weight barbell [1]. Also, with the ongoing Covid-19 atmosphere and the difficulty of consistently aligning gym schedules between people, users more often now than ever find themselves at the gym alone.

A weightlifting device called BarPro, shown in Figure 1, is designed for people who do barbell exercises such as bench press and deadlift. Many weightlifters, especially beginners, have a problem with keeping the barbell level while doing their repetitions which can lead to serious injuries. Many weightlifters also do not complete full movements of their repetitions, especially at the end of their sets when muscle fatigue is forming. The BarPro solves these problems by checking if the barbell is level and notifying the lifter if it is not. It also allows the lifter to calibrate the minimum and maximum heights of their lifts and notifies them if they are not doing their full repetition. Finally, the device also keeps track of repetitions and sets so the lifter can focus more on their workout.

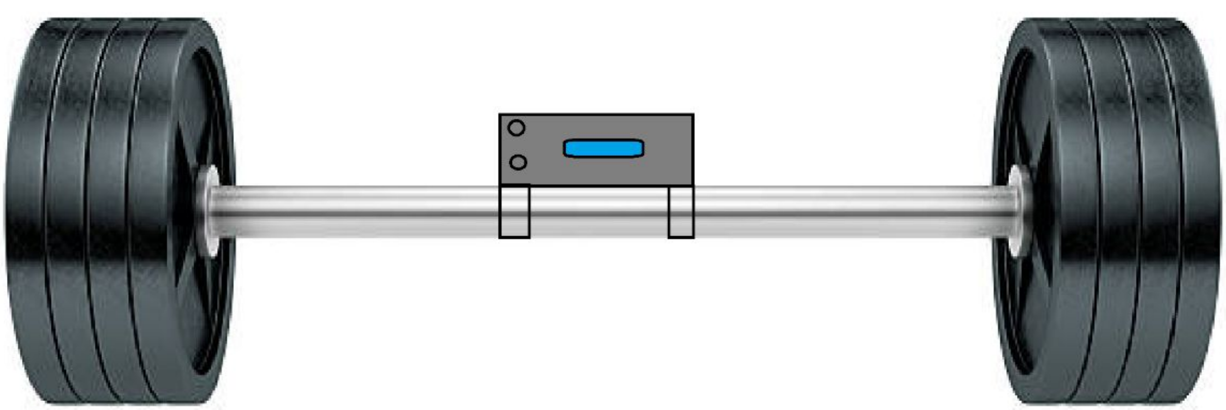

Figure 1: Physical Design (barbell not to scale)

1.2 Background

Uneven barbell positioning could result in serious injuries, especially when lifting heavy weights. This uneven positioning causes uneven weight distribution on muscles and joints such as shoulders [2] during the bench press exercise. To reduce the risk of these injuries, a weightlifter has to make sure he or she is keeping his or her barbell level at all times. Although a weightlifter can sometimes notice an uneven barbell by him- or herself, oftentimes weightlifters go through an entire motion with an uneven barbell unnoticed. A spotter or partner can definitely notice an uneven barbell, but many gym-goers work out alone, especially now during the COVID-19 pandemic where social distancing measures are enforced. The BarPro device has the ability to serve as a spotter or partner and notify the weightlifter when the barbell is uneven. It will perform even better than a human being by using an accelerometer to know exactly when a barbell is not positioned evenly.

Exercises such as the bench press and squat require full motion to activate the desired muscle groups. When full motion is not completed by the weightlifter, maximum efficiency is not reached from the workout and some muscles may undergo minimum usage. To eliminate the possibility of doing exercises with incomplete motion, weightlifters should practice proper form with little weights to create the muscle memory needed for a proper lift. The BarPro device can aid in this process by allowing the user to calibrate his or her full range of motion for the workout and providing a notification if the user is not completing a full repetition of motion by using an ultrasonic height sensor.

Finally, keeping track of repetitions and sets is an important factor of every weightlifting session. Different repetitions and sets are executed by the weightlifter depending on what his or her work out goal is. Some people want to build muscle strength and size so they stay in the lower range of repetitions, while others want to build muscle endurance and train with higher repetitions. It is actually recommended to train with less weight and more repetitions if reducing the risk of injuries is desired [3]. Although mentally keeping track of repetitions/sets seems like a fairly easy process, lifting heavy weights for a long duration of time does lead to fatigue that may cause a weightlifter to forget what set he or she is on or how many reps he or she has completed. BarPro will have the ability to keep track of these repetitions and sets so the user can focus solely on lifting the weight and keeping the barbell level.

1.3 High-Level Requirements

- Accurately count repetitions of motion during a workout (+/- 1 rep). This is done using an accelerometer. An intuitive user interface with buttons and LED display will allow the user to see the repetitions/sets and reset them using the buttons. These reps/sets are displayed on an LCD display.

- Accurately read the user's barbell tilt angle (~30°) established during initial testing. This is done using an accelerometer. The two LEDs will display which side is unlevel and a buzzer will buzz with a frequency corresponding to the level of the bar at 3° increments.

- Measure the height of motion (bench press: +/- 2cm, deadlifts: +/- 5cm) during a workout using an ultrasonic sensor. If the user is not performing full repetitions, their reps/sets will not be counted on the LCD display.

2 Design

2.1 Block Diagram

The BarPro will require five main component areas to operate as desired as shown in Figure 2. These include the power module, sensing module, control module, user interface and LEDs. The power module will supply the 9V to run the components of the device. The sensing module contains the accelerometer and ultrasonic sensors needed for device operation. The control module will send and receive data to control various device components. Lastly, the user interface will contain the buttons and LEDs for the user to read and also provide input to the device.

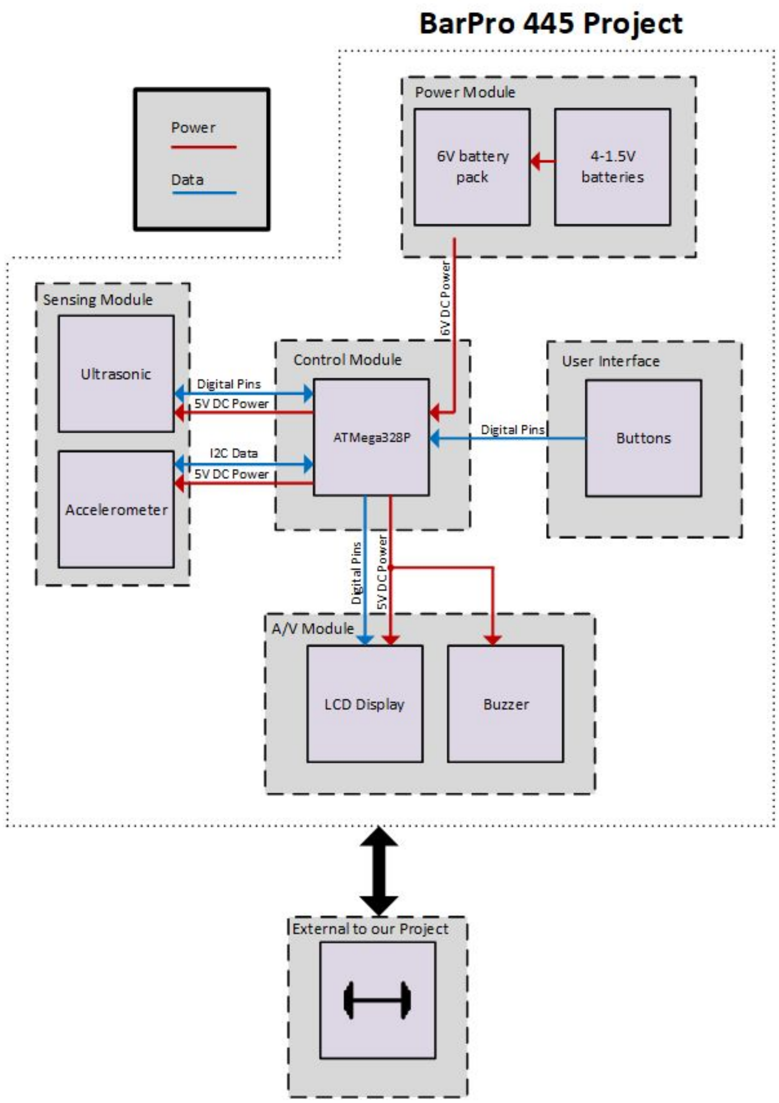

Figure 2: BarPro Device Block Diagram

2.2 Subsystems

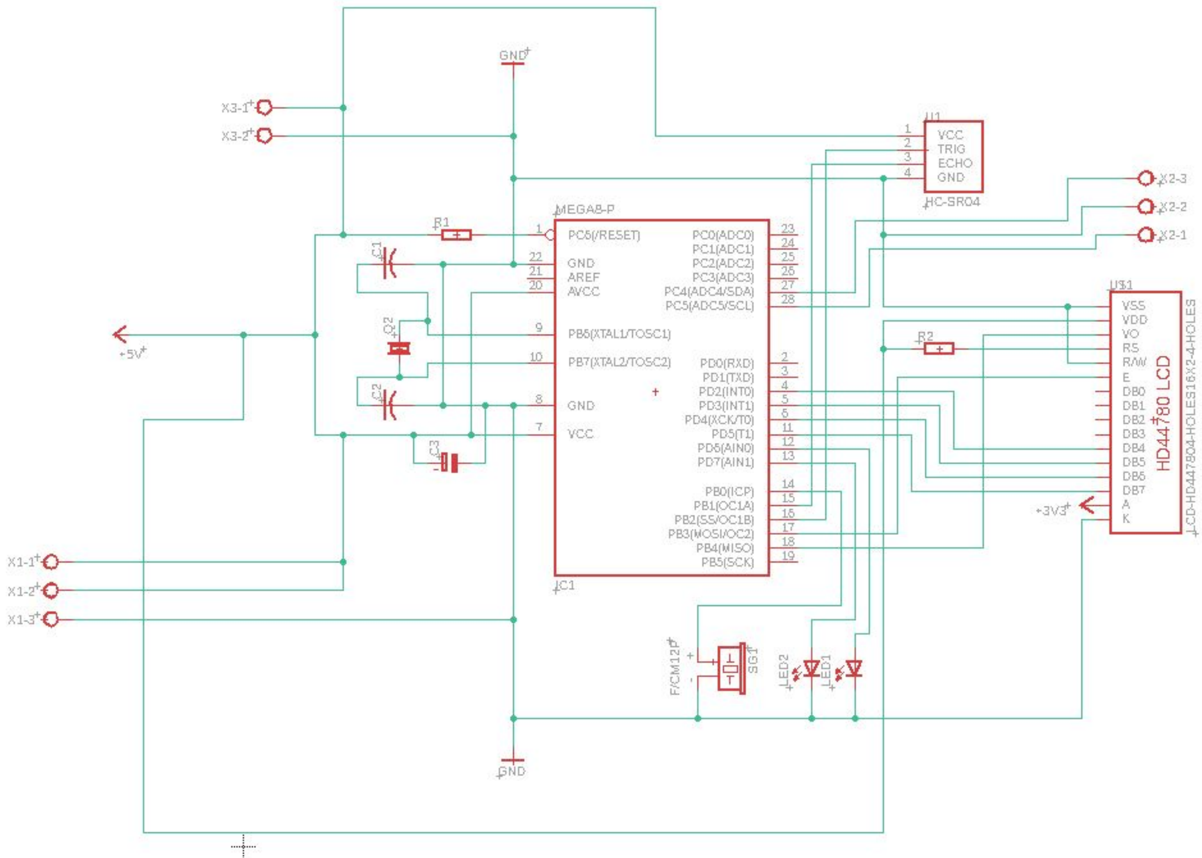

Figure 3: Circuit Schematic of BarPro Device

The circuit schematic in Figure 3 conveys our entire BarPro project. We have our ATMega328P chip at the core. Connected to it are our ultrasonic sensors, an accelerometer, and LCD display. Outputted are a buzzer and LEDs. The rest of the circuitry is required to have proper ATMega328P functionality.

Figure 4 details our physical design, and a box roughly 3” x 6” box holds our PCB. It has the BarPro branded in the middle and a caution label in the corner. A rectangle is carved out of the center for the LCD display. There are holes on either side for the LEDs. The remaining holes hold our ultrasonic sensor.

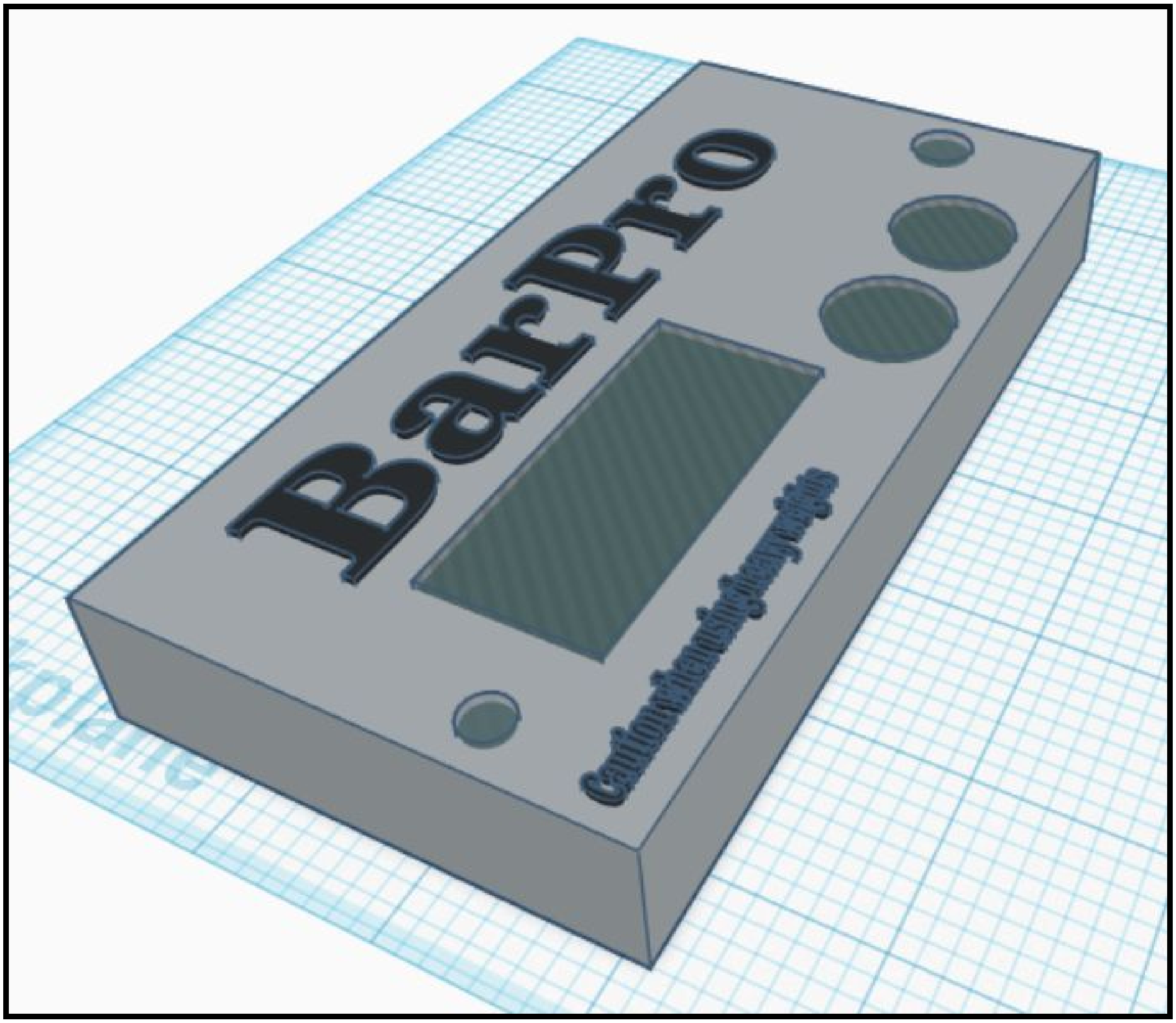

Figure 4: Physical Diagram

2.2.1 Power Module

This module is clearly providing the power for the rest of our system. Since we are not working with high voltages or magnetism, this module is simplified to strictly low voltage DC power. The Arduino needs a range of 5-12V to operate, and we currently have a 9V battery clip, so that was our inspiration for this module. There is no data transfer between the power module and the rest of the system, so only two wires will leave this module.

2.2.2 Control Module

This is the entire brain of our system, and we are using an ATMega328P chip for our prototype. This module will receive 9V DC power from the power module and distribute 3.3 V and 5V DC power to the rest of the modules that need it.

Regarding data, the digital IO pins are used for the majority of our system. Every other module will be connected through digital pins, with the exception that the accelerometer will communicate with the control module with additional I2C protocol. It will have a strict input from user interface, strict output to our LEDs, and input/output to our sensing module.

2.2.3 Sensing Module

Our sensing module is currently composed of two sensors: the accelerometer and ultrasonic sensor. This is where the reps a user is doing are counted, and the movement/level is tracked and sent back to the control module for interpretation. The sensors in the sensing module will be wired in parallel to the control module receiving 5V DC power. In terms of data transfer, the sensors receive a data request from the control module and send back data, one sensor after the other. Both sensors will communicate through digital IO pins, with additional I2C protocol for the accelerometer.

2.2.4 User Interface

This module consists of buttons allowing the user to interact with the control module. It will have a calibration button when beginning a workout, a start/stop button for counting reps,

2.2.5 A/V Module

This module will primarily allow the user to see the level of the bar in real-time and hear the buzzer when the barbell is unlevel. Our current idea is to use two RGY SMD LEDs on either side to illuminate to the user the level of the bar. Same idea on both sides, if the bar is under 5° it will show green, 5-10° will show yellow, and >10° will show red. We could also increase the resolution to show smaller increments by displaying together green-yellow and yellow-red lights or blinking the LEDs. The buzzer is activated when the barbell is unlevel to notify the user.

2.3 Requirements and Verifications

Table 1: RV Table

Requirements	Verification
1) Control Module: Accurately count repetitions of motion during a workout (+/- 1 rep)	1) A user will do full repetitions of motion during various workouts and compare actual rep counts to rep count shown on the LCD screen to check if it is within the required range.
2) Sensing Module: Accurately read the user's barbell tilt angle (+/- 3 degrees)	2) An experienced user will purposely tilt the barbell with no weight to the left and right side to see if the unlevel barbell tilt angle notification is given by LEDs and buzzer after 10 degrees. This angle measurement will be verified by either a smartphone using its level of tilt angle detecting feature or Arduino IDE's serial display to see if it is within required range.
3) Sensing Module: Accurately measure the height of motion during a workout and count a rep if height is within 5cm of min or max height depending on workout	3) An experienced user will do a full range motion exercise to set the min. and max. heights, and then the user will do half of a repetition to see if no rep is actually counted since a full rep was not completed and the actual height measured during the repetition was less than the min. and max. range of motion. The current height measured will also be displayed on Arduino IDE's serial display and compared with the min and max heights to test if a rep is counted if current height is within 5cm of min and max height.
4) User Interface: Intuitive user interface with buttons and LEDs	4) A weightlifter will do a workout with the device, pressing each button to test functionality such as total reset and set increment / rep reset and checking if LED/buzzer signal is given for uneven barbell. This includes testing the on/off power

	button to check if the device turns on and off.
5) Power Module: 9V battery will power the Power Supply Module that will provide a voltage in the range 2.8-3.8V and 4.5-5.5V, respectively, for the 3.3V/5V power supply connections on the board	5) A multimeter will be used to measure the voltage on the board on both 3.3V and 5V power supply connections on the board to make sure it is within requirement range.
6) A/V module: Minimal delay between user/input and response from project	6) A timer will be used to check if the time between a user input such as an unlevel barbell position and notification from the device in the form of LED/LCD display and buzzer is less than 1 second.

2.4 Tolerance Analysis

Quantitative analysis is required on the tolerance of the accelerometer. The accelerometer will read acceleration values corresponding the level of tilt of the barbell. These acceleration values will need to be converted into degrees of tilt using Eq. 1 And Eq. 2, in order.

$$angle\ of\ tilt\ (degrees) = 90 - arctan(z_{acceleration}/x_{acceleration}) * (180/pi) \qquad \text{(Eq. 1)}$$

$$if\ angle\ of\ tilt > 90,\ then\ angle\ of\ tile = angle\ of\ tilt - 180 \qquad \text{(Eq. 2)}$$

A tradeoff is needed to be made between desired maximum tilt angle and acceleration values depending on how closely a relationship can be calculated between degree of tilt and m/s^2 of acceleration. Table 2 shows the magnitude of difference between actual angle measured using an angle tilt measuring device and angle calculated by the acceleration values from the accelerometer.

Table 2: Actual Angle vs. Calculated Angle

Actual Angle (degrees)	Calculated Angle (degrees)
0	.53
2	2.8
4	5.29
6	6.74
8	9.85
10	11.7
12	13.66
14	15.73
16	17.75
18	20.02
20	22.18
22	24.02
24	25.9
26	27.3
28	28.95
30	31.3
40	41.3
50	52.7
60	62.4
70	72.8

Table 2 data reflects an average difference in angle of 1.65 degrees. This average difference in angle of 1.65 degrees was then multiplied by 2 in order to roughly give the accepted range in barbell tilt angle of 3 degrees mentioned in requirement #2 in Table 1. A multiple of 2 was chosen because the maximum angle difference value seen was 2.8 degrees so 3 degrees would be a reasonable maximum value.

2.5 Risk Analysis

Our greatest threat to a successful final project is a malfunctioning sensing module. The entire system relies on the accuracy of the sensors within it to send back accurate information to the control module for correct parsing and data interpretation. The user interface is very difficult to not use correctly because it is primarily passive buttons. Faulty LEDs are easily replaceable and programming them comes very easy. The control module accepts a wide range of voltages (5-12V), so the power module providing the wrong power is not a big issue. Arduinos are very reliable, but the control module can malfunction if the code implemented on ours is not optimized or written correctly. This is an issue, but regardless if our sensors do not have a high tolerance, our code (whether written well or not) will not work anyway. So that is how we decided our sensor module is the riskiest module to combine into our system.

2.6 COVID-19 Contingency Planning

If the University transferred to all online classes due to COVID-19, the overall project would not change at all. The team members all have physical access to each other while following COVID-19 guidelines, and testing items such as a barbell and bench are available without going to a gym. If component shipments are cancelled or delayed due to COVID-19, similar and readily available components will be substituted to make the BarPro device function to meet high-level requirements.

3 Cost and Schedule

3.1 Cost Analysis

Assuming an average hourly pay of $35/hour the total labor cost is calculated to be $39,375 in Eq. 3. The estimated ECE shop cost will be $140 as calculated in Eq. 4.Total price for the BarPro project is $39,573.49 using Table 2’s total part cost and Eq. 5.

$$Labor\ cost = 3\ students * \$35/hr * 150 hours * 2.5 = \$39,375 \qquad \text{(Eq. 3)}$$

$$ECE\ shop\ cost = \$35/hr * 4\ hours = \$140 \qquad \text{(Eq. 4)}$$

$$Total\ BarPro\ cost = \$39,375 + \$140 + \$58.49 = \$39,573.49 \qquad \text{(Eq. 5)}$$

Table 3: Cost Analysis

Part	**Price [$]**	**Quantity**	**Part #**	**Manufacturer**
Atmega328P	2.08	1	32538KB	Microchip
LCD Display (HD44780	7.99	1		HiLetgo
ADXL 355Z	35	1	584-EVAL-ADXL355Z	Analog Devices
Ultrasonic Distance Sensor HCSR04	3.95	1	15569	Sparkfun
Buzzer	8.52	15 (1 required)	G306	GFORTUN
16MHz Crystal (Clock)	0.95	1	00536	Sparkfun
Total	58.49			

3.2 Schedule

Table 4: Group Schedule

Week	Patrick Fejkiel	Kevin Mienta	Greg Gruba
10/5/20	Coding and Finalize Parts List	Coding and Schematic	Schematic and Finalize Parts List
10/12/20	Coding and Schematic	Coding and Schematic	Coding and Schematic
10/19/20	Physical Design and Build	Physical Design and Build	Physical Design and Build
10/26/20	Physical Design and Build	Physical Design and Build	Physical Design and Build
11/02/20	Testing and Improvements/Verification	Testing and Improvements/Verification	Testing and Improvement/Verification
11/09/20	Testing	Testing	Testing

4 Ethics and Safety

The product that emerges from completing this project has the possibility of providing a fantastic aid to the general public that enhances workouts and body fitness goals. This also comes at the cost of possible misuse causing safety issues. We do not recognize any ethical issues with the BarPro product. It is simply a device to aid beginners on their workout journey by stopping bad habits with form. It does not store any personal data that could be misused such as user profile information. To avoid safety issues regarding the BarPro product, only very light weight is used for testing purposes. Using light weights will minimize the possibility of injury during testing. When the BarPro is used at the gym, individuals need to make smart decisions about the weight they use in workouts. The BarPro is only present to ensure proper motion and data tracking, it will not stop a careless individual from pushing his or her limits too far. This product will have warnings regarding the use of heavy weights designed to steer individuals in the right direction and promote safety measures. These precautions are in line with rule #9 in the IEEE Code of Ethics regarding the requirement to never injure individuals [4]. Our product will use AA batteries from a reputable manufacturer such as Energizer so they will meet US Consumer

Product Safety Commission regulations, but as with any battery, there is always a possibility for an explosion or fire. The batteries used are alkaline instead of lithium to decrease this possibility, and alkaline batteries are also easier to dispose of by the user.

References

[1] Schwanbeck, S., Chilibeck, P. and Binsted, G., 2020. "A Comparison Of Free Weight Squat To Smith Machine Squat Using Electromyography," *A Comparison Of Free Weight Squat To Smith Machine Squat Using Electromyography,* Dec. 2009. Accessed Sept. 30, 2020. [Online]. Available: 10.1519/JSC.0b013e3181b1b181

[2] D. Hatfield, *Shoulder Injuries,* ISSA, 2020. Accessed on: Sept. 18, 2020. [Online]. Available: https://www.issaonline.com/blog/index.cfm/2011/2/11/shoulder-injuries

[3] Loyola University Health System, *Military Surgeons Report 'Alarming Frequency' Of Bench Press Injuries*, ScienceDaily, March 2018. Accessed on: Sept. 18, 2020. [Online]. Available: https://www.sciencedaily.com/releases/2018/03/180322124948.htm

[4] IEEE, *7.8 IEEE Code Of Ethics,* IEEE Policies, Section 7 - Professional Activities (Part A - IEEE Policies) 7.8. Accessed on: Sept. 18, 2020. [Online] Available: https://www.ieee.org/about/corporate/governance/p7-8.html