Deadlift Assistant

ECE 445 Design Document

Nosa Egiebor, Sean Luo and Johan Mufata

Group 32

TA: Jonathan Hoff

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1 Introduction

1.1 Problem and Solution Overview

Physical fitness is a fundamental aspect of life for a large percentage of the population. Working out is one of the ways people strive to become the best version of themselves. Even though there are several upsides to staying in shape, there are also several risks that cannot be ignored. Every year, nearly 500,000 people get injured in the gym while performing exercises. A large contributor to these injuries is poor technique and form [1]. The deadlift exercise, in particular, while being one of the most useful exercises for building functional strength, is also one of the most dangerous. This is due to the large amounts of weight and the sensitive muscles that are involved in the motion. One of the most common deadlift technique mistakes is arching your back, making your spine vulnerable to an abnormal and unsafe amount of pressure. This simple mistake can lead to severe injuries that can cost thousands of dollars in medical services to rehabilitate. A reliable technique-feedback system could save thousands of people from injury and medical costs.

Our solution to this problem is a computer-vision technique analysis system. Our system records video of a user performing a workout and provides feedback on their technique via green and red LEDs that indicate good and bad form respectively based on the angles detected between the user's joints during the lift. Our system uses a camera, accelerometer, proximity sensor, and computer vision algorithms to provide accurate feedback. This product is intended to be installed in gym equipment so that anyone can integrate it seamlessly into their workout without having to put on any physical sensors.

1.2 Background

There are a few methods people use to learn and correct their form when lifting. One is hiring a physical trainer, and another is looking to the internet for advice. Both have their pros and cons. In regards to personal trainers, they can definitely be a useful asset to a member of a gym who is looking to exercise safely and use good form. However, the majority of people who go to the gym are not interested in hiring a trainer due to not being comfortable with the personal interaction or not wanting to pay more on top of a gym membership.As a result, only 15% of people with gym memberships use personal training services [3].

In regard to looking to the internet for advice, there are a vast amount of resources a person who is looking for workout advice can use. The problem here is that there are a lot of varying opinions between these resources of what constitutes good form, and using the internet leaves the user to try to correct their own form based on the material they see. This leaves a lot of uncertainty due to the lack of active and personalized feedback to the user.

Our system must be able to give accurate analysis and accurate feedback of the user's deadlift form to ensure optimal safety to the user so they know what good form. This requires a clear cut and consistent guideline for good deadlifting form. We believe that this system can provide enough value to the consumer to be either purchased by the individual or to be purchased by gyms to be implemented into their equipment. This will minimize a gym member's chance of getting injured, and provide a benefit to both the users and the gyms they go to via increased customer traffic.

1.3 Visual Aid

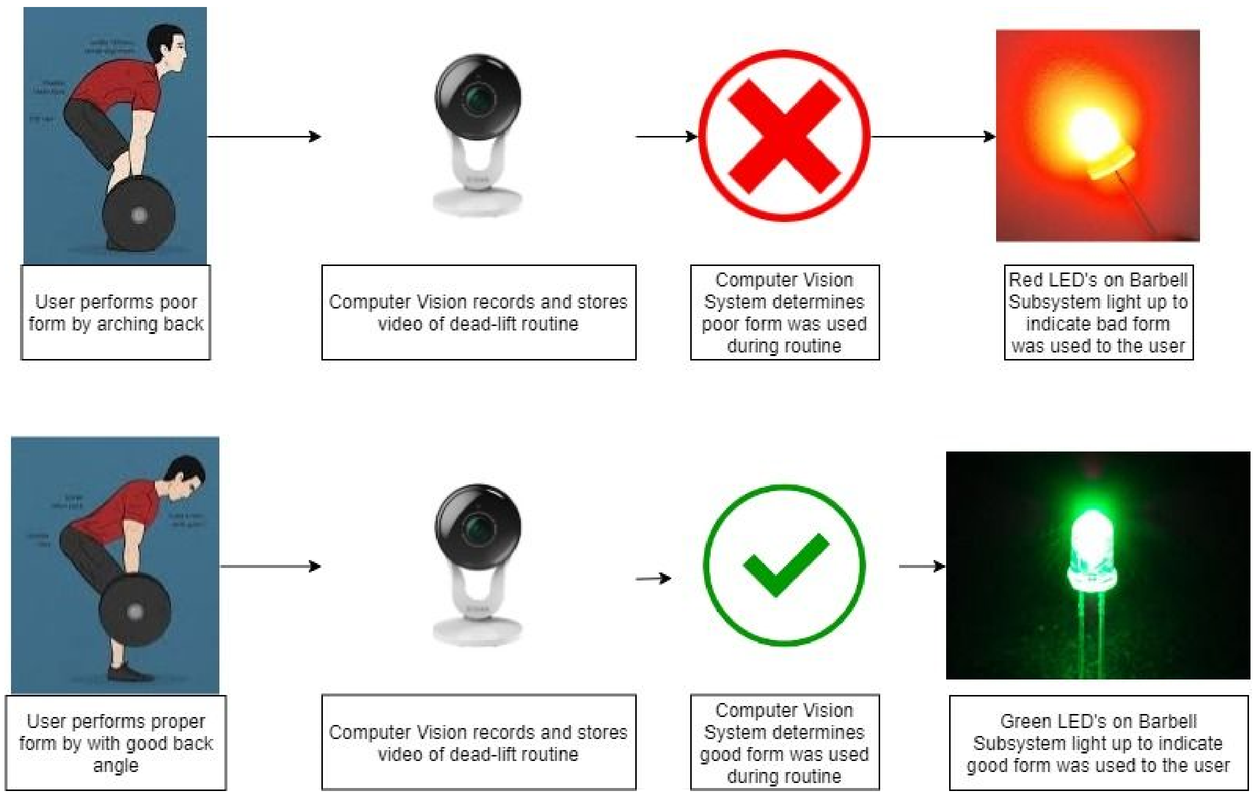


Figure 1: Visual Aid for Dead-lift Assistant Functionality

1.4 HIgh-Level Requirements List

1. The user should be able to receive a feedback based on the angle of his/her back at every repetition. The feedback system will be a simple red or green LED to indicate bad or good form that is easy to understand for anyone.
2. The weight of the barbell module should weigh no more than 500g in order to not make the deadlift workout any more difficult.
3. The cost of the product should be under $150 to make sense for both users and gyms to purchase as a fitness enhancement product.

2 Design

2.1 Block Diagram

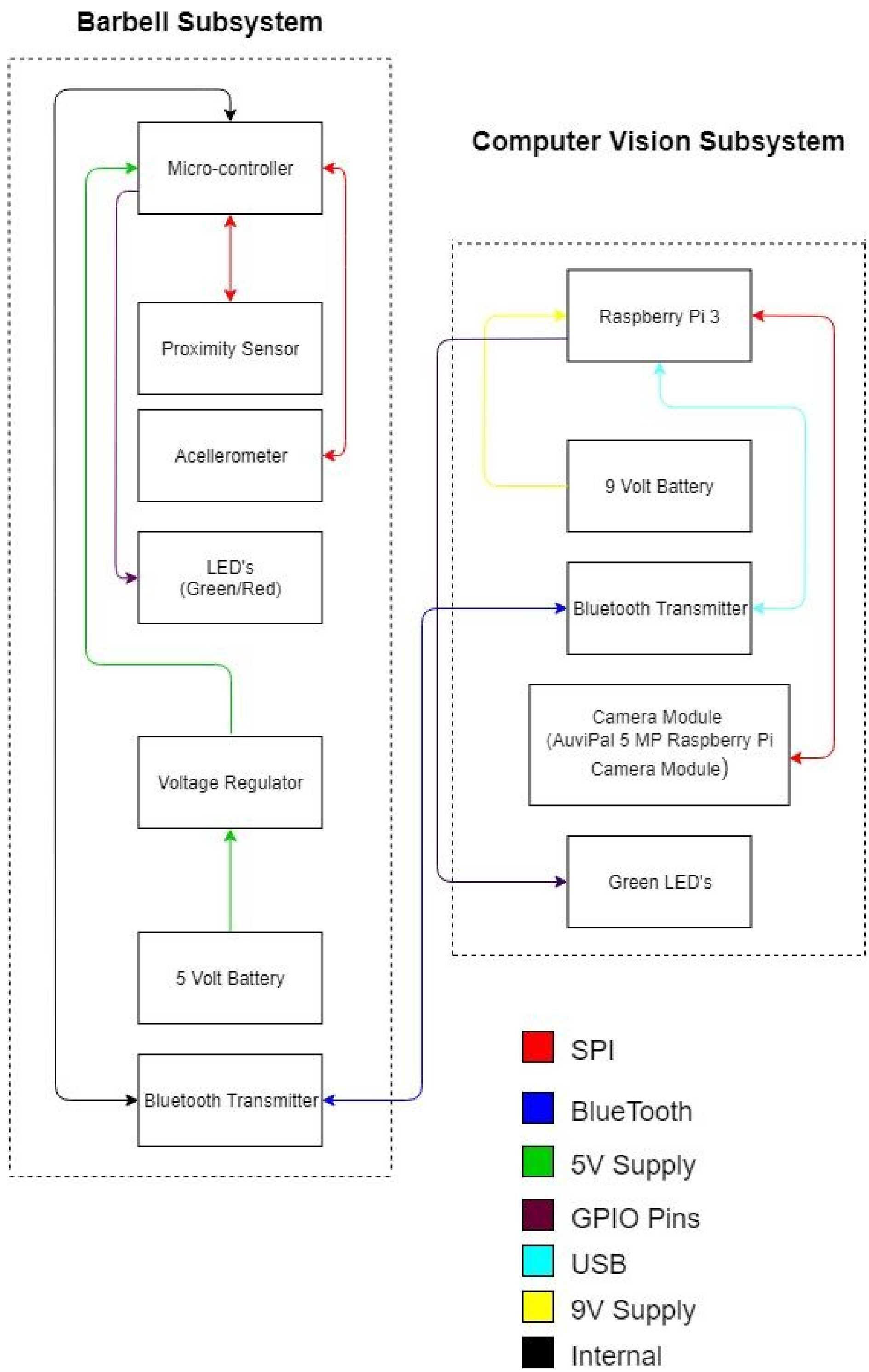


Figure 2: Deadlift Assistant Block Diagram

2.3 Physical Design

The physical design of the project will consist of two devices, one for each subsystem (see Figure 3).

The Barbell Subsystem will be held in a plastic, waterproof case to protect the module from sweat and moisture. Within the case are all the components of this subsystem. The casing contains holes on the bottom to allow the proximity sensor to detect the ground. The casing is held to the barbell via a clamp that wraps around the barbell snugly.

The other physical device is the Computer Vision Subsystem. Similar to the Barbell Subsystem, this device has all of its components contained within a see-through plastic container. It is propped up by a four-foot tall stand which is used to regulate the height at which video is recorded for all users.

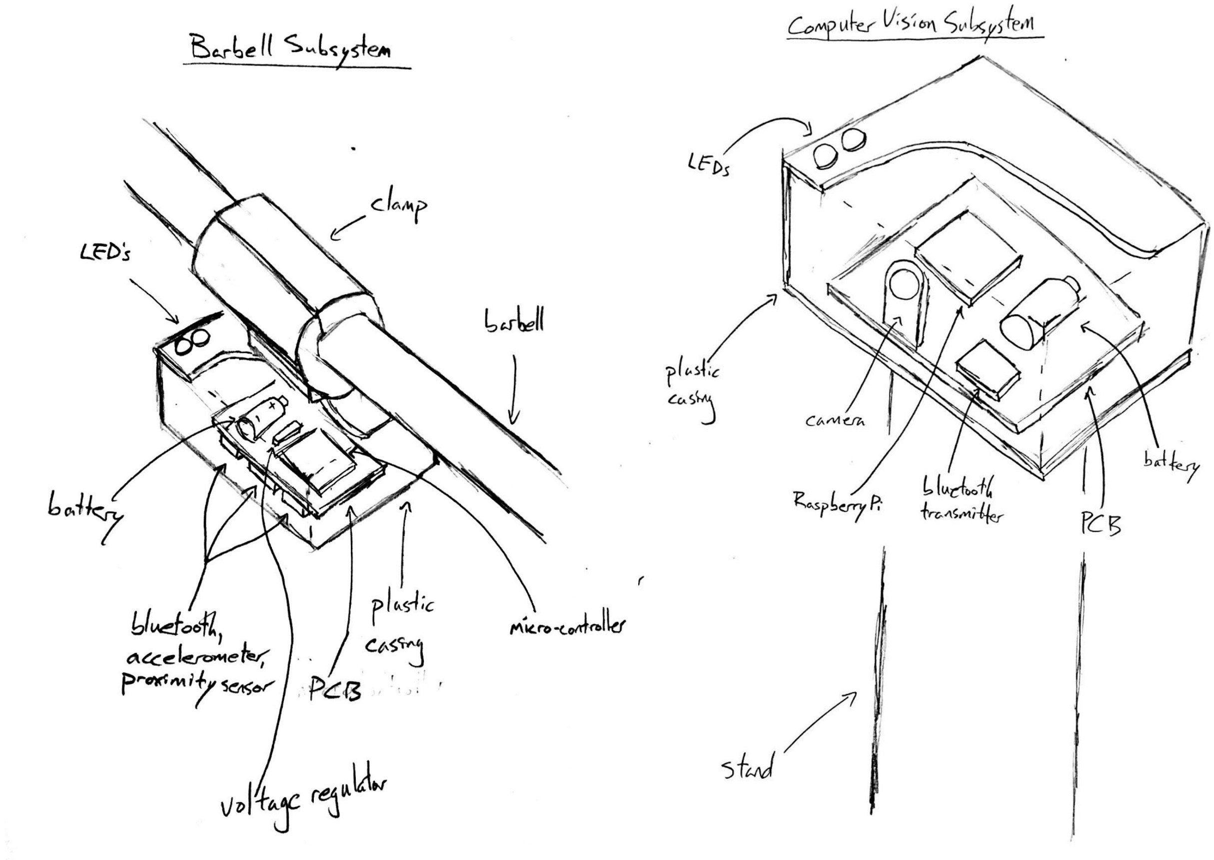


Figure 3: Physical Designs

2.4 [Barbell Subsystem]

The Barbell Subsystem is the device that is physically attached to the barbell. Its purpose is to poll information from the barbell's movement and indicate to the Computer Vision (CV) Subsystem via Bluetooth connectivity which part of the exercise the user is currently on. This is important to the success of the project since it tells the Computer Vision Subsystem when the routine has begun, when the barbell is being raised, when the barbell is being lowered, and when the routine is finished. After the routine is completed the CV Subsystem will relay back signals via Bluetooth Connectivity whether the routine was performed correctly and the appropriate LEDs will light up (Red/Green)

2.4.1 Proximity Sensor

The sections of the routine will be segmented by the coordination of the accelerometer and proximity sensors. The proximity sensor will be connected to the microcontroller chip through SPI and will indicate to the CV system when the routine has started and stopped. Proximity sensors have a smaller threshold for movement, so we are aiming for the sensor to detect height differential up to a centimeter.

Requirements	**Verifications**
1. Relays signal to the CV Subsystem is <= .5s	1. LEDs light up <= 1s after barbell lifted 2. LEDs shut off <= 1s after barbell dropped and routine finishes
2. Can detect a proximity difference at a threshold of 1 cm	1. LEDs light up <= 1s after barbell lifted 2. LEDs shut off <= 1s after barbell dropped and routine finishes 3. Test proximity differential outputs to the raspberry pi

Table 1: Requirements and Verifications for the Proximity Sensor

2.4.2 Accelerometer

The accelerometer then tells us the direction the barbell is moving. This is important because the movement and anticipated angles of a person's back is different during these two motions. So, when the accelerometer on the barbell is being raised, the CV will do one algorithm to determine proper back angles, and when the accelerometer is being lowered The CV Subsystem then critiques the user's joints' angles depending on if the current motion of the exercise is raising and lowering the bar.

Requirements	**Verifications**
1. Relays signal to the CV Subsystem is <= .5s	1. LEDs stay lit during routine 2. Check output signal and information to the Raspberry Pi 3
2. Can log when the motion changes so that it can be synced with the computer vision	1. Check output signal and information to the Raspberry Pi 3

Table 2: Requirements and Verifications for the Accelerometer

2.4.3 Voltage Regulator

Since we're using a microcontroller chip, we need to make sure the voltage rating of the chip is not violated, preventing the chip from being damaged while we're supplying power to it.

Requirements	**Verifications**
1. Can take a battery of ___V and can supply a fairly constant voltage of __V to the microcontroller	1. Use a voltmeter to make sure the regulator doesn't surpass microcontroller rating of ___[V], and to ensure that its own rating isn't being violated by the battery
2. Can connect to the power pin of the microcontroller	1. Visual inspection

Table 3: Requirements and Verifications for the Voltage Regulator

2.4.4 LEDs

The Computer Vision Subsystem will relay back signals to the Barbell Subsystem to turn on the appropriate LEDs (Green for Good form detected, Red for bad form detected). This is how the user gets feedback on their form.

Requirements	**Verifications**
1. LEDs can handle __ [A] rating	1. Ammeter detects <= __[A]
2. Light up after Computer Vision processes results	1. Visual detection of lights turning on

Table 4: Requirements and Verifications for the LEDs

2.4.5 Microcontroller chip

This microcontroller chip is responsible for coordinating the different signals coming from the sensors through SPI (Serial Peripheral Interface) and send those signals via Bluetooth connectivity to the Computer Vision Subsystem. It will be powered by the __[V] regulator to ensure it is receiving a constant and safe voltage during operation. It must not receive or give out more than ___[mA] to also ensure its ratings are not violated. It will be programmed to send proximity sensor and accelerometer data and receive signals from the CVSubsystem via BlueTooth, so it must also have internal Bluetooth capabilities that are compatible with the Raspberry Pi 3 - Model B.

Requirements	**Verifications**
1. BlueTooth compatibility with Raspberry Pi 3 - Model B	1. Analyze raspberry pi code to see if it is receiving the proper signals from the microcontroller chip
2. Pins for the voltage regulator, the proximity sensor, accelerometer, and general-purpose input/output (GPIO) pins for the LEDs	1. Look at the datasheet to ensure a sufficient amount of pins

Table 5: Requirements and Verifications for the MicroController Chip

2.5 [Computer Vision Subsystem]

Our computer vision subsystem consists of a BlueTooth transmitter, a 9V battery, a camera module, green LED's, and a RaspberryPi running our body tracking algorithm. It is the brain of our product that processes all of the data we are working with. While the camera module is recording the deadlift routine, the LED's on the Computer Vision Subsystem while being lit. After this subsystem processes the Computer Vision Algorithms and if the user has performed good or bad form, it will relay back to the Barbell System to light up the appropriate LED's on it.

2.5.1 Bluetooth transmitter

The BlueTooth transmitter here receives data from the barbell subsystem's equivalent transmitter. The information it is receiving tells the computer vision algorithm which phase of the workout the user is currently in. Once the workout motion is complete, this transmitter sends information back to the barbell subsystem's transmitter to indicate whether or not the user had good form in their workout.

Requirements	**Verifications**
1. Receives information from barbell subsystem correctly and <= .5[s]	1. "Recording" LED lights up when barbell begins moving 2. Proper signals are relayed to Raspberry Pi 3 output
2. Relays information to the barbell subsystem after the algorithm is finished	1. Correct form indicator LED lights up on barbell subsystem after deadlift motion is complete 2. Proper signals are relayed to Raspberry Pi 3 output

Table 6: Requirements and Verifications for the BlueTooth Transmitter

2.5.2 9V Battery

The battery here provides power to the entire subsystem.

Requirements	**Verifications**
1. Battery powers entire subsystem	1. Power indicators on RaspberryPi light up, "recording" LED lights up during the workout

Table 7: Requirements and Verifications for the 9-volt Battery

2.5.3 Camera Module

The camera module is used to record video of the user while they are performing the deadlift exercise. It starts and stops recording video according to the data received by this subsystem's BlueTooth transmitter. We are using a 5-megapixel camera. This quality of the video is high enough to allow our computer vision algorithm to clearly recognize the user's body in the video and is low enough to make sure that we don't have too much video processing overhead.

Requirements	**Verifications**
1. Begins recording at deadlift movement start	1. Recording LED lights up at the start of workout motion 2. Film starts when the proximity sensor is above the baseline height
2. Stops recording at deadlift movement end	1. Recording LED turns off at the end of workout motion 2. Film starts when the proximity sensor is back at the baseline height

Table 8: Requirements and Verifications for the Camera Module

2.5.5 Recording LED

This LED is used to indicate if the camera is recording.

Requirements	**Verifications**
1. The LED's lights up during deadlift motion	1. LED only turns on when motion is in progress
2. LED turns off when deadlift motion is over	1. LED is off otherwise

Table 9: Requirements and Verifications for the Recording LED

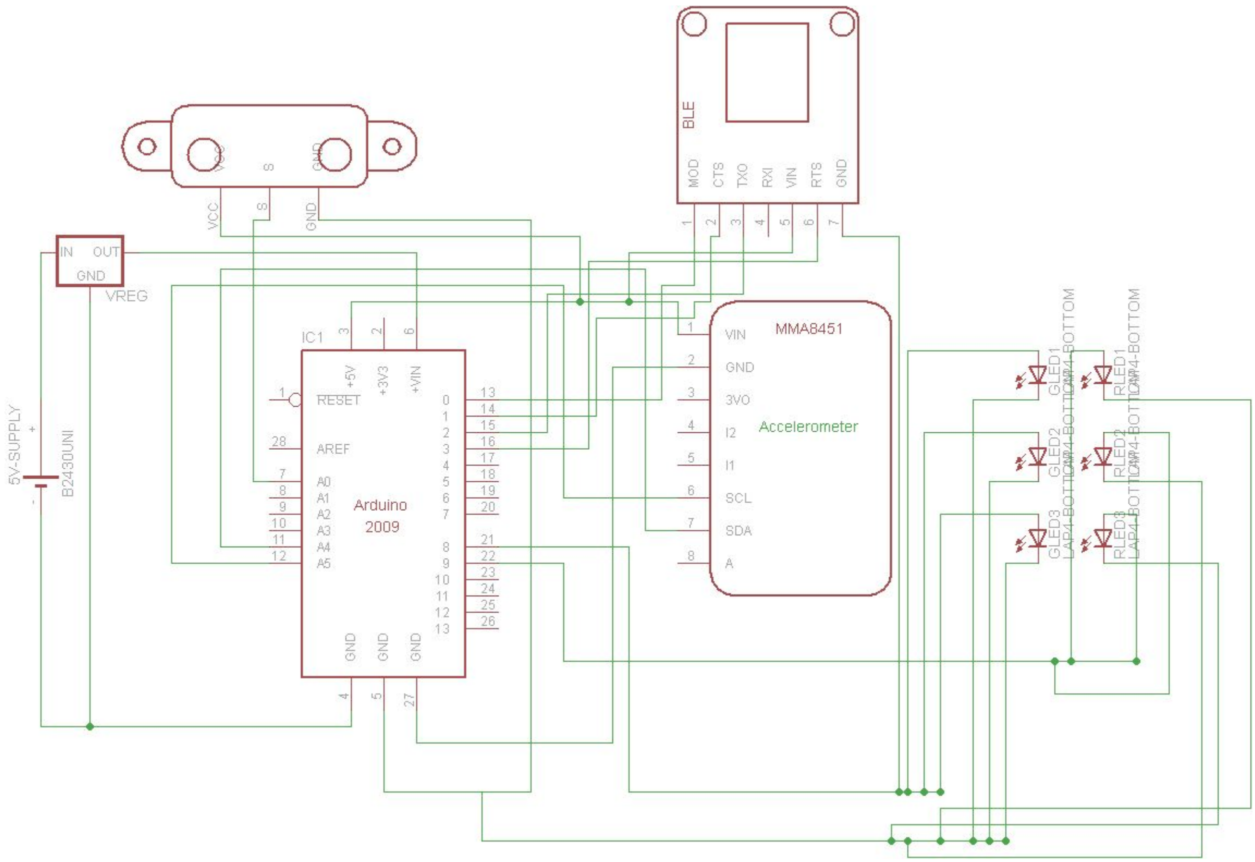
2.5.6 RaspberryPi 3

The RaspberryPi is used to process all of the data received from the barbell subsystem as well as the camera module. It runs a body-tracking algorithm, multi-person pose estimation, developed by the Perceptual Computing Lab at Carnegie Mellon University [7] to track the user while they are performing the exercise based on the data received from the barbell subsystem and the camera module. Our modified version of the algorithm also calculates the angles at every joint in the model in order to provide deadlift technique feedback. The RaspberryPi takes the output of our algorithm and sends it back to the barbell subsystem via the BlueTooth transmitters.

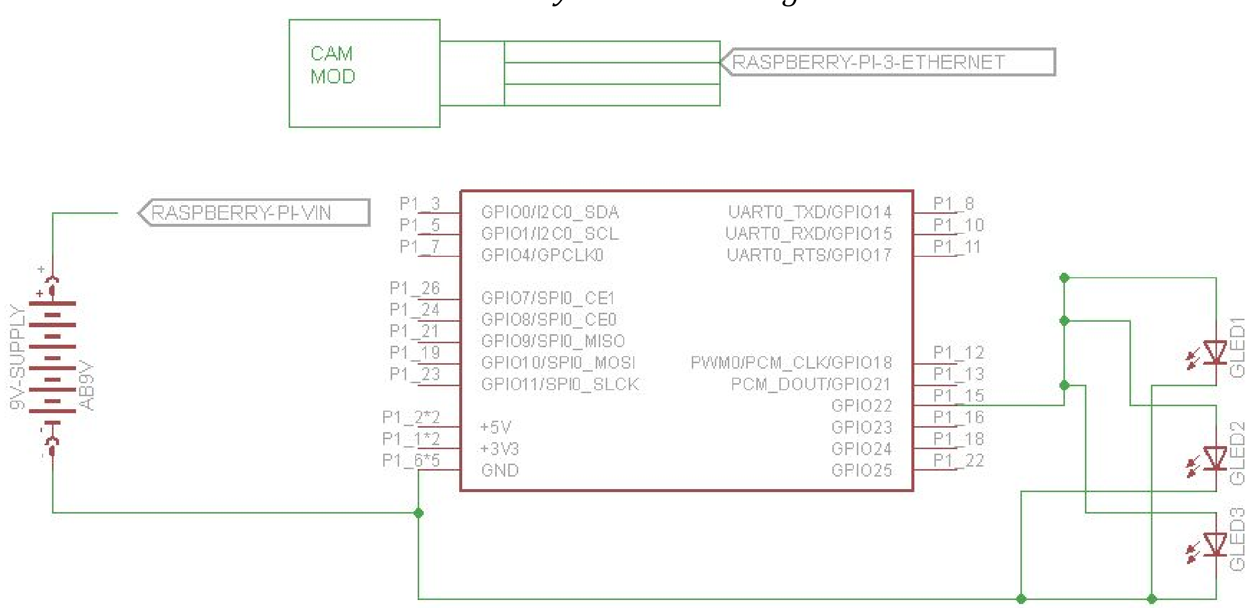
Requirements	**Verifications**
1. Receives data from the barbell subsystem and camera module	1. Feedback is correct based on user technique as shown on barbell subsystem LEDs 2. Analyze input signals Raspberry Pi is receiving via bluetooth and pins
2. Returns feedback via BlueTooth transmitters	1. Analyze input signals Raspberry Pi is giving out via bluetooth 2. Proper LEDs light up after routine

Table 10: Requirements and Verifications for the Raspberry Pi 3

2.6 Schematics



Barbell Subsystem Circuit Diagram



Computer Vision Subsystem Circuit Diagram

2.7 Tolerance Analysis

In the context of our project, the most critical tolerance that we must maintain is the analysis of joint angles in our computer vision algorithm. We must have very accurate calculations in order to prevent injury in users.

Our algorithm's calculated angles are compared to an ideal deadlift form to determine if the user had good or bad form in their motion. We will run our algorithm on a professional weight lifter performing a deadlift to get an ideal model of joint angles for our program.

We will be using the Multi-Person Pose Estimation algorithm [7] to recognize the human body and its joints through video. With some basic calculus, we can take the lines drawn in this algorithm (see Figure 4) to calculate the angles at each joint and compare them with ideal deadlift angles calculated through the same process with a professional's technique.

The calculus we require is as follows.

$$\emptyset = \theta_1 - \theta_2$$

$$or, \tan\emptyset = \tan(\theta_1 - \theta_2)$$

$$or, \tan\emptyset = \frac{\tan\theta_1 - \tan\theta_2}{1 + \tan\theta_1 \tan\theta_2}$$

$$or, \tan\emptyset = \frac{m_1 - m_2}{1 + m_1 m_2}$$

$$or, \emptyset = \tan^{-1}\left(\frac{m_1 - m_2}{1 + m_1 m_2}\right)$$

In order to make sure that our algorithm provides accurate feedback on a user's form, we will maintain a small window of error to be considered "good" form, a range of $\pm 5\,°$ in leg joints and $\pm 3\,°$ in back joints from the ideal model.

Figure 4: Current output of the algorithm without angles

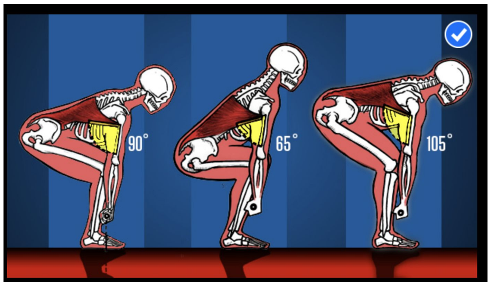


Figure 5: Proper joint-angle references [8]

3 Cost and Schedule

3.1 Labor Costs

We are working as a team of three engineers to develop this project. Using the average UIUC ECE new-graduate annual salary as of 2016-17 of $96,518, we can get a rough estimate on the cost it would require to develop this project in industry. Assuming that this salary is the outcome of 40 hour work weeks, 52 weeks a year, the hourly pay for ECE new-grads is $46.40. This course is 16 weeks long, and each of us put in, on average, 15 hours a week for this course. With all these assumptions, the development cost for this product would be ($46.40/hour)(16 weeks)(15 hours/week)(3 students) = $33,408.

3.2 Parts Cost

Part Name	Part Description	Cost
Raspberry Pi 3 Model B Motherboard	Used for Computer Vision processing	$35.88
Bluetooth Transmitter: ideapro USB Bluetooth Adapter	Relays signals back and forth between Raspberry Pi and Barbell Subsystem Microcontroller	$7.99
Proximity Sensor: Adafruit IR distance sensor includes cable (10cm-80cm) - GP2Y0A21YK0F [ADA164]	Senses when the barbell is on the ground or not	$20.19
Accelerometer: Gy-521 MPU-6050 MPU6050 Module 3 Axis Analog Gyro Sensors+ 3 Axis Accelerometer Module	Tracks motion of the barbell	$5.86
5-Volt Regulator: 5v Regulator, DROK 5pcs Mini Voltage Reducer DC	Ensures the power supply the appropriate voltage to the Barbell Microcontroller	$8.99
9-Volt Battery: Energizer E522 Max 9V Alkaline battery	Powers the CV Subsystem	$8.04
Red and Green LED's:	Indicates when the camera is recording, good form, and bad form	$9.88
Camera Module: Dorhea Raspberry Pi 4 B 3 B+ Camera Module	Records deadlift routine	$21.59
Micro-Controller: KeeYees ESP32 ESP-32S Development Board	Coordinates and relays back and forth between the subsystems	$12.99

Table 11: Cost Analysis Table

3.3 Total Cost

Development cost + Parts cost = $131.41

3.4 Schedule

Week	Sean	Johan	Nosa
10/07	Clean up existing code	Formulate math for angle calculations	Order parts
10/14	Optimize code	Integrate joint-angle calculations in the algorithm	Determine how to build plastic casings
10/21	Learn how to work with RaspberryPi	Update code for I/O with hardware	Piece together hardware
10/28	Integrate hardware feedback into the algorithm	Integrate hardware feedback into the algorithm	Verify that hardware works with each other
11/04	Define specific values for joint angles in algorithm	Define specific values for joint angles in algorithm	solder parts at a time for modularity
11/11	Initial testing in controlled setting	Initial testing in controlled setting	Initial testing in controlled setting
11/18	Testing in public gym setting	Testing in public gym setting	Testing in public gym setting
11/25	Algorithm optimization	Algorithm optimization	Testing in public gym setting

Table 12: Work Schedule

4 Discussion of Ethics and Safety

There are a handful of safety hazards that we must consider with our project. Because our project is meant to be commercialized within the fitness community, all of the intrinsic safety hazards that come with working out are attached to our product. In accordance to the IEEE Code of Ethics #1, we need to inform the public about any dangers that can come with the use of our equipment [5]. Injuries due to poor form as well as miscellaneous accidents that can occur in the gym are things we must consider while designing our product.

Luckily, as our product does not require any peripherals to be placed on the user, there are very few added physical risks when using our product beyond the regular risks of working out.

The most common injury that occurs when performing a deadlift is straining your back due to too much curvature in the back while moving the barbell up during the concentric phase of the exercise. To address this issue, we need to make sure that our algorithm places extra emphasis on analyzing back angles correctly. In order to do this, we will be more strict with the allowed angles in the back joints in our model. For example, while we may allow a range of $\pm 5°$ from the ideal angle for knee bend to constitute good form, we will restrict the back curve range to $\pm 3°$ from the ideal angle. This extra emphasis on back angles will make sure that our algorithm only tells the user they have good form when their back matches the ideal model more closely.

Another risk that our product faces is short-circuiting due to being in a gym. Spilled water and sweat are things that we need to be wary of when designing our product. While the computer vision subsystem will not be in direct contact with our users, the barbell subsystem will be because it will be attached to the barbell that the user is moving. We need to make sure that the barbell subsystem is water-proof so that it cannot short-circuit and hurt the users. In order to accomplish this, we will be placing the barbell subsystem in a plastic casing that will protect it from liquids. Protection from liquids should be sufficient in preventing short-circuiting, but in the case that our device still short-circuits, we will be attaching the barbell-subsystem to the actual barbell via a clamp that separates the electronics from physically touching the barbell. This way, users can use our device without any risk of being electrocuted.

Citations

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