LiftSense Barbell Collars

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Abstract

LiftSense Barbell Collars are a pair of weightlifting collars intended to provide the recreational Olympic Lifter with the necessary feedback to improve his or her Olympic Lifts. The LiftSense Barbell Collars in conjunction with a fully integrated python application allows the lifter to see his or her barbell path, velocity versus time, and peak velocity for every lift that he or she performs. The python application uses the built-in webcam of the PC to successfully track the barbell path in real-time using computer vision. The python application also simultaneously pulls data via Bluetooth from the inertial measurement unit (IMU) embedded in the LiftSense Barbell Collars to determine the velocity versus time and peak velocity of every lift. These metrics work jointly to provide the necessary critique to the Olympic Lifter on how to refine his or her technique.

Contents

1. Introduction

Olympic weightlifting is a sport that comprises of two lifts - the clean and jerk and the snatch. The clean and jerk is the movement of a barbell from the ground to the shoulders, then from the shoulders to overhead. The snatch is the movement of a barbell from the ground to overhead in one movement. Both lifts require a very high level of technical skill and years of practice to master. The optimal technique for both of these lifts is for the barbell to travel at a 180-degree angle from the ground to overhead with little deviation [1]. Also, it is imperative to accelerate the barbell as fast as possible in between the second pull (above the knee to full hip extension) and the third pull (full hip extension to receiving the barbell on the shoulders or overhead) [2]. All this must be done while maintaining a high velocity on the barbell throughout both pulls of the lift.

The main challenge with Olympic weightlifting is developing the precise technique required for a successful lift. Many recreational Olympic weightlifters do not have access to a coach who watches and critiques their every lift. As a result, creating a way for the recreational Olympic weightlifter to view their barbell path, velocity versus time, and peak velocity allows them to receive the feedback necessary to make significant improvements without the need of a personal coach. Some solutions attempt to characterize the important metrics in Olympic weightlifting, but these solutions are not viable for the recreational Olympic weightlifter. For example, professional Chinese Olympic lifters routinely use an “Instant Lift Assessment System Presentation”, which is a Microsoft Kinect camera system that provides real-time measurement and instant feedback of barbell path, barbell height, barbell velocity, barbell acceleration, and horizontal barbell displacement [3]. This system is used for every professional Chinese weightlifter during every training session thus demonstrating the importance of such metrics. Unfortunately, these systems are very expensive and are unrealistic for the recreational Olympic weightlifter. On the other hand, a few app developers have created affordable phone applications to track just the barbell path. Although phone applications are a more viable solution for the recreational Olympic weightlifter, numerous reviews of these applications have reported inaccuracies in these applications concerning the barbell path tracking [4].

1.1 Objective

Our solution is to create two barbell collars that will be placed on either end of the barbell. One of these collars will be equipped with a low-cost IMU to determine the peak velocity of the barbell. The other attachment will serve as a counterweight to the attachment containing the electronic components, so that weight is equally distributed across the barbell. The acceleration data gathered from the LiftSense barbell collars will be processed to determine the velocity versus time and peak velocity. This data will be displayed on a python application. Additionally, the python application will utilize computer vision algorithms to track the barbell path in real-time. The python application will display the barbell path, velocity versus time, and peak velocity for every lift completed by the Olympic weightlifter. LiftSense barbell collars will accurately capture the important metrics necessary for improving Olympic lifting technique while being at an affordable price for the recreational Olympic lifter or small gym owners.

1.2 Block Diagram

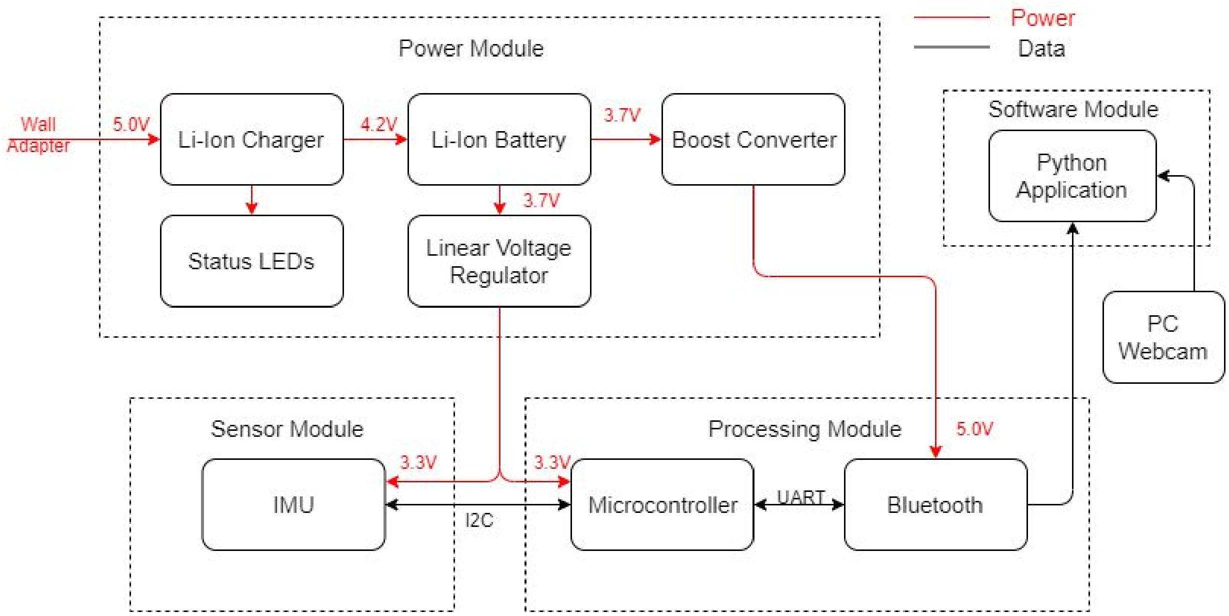

Figure 1. Top-Level Diagram

Figure 1. shows the block diagram of subsystems and interconnections. There are four main modules: Power, sensor, processing, and software.

2. Design

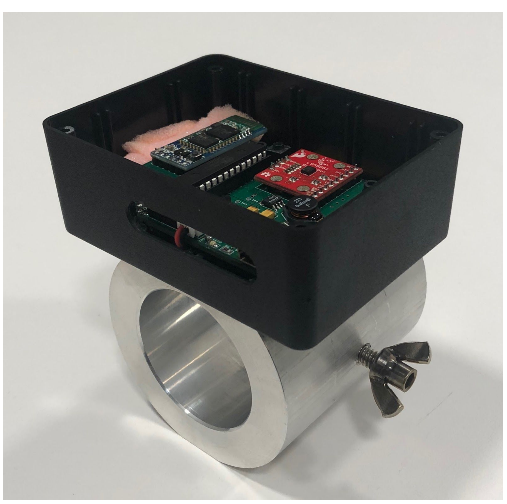

Figure 2. LiftSense Barbell Collar Full Design

Figure 2. illustrates the full design of LiftSense Barbell Collars. This design features an electronic components encasing, which is bolted to a lightweight, yet durable steel barbell clamp.

2.1 Power System

The power system consists of five modular components: Li-ion battery, Li-ion charger, status LEDs, linear voltage regulator, and boost converter.

2.1.1 Li-Ion Battery

Due to the fact that the device needs to be portable, the LiftSense Barbell Collars which contain the components will need a rechargeable Li-Ion battery to power it. The battery chosen for this project is a 3.7 V, 500 mAh battery to power the IMU, Bluetooth, and microcontroller modules. The Micro-Lipo Charger will charge the battery, and when fully charged, the battery voltage will be 4.2 V. The battery will feed into two different DC-DC converters - a linear voltage regulator and a boost converter. The battery is compact to fit within the encasing containing the other components. This is why an energy capacity of 500 mAh was chosen, as larger capacities result in larger batteries which may be too large for our encasing. The 500 mAh battery allows for the project to optimize energy capacity while also limiting size.

2.1.2 Li-Ion Charger

LiftSense barbell attachments will use rechargeable Lithium-Ion batteries so that the device will be portable and able to attach to the barbell without needing to be plugged into a wall outlet. As such, a charger is necessary to convert 120 V AC from the wall into the 3.7 V DC necessary to charge the battery. This project will utilize a standard 5 V, 1 A wall plug and micro-USB cable which will be connected to a lithium-ion battery charger IC. The charger IC can be programmed to charge at various currents by using different programming resistors, but for the purposes of this project, the IC will be programmed to charge at 500 mAh to keep charge times below 1.5 hours.

2.1.3 Status LEDs

Status LEDs will be used to show whether the Lithium-Ion batteries are charging (indicated by a red LED) or fully charged (indicated by a green LED). When the device is fully charged, the red LED will turn off and the green LED will turn on. The LEDs operate safely with a current draw of 2 mA.

2.1.4 Linear Voltage Regulator

Since many components within the encasing are rated at voltages different than the voltage that the battery provides, various DC-DC converters are necessary to meet the voltage needs of each component. The first DC-DC converter, a linear voltage regulator, will take the DC voltage from the Li-Ion battery and lower the voltage so the other components can be powered safely. The linear voltage regulator lowers the voltage from the battery to 3.3 V at a max of 250 mA.

2.1.5 Boost Converter

As shown in Figure 1., the Bluetooth module requires 5 V. Given the fact that the lithium-ion battery only supplies as much as 4.2 V at full charge, a boost converter is necessary for the power module to take the lower voltage from the battery and step it up to a higher voltage for the Bluetooth module.

2.2 Sensor System

The sensor system consists of the IMU.

2.2.1 IMU

The IMU chosen for this project was the LSM9DS1. This IMU contains an accelerometer, gyroscope, and magnetometer. The accelerometer measures linear acceleration in the x, y and z directions. The gyroscope measures angular velocity. The magnetometer measures magnetic field strength. These nine degrees of freedom were needed to calculate roll, pitch, and yaw. The importance of the roll, pitch, and yaw is that it is used to determine the orientation of the LiftSense Barbell Collar relative to the gravity vector. Therefore, the true acceleration value can be determined by taking the acceleration measurement from the accelerometer and subtracting the gravity vector.

2.3 Processing System

The processing system consists of two modular components: Microcontroller, and HC-05 Bluetooth module.

2.3.1 Microcontroller

The microcontroller chosen for this project was the ATMega328P. For this project, the microcontroller was used to pull data from the IMU via I2C when a lift has begun. The data gathered from the IMU is then used to calculate roll, pitch, yaw. Once these calculations have been conducted, the roll, pitch, yaw, and acceleration in the x, y and z directions are sent to the HC-05 Bluetooth module via UART. The reason for choosing this microcontroller was its ability to interface with the Arduino IDE as well as its ability to transmit data via both UART and I2C.

2.3.2 Bluetooth

The Bluetooth module chosen for this project was the HC-05. The purpose of the HC-05 Bluetooth module was to have wireless data transmission functionality. The HC-05 Bluetooth module establishes a serial port connection to the PC which enables the PC to receive the data from the IMU once the lift is complete.

2.4 Software System

The software system consists of the python application and interfaces with the built-in PC webcam.

2.4.1 Python Application

The python application contains two components within the fully-integrated script. The first component performs trapezoidal integration on the true acceleration data received via Bluetooth. As a result, velocity vs. time and peak velocity can now be obtained. The second component utilizes computer vision to track the barbell path. The computer vision algorithm first prompts the user for the color which wants to be tracked. Based on the user input, a lower and upper bound for this color is set in the RGB color space. These lower and upper bound values are then converted to the HSV color space since it is easier to distinguish color in the HSV color space versus the RGB color space. Subsequently, localization and filtering of this object being tracked are conducted. The centroid of this object is then calculated and stored in a deque data structure. The deque data structure was chosen because of its O(1) time complexity for all operations. The barbell path is then displayed by drawing a line between the previous centroid position and the current centroid position. The advantages of using this algorithm is that tracking color is much faster than tracking an object using a neural network. However, the disadvantage of this algorithm is that interference will likely occur when two objects in the same frame have the same color.

2.4.2 Computer Webcam

The built-in PC webcam is used to determine the barbell path through computer vision.

3. Design Verification

The verification of LiftSense Barbell Collars was a fully integrated test of the four modules of this project. To ensure this project functioned as expected, modular design and unit testing were used to verify that each component performed individually before being integrated.

3.1 Power System Verification

Table 4. depicts the details of the requirements and verifications for the power module. The HC-05 Bluetooth module flashes red upon switching the LiftSense Barbell Collars on, indicating the functionality of the boost converter. The status LEDs are red when the LiftSense Barbell Collars are charging and green when fully charged, demonstrating that the wall adapter is supplying 5V to the Li-Ion charger. Finally, the microcontroller and IMU function as expected, indicating that the 3.7 V Li-Ion battery is being regulated by the linear voltage regulator to supply 3.3 V.

3.2 Sensor System Verification

Table 5. illustrates the details of the requirements and verifications for the sensor module. The accelerometer can measure acceleration in the x, y, and z directions with an accuracy of ±90 mg. This is a datasheet requirement and is not specific to the design. Requirements and verifications for the sensor system that are specific to this design will be discussed below in 'Processing System Verification' and 'Software System Verification'.

3.3 Processing System Verification

Table 6. outlines the details of the requirements and verifications for the processing module. It can be visually validated that 'LiftSense' is connected via Bluetooth through the Bluetooth devices icon on the PC. This indicates that the HC-05 Bluetooth module successfully connects to the PC via the COM6 serial port. Furthermore, the velocity versus time graph denotes that the microcontroller is pulling data from the IMU via I2C and is transferring that data to the HC-05 Bluetooth module via UART.

3.4 Software System Verification

Table 7. exhibits the details of the requirements and verifications for the software module. It can be visually substantiated that the centroid can track various bumper plate colors for different Olympic lifts. This is confirmed in Figure 3., in which the computer vision can accurately track the barbell path. Furthermore, the velocity versus time graph successfully indicates a discrepancy between a visually faster and slower lift, as shown in Figure 4. Finally, the peak velocity measurement designates the highest peak in the velocity versus time graph.

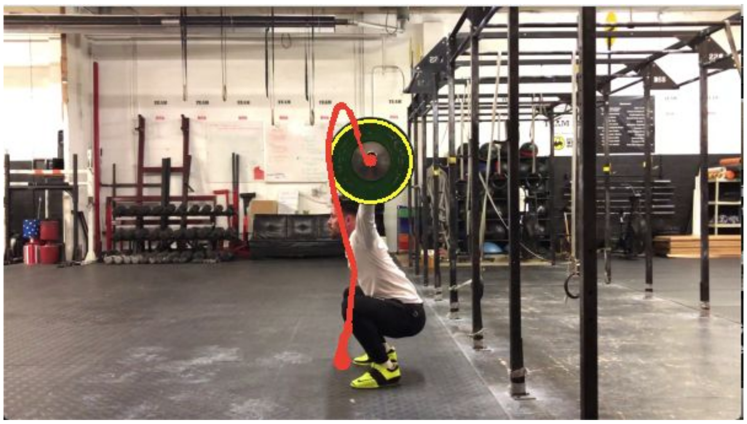

Figure 3. Barbell Path Tracking for a Snatch

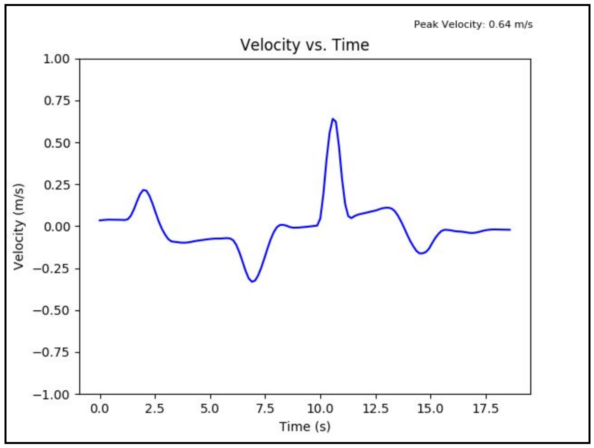

Figure 4. Velocity vs. Time for One Slow Deadlift and One Fast Deadlift

4. Costs and Schedule

As indicated in Table 1., the total parts cost for this project is \$79.00. Additionally, as specified by Table 2., the total labor cost for this project is \$48,000. Furthermore, Table 3. conveys the project schedule and task allocation that was utilized throughout the semester to complete this project successfully.

4.1 Parts

Table 1. Parts Costs

Description	Manufacturer	Part #	Quantity	Total Cost
IMU	Sparkfun	IMU Breakout - LSM9DS1	1	$15.95
Microcontroller	Microchip	ATMEGA328-P-AU	1	$2.01
Bluetooth	Amazon	DSD Tech HC-05 Bluetooth Serial Pass-through Module	1	$8.49
Li-Ion Battery	Adafruit	Lithium Ion Polymer Battery - 3.7v 500mAh	1	$7.95
Li-Ion Charger	Adafruit	Adafruit Micro-Lipo Charger for LiPo/LiIon Batt w/MicroUSB Jack - v1	1	$6.95
Voltage Regulator 3.3V	Adafruit	3.3V 250mA Linear Voltage Regulator - L4931-3.3 TO-92	1	$0.95
Voltage Regulator 5V	Adafruit	5.0V 250mA Linear Voltage Regulator - L4931-5.0 TO-92	1	$1.50
Boost Converter	Adafruit	PowerBoost 500 Basic - 5V USB Boost @ 500mA from 1.8V+	1	$9.95
ISCP USBTinyISP	Adafruit	USBTiny USBtinyISP AVR ISP Programmer Bootloader Meag2560 Uno r3 6pin Programming Cable	1	$3.24
Miscellaneous PCB Components	Various	Various	N/A	$22.01
Total				$79.00

4.2 Labor

Table 2. Labor Costs

Name	Hourly Rate	Hours	Total	Total x 2.5
Rohin Kumar	$40	160	$6,400	$16,000
Chase Johnston	$40	160	$6,400	$16,000
Ethan Filzone	$40	160	$6400	$16,000
Machine Shop	N/A	8	N/A	N/A
Total				$48,000

4.3 Schedule

Table 3. Project Schedule and Task Allocation

Week	Task	Responsibility
10/07/2019	**Design Review**	All
	Start Development of Barbell Path Tracking	Rohin
	Finalize and Submit Parts Order	Chase
	Coordinate with Machine Shop Regarding Physical Design	Ethan
10/14/2019	**Teamwork Evaluation I, and Soldering Assignment**	All
	Continued Development of Barbell Path Tracking	Rohin
	Submit PCB Order After Audit	Chase
	Submit Finalized CAD File of Physical Design for Machine Shop	Ethan
10/21/2019	**Individual Progress Reports**	All
	Finalize Barbell Path Tracking	Rohin
	Start Programming Microcontroller, IMU, Bluetooth	Chase
	Complete Development of Power Module	Ethan
10/28/2019	Transfer Raw IMU Data via Bluetooth	Rohin
	Finish Programming Microcontroller, IMU, Bluetooth	Chase
	Integrate Power Module with Sensor and Processing Module	Ethan
11/04/2019	Finish Python Application Development	Rohin
	Determine Processing Algorithms for Peak Velocity and Peak Acceleration	Chase
	Physical Packing of Components and Stress Testing LiftSense Attachments	Ethan

Table 3. Project Schedule and Task Allocation (Cont.)

11/11/2019	Integrate All Modules for Final Product and Conduct Testing	All
	Corrections to Python Application If Necessary	Rohin
	Corrections to Microcontroller, IMU, and Bluetooth	Chase
	Corrections to Physical Packing If Necessary	Ethan
11/18/2019	**Mock Demo**	All
	Start on Final Paper	Rohin
	Start on Final Presentation	Chase
	Start on Extra Credit Poster Session	Ethan
11/25/2019	Post Mock Demo Adjustments	All
	Continued Work on Final Presentation	Rohin
	Continued Work on Extra Credit Poster Session	Chase
	Continued Work on Final Paper	Ethan
12/02/2019	**Final Demo, and Mock Presentation**	All
	Finalize Presentation	Rohin
	Finalize Paper	Chase
	Finalize Presentation	Ethan
12/09/2019	**Teamwork Evaluation II, Final Presentation, Final Paper Submission, Lab Notebook Submission, and Extra Credit Poster Session**	All

5. Conclusion

5.1 Accomplishments

Our project exceeded expectations in terms of successes and functionality. The computer vision algorithm was able to very accurately track the barbell path of four distinct bumper plates colors in real-time. In addition, the computer vision algorithm was able to track the barbell path of random Olympic lifts, indicating that this aspect of our project is very robust and works not just in a test environment. The velocity versus time and peak velocity component of our project met expectations. We expected the raw data from the IMU to not be very accurate due to drift and noise; however, we were able to distinctly see relative differences in the velocity measurements between a visually faster and slower lift. Combining these two facets of our project, we were able to accomplish our objective - provide the recreational Olympic lifter with the necessary feedback to improve their Olympic lifts.

5.2 Uncertainties

Although our expectations were met for this project, certain unsatisfactory results became evident throughout the course of the semester. The IMU used in this project was inexpensive; therefore, the measurements from the IMU was not as precise and accurate in comparison to higher-priced IMUs. This lack of precision and accuracy resulted in increased noise and drift which propagated as acceleration was integrated to determine velocity.

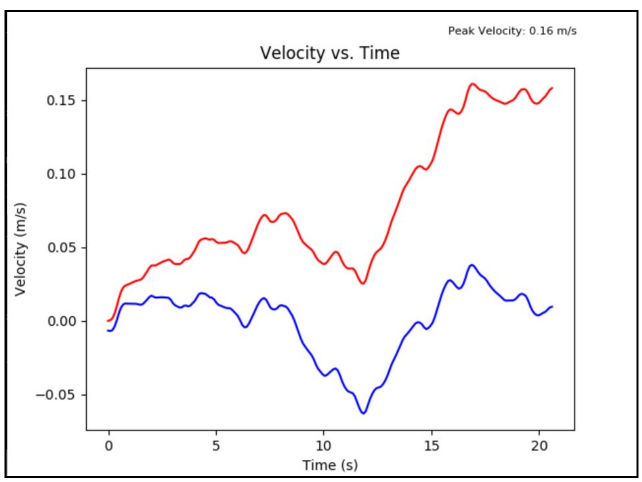

Figure 5. Comparison of LiftSense Barbell Collars at Rest With (Blue) / Without (Red) Drift Removal

Despite utilization of drift removal methods, there is approximately 0.8 m/s error in the velocity measurement, as shown in Figure 5. Achievable solutions to this uncertainty can be found in the 'Future Work' section below.

5.3 Ethical Considerations

One of the largest concerns associated with this project is the potential dangers of Lithium-Ion batteries, which have been known to malfunction and explode. Although Lithium-Ion batteries typically have built-in protection against overcharging, this malfunction could lead to serious injuries or even death, which is why these risks need to be addressed. While the chances of explosions occurring are very small and usually only happen in poorly made Lithium-Ion batteries, it is still important to design LiftSense Barbell Collars with the risks of overheating in mind in accordance with IEEE Code of Ethics #1 - “To hold the public safety first and to disclose factors of our project that might endanger the public” [12]. To mitigate these issues, Li-Ion batteries will need to be charged while the device is not in use. Additionally, the components within the encasing (PCB, IMU, and Li-Ion batteries) have been properly compartmented to avoid overheating as much as possible. This means that components have been spaced out accordingly to avoid any sort of unwanted electrical contact that could cause short-circuiting and lead to the device malfunctioning.

Also, it will be important to abide by the IEEE Code of Ethics #3 - “To be honest and realistic in stating claims or estimates based on the available data.” [12]. To comply with this statement, it must be acknowledged that the IMU being utilized in this project is low-cost. As a result, there will be some amount of error in the data being gathered from the IMU. This will ultimately result in less precise measurements that are displayed to the user. Additionally, mathematical formulas and derivations will be utilized throughout the process of converting the raw data from the IMU to determine the velocity versus time and peak velocity of the barbell. This will ensure that the user can be confident that the data visualized on the python application is accurate and will be advantageous to improving their Olympic lifting technique.

Finally, it is imperative to adhere to the IEEE Code of Ethics #9 - “To avoid injuring others, their property, reputation, or employment by false or malicious action.” [12]. Specifically, it is crucial that the LiftSense Barbell Collars are secured on the barbell and cannot injure the user during a lift. As a result, appropriate measures were taken to minimize the chance of these attachments flying off the barbell and potentially injuring the weightlifter or any bystanders. The LiftSense Barbell Collars consist of an aluminum clamp that can be adjusted to firmly fit on the barbell to ensure that the collars do not spin or slide. In addition, the encasing containing the electronic components are welded to the clamp mechanism to ensure that the encasing is secure. Also, in accordance with the high-level requirements of this project, the LiftSense Barbell Collars must be able to withstand being dropped from hip height and still be intact mechanically and electronically.

5.4 Future Work

There are three main aspects of our project that we could improve upon in the future. The first improvement that we would target is to improve the removal of drift and noise via advanced filtering techniques. This would be accomplished by utilizing a Kalman filter. A Kalman filter is a way of mitigating error in sensor measurements through the use of combining data from various sources and sensors to result in a more accurate measurement. Another facet of our project that can be refined is our front-end application. Currently, using a python application is not as user-friendly as using a phone application. Ideally, we would have both a working Android and iPhone application so that the user of LiftSense Barbell Collars has a more seamless experience. The last feature of our project that we would like to enhance is the barbell path tracking computer vision algorithm. Currently, the computer vision algorithm tracks color as opposed to an actual object. The rationale for this choice was that tracking color is faster than tracking an object. However, if we can track a bumper plate using a neural network with adequate speed, this solution would be much more accurate than the current solution.

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Appendix A Requirements and Verifications Table

Table 4. R&V Table for Power Module

Requirements	Verification
1. 3.7 V Li-Ion battery voltage is stepped up by the boost converter to supply 5 V to the HC-05 Bluetooth module. 2. Wall adapter is supplying 5 V to the Li-Ion charger. 3. 3.7 V Li-Ion battery is regulated by the linear voltage regulator to supply 3.3 V to the IMU and microcontroller.	1. A. Visually verify that the HC-05 Bluetooth module is flashing red upon switching 'On' the LiftSense Barbell Collars. 2. A. Visually confirm that status LED is 'Red' indicating that LiftSense Barbell Collars is charging when plugged into micro USB port. B. Visually confirm that status LED is 'Green' indicating that LiftSense Barbell Collars is fully charged when plugged into micro USB port. 3. A. Observe that the error message 'Failed to communicate with the LSM9DS1' is not present on the serial line. B. Visually confirm that the lift velocity versus time graph is not empty.

Table 5. R&V Table for Sensor Module

Requirements	Verification
1. The accelerometer can measure acceleration in the x, y, and z direction with an accuracy of ±90 mg.	1. A. This is a datasheet requirement and is not specific to our design.

Table 6. R&V Table for Processing Module

Requirements	Verification
1. HC-05 Bluetooth module successfully connects to the PC via the COM6 serial port at a baud rate of 38,400 Bd. 2. Microcontroller pulls data from the IMU via I2C and transfers that data to the HC-05 Bluetooth module via UART.	1. A. Visually confirm that 'Connected' is printed on the terminal when running the python script. B. Visually validate that 'LiftSense' is connected via Bluetooth through the Bluetooth devices icon on the PC.

	2. A. Velocity versus time graph indicates that this requirement is being successfully met.

Table 7. R&V Table for Software Module

Requirements	**Verification**
1. Computer vision is able to accurately track the barbell path for various bumper plate colors of red, yellow, and green using real-time video or pre-recorded video. 2. Velocity for a visually faster lift should be greater than velocity for a visually slower lift. 3. The peak velocity measurement indicates the highest peak in the Velocity vs. Time graph.	1. A. For real-time video, visually verify that the centroid is tracking a snatch for a green colored bumper plate. B. For real-time video, visually verify that the centroid is tracking a clean and jerk for a red colored bumper plate. C. For real-time video, visually verify that the centroid is tracking multiple deadlifts for a yellow colored bumper plate. D. For pre-recorded video, visually verify that the centroid is tracking a snatch for a green colored bumper plate 2. A. Velocity vs. Time graph successfully indicates a discrepancy between a faster lift and slower lift. B. The faster lift is indicated by a higher peak in the Velocity vs. Time graph. The slower lift is indicated by a lower peak in the Velocity vs. Time graph. 3. A. Visually confirm that the velocity of the highest peak in the graph is equal to the peak velocity measurement being displayed.

Appendix B Subsystem Schematics

Figure 6. depicts the schematic for the Li-Ion Charger utilized in the power module of LiftSense Barbell Collars.

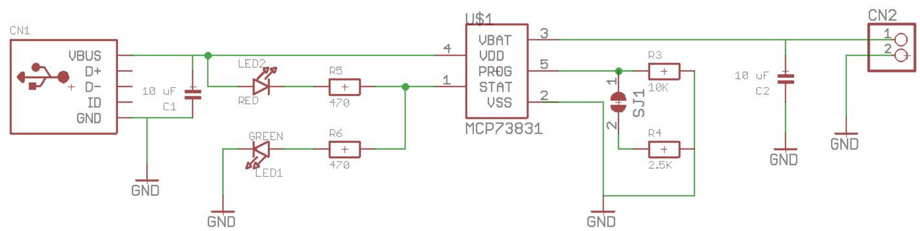

Figure 6. Li-Ion Charger Schematic

Figure 7. depicts the schematic for the linear voltage regulator utilized in the power module of LiftSense Barbell Collars.

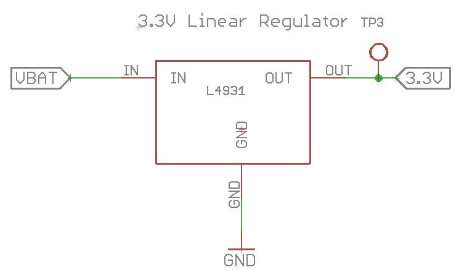

Figure 7. Linear Voltage Regulator Schematic

Figure 8. depicts the schematic for the boost converter utilized in the power module of LiftSense Barbell Collars.

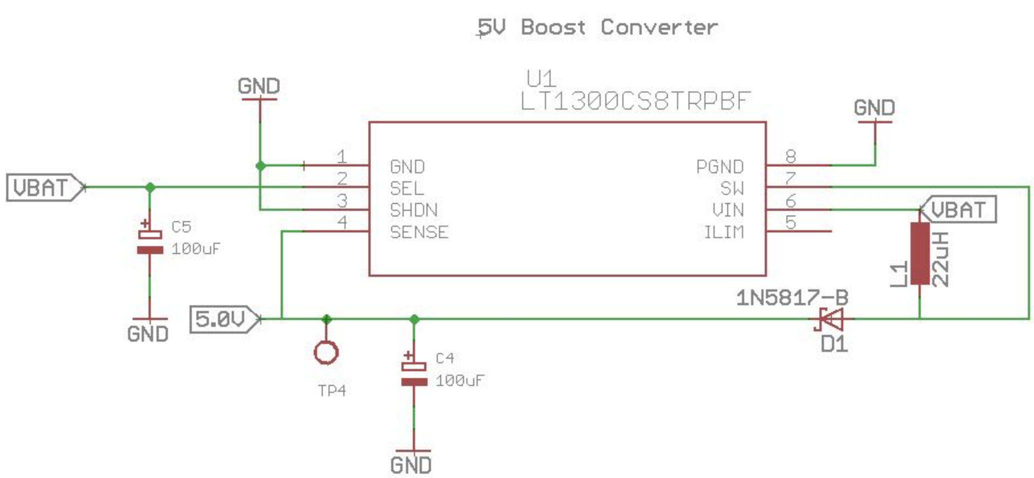

Figure 8. Boost Converter Schematic

Figure 9. depicts the schematic for the inertial measurement unit (IMU) utilized in the sensor module of LiftSense Barbell Collars.

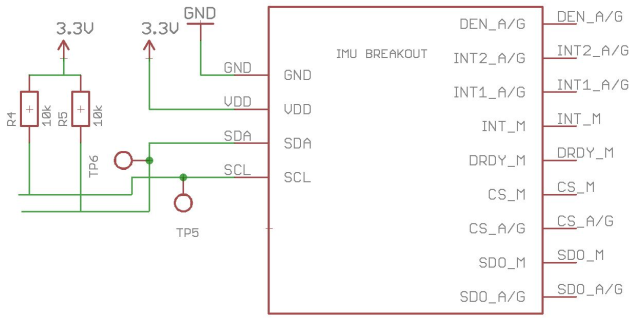

Figure 9. IMU Schematic

Figure 10. depicts the schematic for the microcontroller utilized in the processing module of LiftSense Barbell Collars.

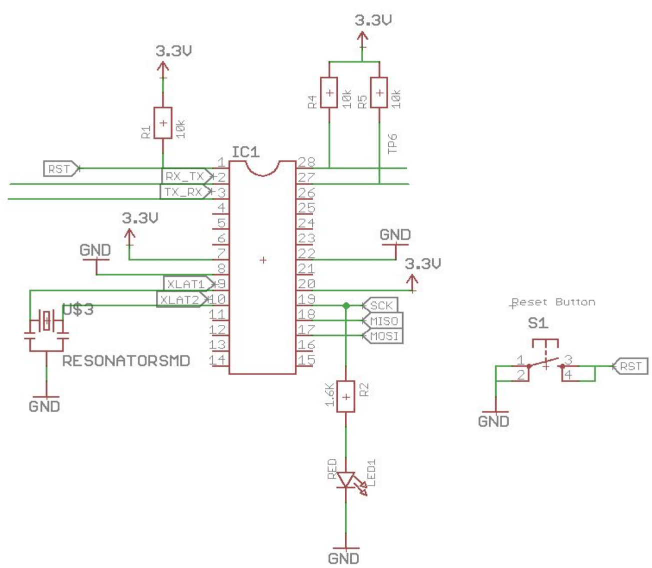

Figure 10. Microcontroller Schematic

Figure 11. depicts the schematic for the Bluetooth module utilized in the processing module of LiftSense Barbell Collars.

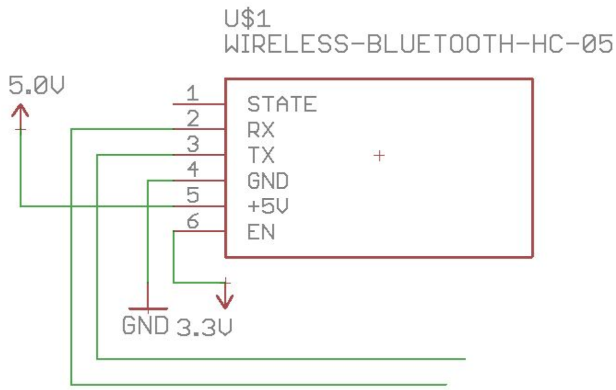

Figure 11. HC-05 Bluetooth Module Schematic