# LiftSense - Olympic Weightlifting Technique Analyzer

ECE 445 - Design Document

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# 1. Introduction

## 1.1 Problem and Solution Overview

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 of these lifts require a very high level of technique and years 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, 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].

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 inertial measurement unit (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 peak velocity and displayed on an Android application. Additionally, the Android application will utilize computer vision algorithms to track the barbell path in near-real-time. The Android application will display the barbell path, 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 Visual Aid

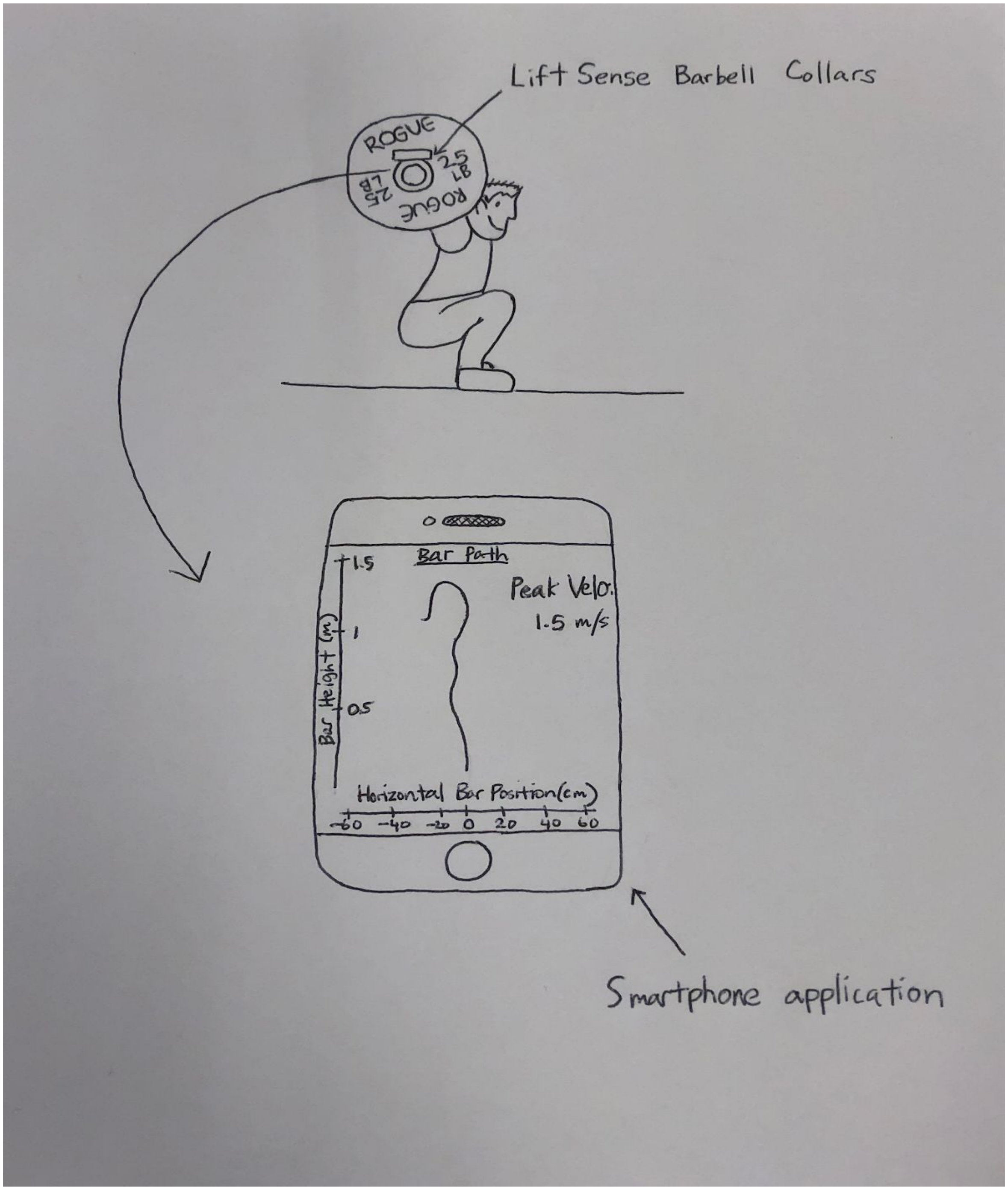


**Figure 1.** LiftSense Barbell Collars in Context

### 1.3 High-Level Requirements List

- The Olympic weightlifter must be able to see the barbell path, and peak velocity of the barbell on the Android application within at most 30 seconds after completing the lift.
- The LiftSense barbell collars must be relatively low cost, ideally under $105. High-quality weightlifting collars cost around $50-75, so LiftSense barbell collars which function as weightlifting collars while containing electronic components should be less than $105 [5].
- Both of the LiftSense barbell collars must be able to withstand being dropped from hip height and still function as intended mechanically as well as electronically.

# 2. Design

### 2.1 Block Diagram

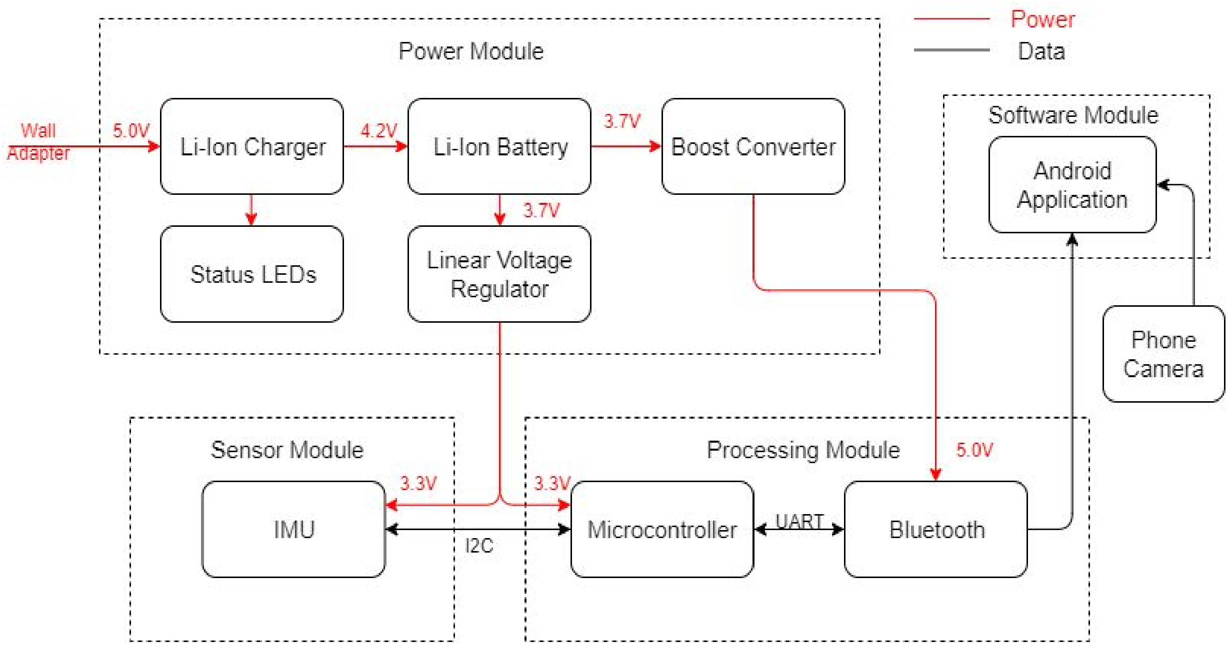


**Figure 2.** Block Diagram

## 2.2 Physical Design

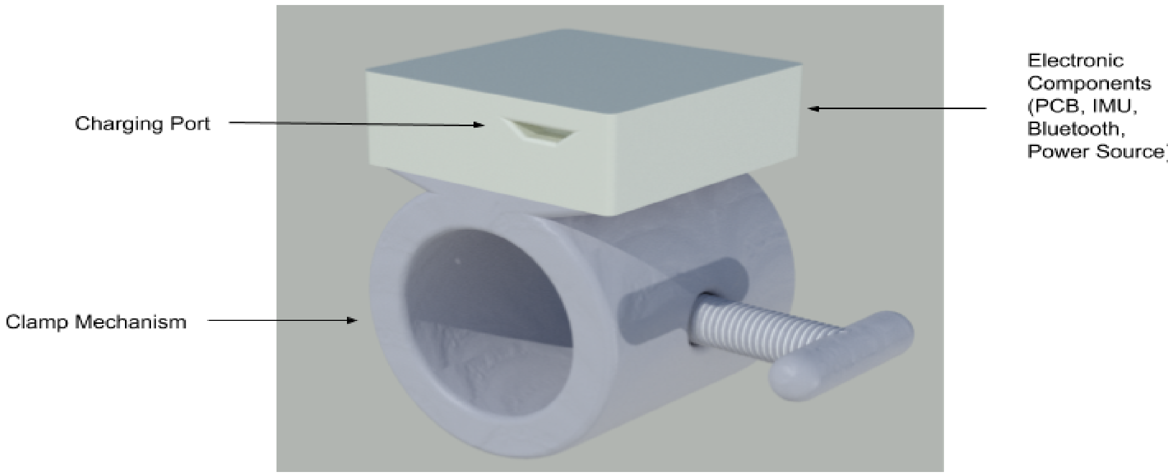


**Figure 3.** LiftSense Barbell Attachment

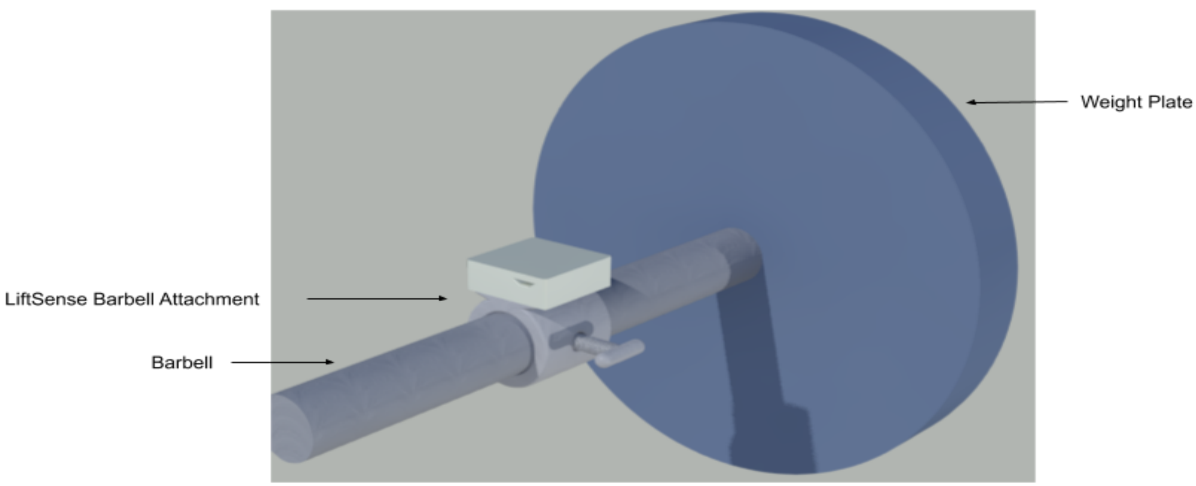


**Figure 4.** LiftSense Barbell Attachment on Barbell

## 2.3 Block Design

### 2.3.1 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 5V 1A wall plug and micro-USB cable which will be connected to an Adafruit Micro-Lipo Charger. The charger charges at a current of 100mA, but can be adjusted via soldering jumper to charge at a current of up to 555mA.

| Requirements | Verification |
|---|---|
| 1. Li-Ion battery charges to 4.15-4.25 V when a continuous 5V input voltage is applied<br>2. The Li-Ion battery must not exceed its operating limit of 45°C during charging | 1.<br>A. Completely discharge Li-Ion battery to 3.7 V.<br>B. Charge battery via the Micro-Lipo Charger with 5V.<br>C. When status LED turns from red to green, verify that the voltage across the battery is between 4.15-4.25V.<br>2.<br>A. Periodically check the temperature of the battery throughout the entire charging cycle with an IR thermometer and verify that the temperature of the battery is less than 45°C. |

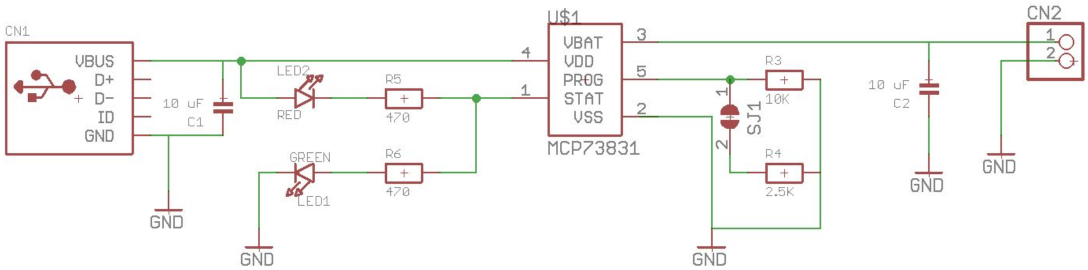


**Figure 5.** Li-Ion Charger Schematic

### 2.3.2 Li-Ion Battery

The attachment which contains the components will need a rechargeable Adafruit Lithium-Ion 3.7V, 500mAh 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 4.2V. The battery will feed into two different DC-DC converters- a linear voltage regulator and a boost converter. The battery will need to be compact to fit within the encasing containing the other components.

| Requirements | Verification |
| --- | --- |
| 1. The voltage on the Li-Ion battery must be between 3.7V - 4.2V at 500mAh | 1. <br>A. Fully charge the battery using the Micro-Lipo Charger and verify that the voltage is 4.15-4.25V using a voltmeter.<br>B. Discharge the battery fully at 500mAh for 1 hour.<br>C. Verify that the voltage is 3.5-3.9 when battery is fully discharged with a voltmeter. |

### 2.3.3 DC-DC Converters

Since some components within the encasing are rated at a lower voltage than others, various DC-DC converters are necessary to meet the voltage needs of each component.

The first component, 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. As shown in the block diagram, the Bluetooth module requires 5V. Given the fact that the lithium-ion battery only supplies as much as 4.2V at full charge, a boost converter will be necessary for the power module to take the lower voltage from the battery and will step it up to a higher voltage for the Bluetooth module. The linear voltage regulator lowers the voltage from the battery to 3.3V at a max of 250mA, and the boost converter steps up the voltage of the battery to 5V at 500mA.

| Requirements | Verification |
|---|---|
| 1. Linear voltage regulator provides 3.135-3.465V from a 3.7-4.2V source and outputs current within 0-250mA<br>2. Boost converter provides 4.75-5.25V from a 3.7-4.2V source and outputs current within 0-220mA | 1.<br>A. Use a DC power supply to provide 3.7-4.2V with a current limit of 250mA.<br>B. Measure output voltage of linear voltage regulator using an oscilloscope and verify that voltage stays between 3.135-3.465V.<br>2.<br>A. Use a DC power supply to provide 3.7-4.2V with a current limit of 220mA.<br>B. Measure output voltage across a load and verify that voltage is stepped up to 4.75-5.25V using an oscilloscope. |

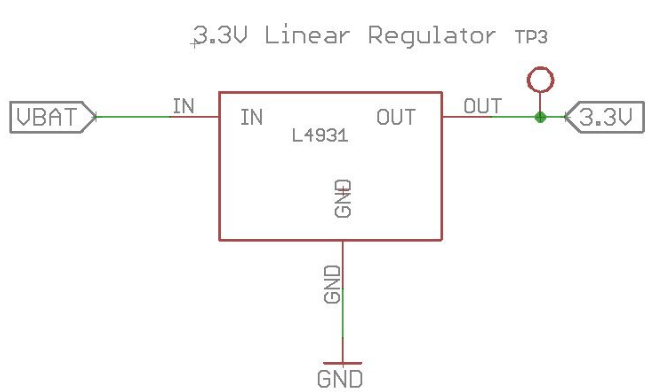


**Figure 6.** Linear Regulator Schematic

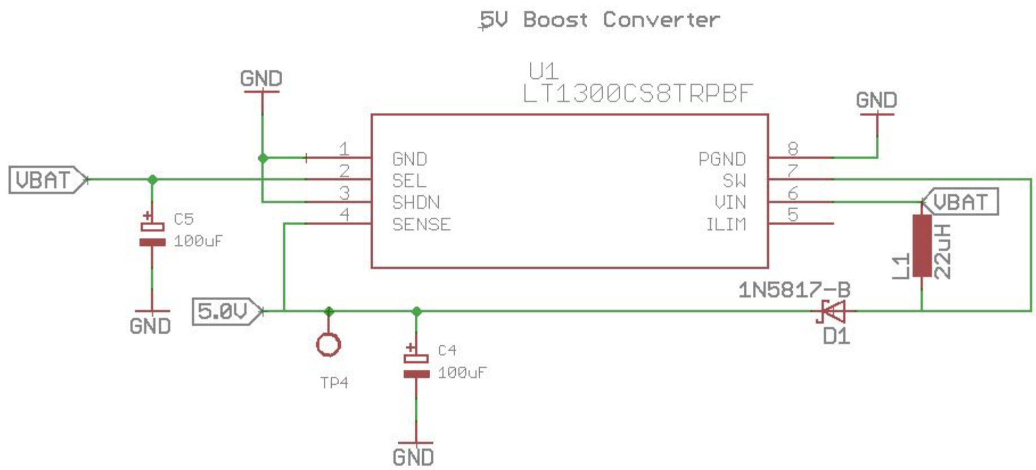


**Figure 7.** Boost Converter Schematic

### 2.3.4 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). The LEDs operate safely with a current draw of 2mA.

| Requirements | Verification |
|---|---|
| 1. Red status LED is on when the battery is charging and green status LED is on when the battery is fully charged. | 1.<br>A. Follow verification process 1. as referenced in 2.3.1. |

### 2.3.5 IMU

The Inertial Measurement Unit (IMU), the LSM9DS1 breakout board, will generate acceleration data in the x, y, and z directions. This data will be sent over I2C in standard mode (100 kbit/s) to the microcontroller to be sent to the Bluetooth module and on to the phone application. This particular IMU provides acceleration, angular velocity, and magnetic data in the x, y, and z directions in a breakout board which is low cost and easy to use. The acceleration data will be primarily used in this project, but it is helpful to have as much information as possible.

| Requirements | Verification |
| --- | --- |
| 1. Can measure acceleration in x, y, and z with accuracy of ±90mg | 1.<br>A. Connect IMU to Arduino RedBoard following LSM9DS1 Breakout Hookup Guide [7]<br>B. Set measurement range to ±16g<br>C. Orient chip so x, y, and z directions are facing down with respect to gravity following figure on page 10 of datasheet<br>D. Request data with serial monitor following Hookup Guide<br>E. Ensure acceleration is within ±90mg of 1g |

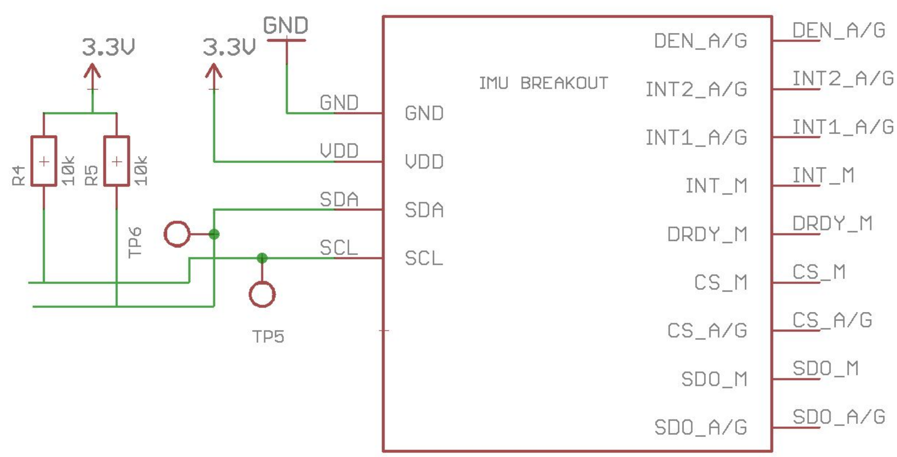


**Figure 8.** IMU Schematic

### 2.3.6 Microcontroller

The microcontroller, the ATMega328P, collects data from the IMU using I2C in standard mode at 100 kbit/s. It then sends this data to the HC-05 Bluetooth module using UART running at 115.2 kbaud rate. This easy to use microcontroller is inexpensive, compatible with the Arduino IDE, and supports UART and I2C. The microcontroller will be programmed through an ICSP (In Circuit System Programming) SPI interface using the USBTinyISP.

| Requirements | Verification |
| --- | --- |
| 1. Can both receive and transmit over UART at a speed of 115.2 Kbps.<br>2. Can both receive and transmit over I2C at at a speed of 100 kbit/s standard-mode. | 1.<br>A. Connect microcontroller to USB UART bridge such as MCP2221, and to terminal such as PuTTY.<br>B. Set up terminal to 115.2 kbaud<br>C. Send and echo 100 characters<br>D. Ensure all characters match those sent<br>2.<br>A. Connect microcontroller to USB I2C bridge such as MCP2221, and to terminal such as I2C/SMBus<br>B. Set terminal to standard mode 100 kbit/s<br>C. Send and echo 100 characters<br>D. Ensure all characters match those sent |

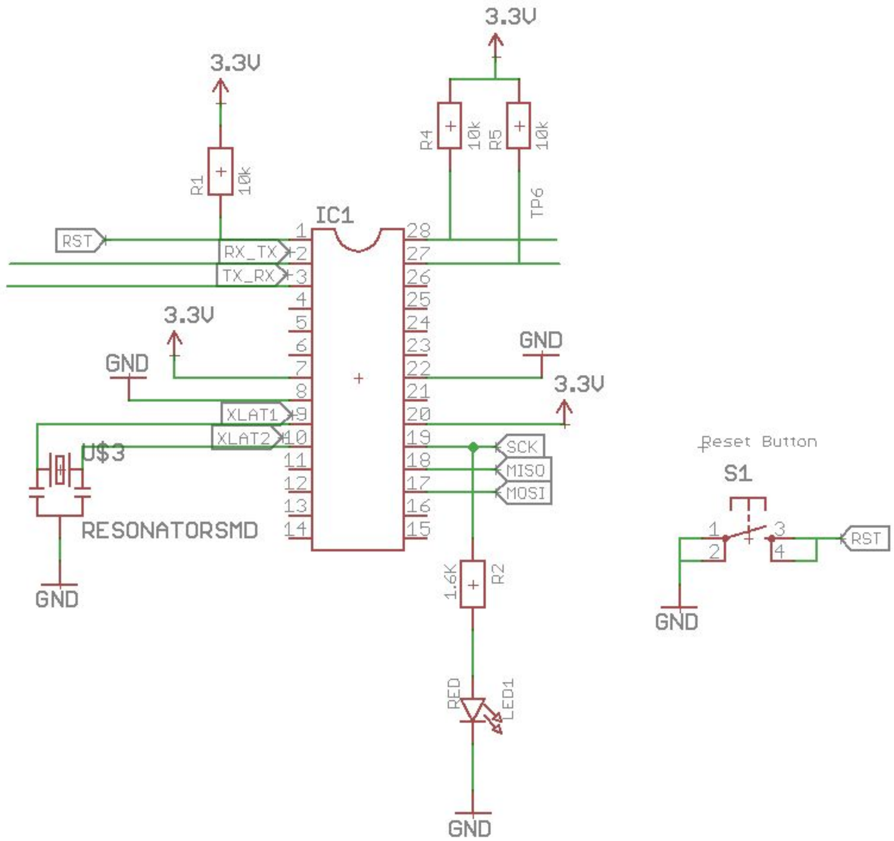


**Figure 9.** Microcontroller Schematic

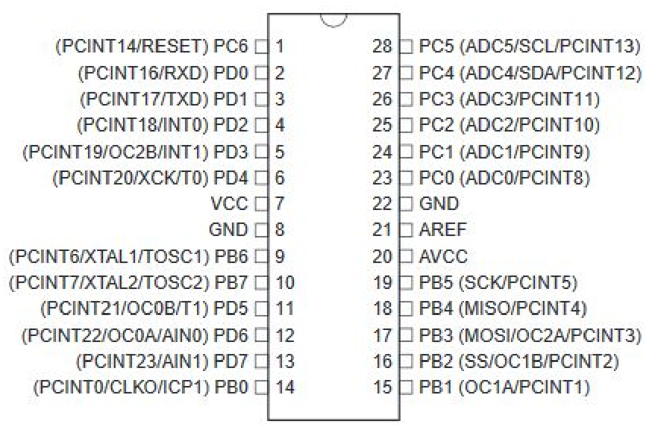


**Figure 10.** ATMega328P Pinout

### 2.3.7 Bluetooth

The Bluetooth module, the DSD TECH HC-05, will collect IMU data from the microcontroller over UART. It will then send this data to the Android application via Bluetooth communication protocol running at 2.4 GHz. [14] This project utilizes a Bluetooth module because it is easy to implement only having 5 pins to interface with, is low power, and doesn't interfere with other wireless devices. There is a push-button connected to the EN pin to put the device in AT mode.

| Requirements | Verification |
| --- | --- |
| 1. Can send and receive data using standard bluetooth communication protocol. | 1.<br>A. Connect HC-05 module and Arduino following guide in reference [15].<br>B. Use parts, code, and procedure listed on the website.<br>C. Visually verify that the LED turns off when you send the LED off command and turns on when you send the LED on command. |

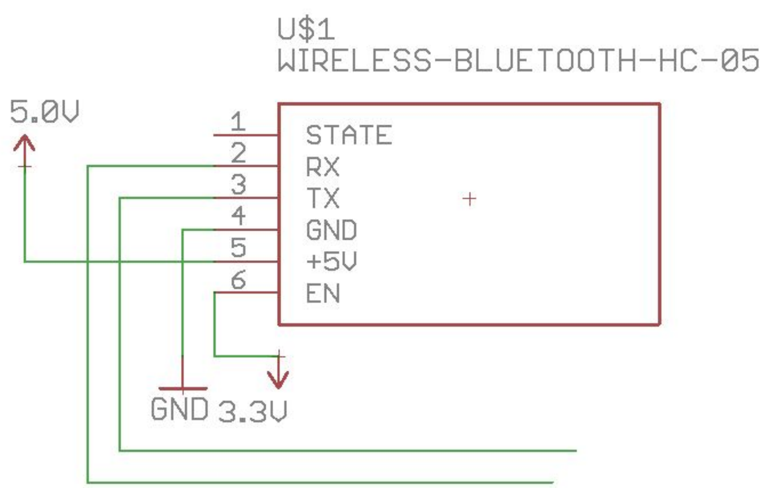


**Figure 11.** HC-05 Schematic

### 2.3.8 Android Application

The phone application will be an Android application that will be available to download on the Google Play store. The Android application will receive the raw data from the IMU via Bluetooth and perform processing on the raw data to determine the peak velocity of the barbell. Additionally, the Android application will utilize computer vision algorithms to track the barbell path during each lift. At the end of each lift, the user of the application will be able to see his/her barbell path throughout the lift and the peak velocity of the barbell during the lift.

| Requirements | Verification |
|---|---|
| 1. Maximum time of 30 seconds latency for raw IMU data to be processed and displayed on Android application from when the lift has been completed.<br>2. “New Lift” button sends enable signal to microcontroller to pull raw IMU data via bluetooth<br>3. “New Lift” button opens phone camera. | 1.<br>A. Use a stopwatch to ensure that this takes at most 30 seconds from when the phone camera has stopped recording.<br>2.<br>A. Connect Android Application to HC-05 module via bluetooth.<br>B. Connect HC-05 module to Arduino Redboard following hookup guide [15].<br>C. Send enable signal to microcontroller and confirm its value in Serial Monitor.<br>3.<br>A. Press “New Lift” button opens and visually confirm camera application on the phone. |

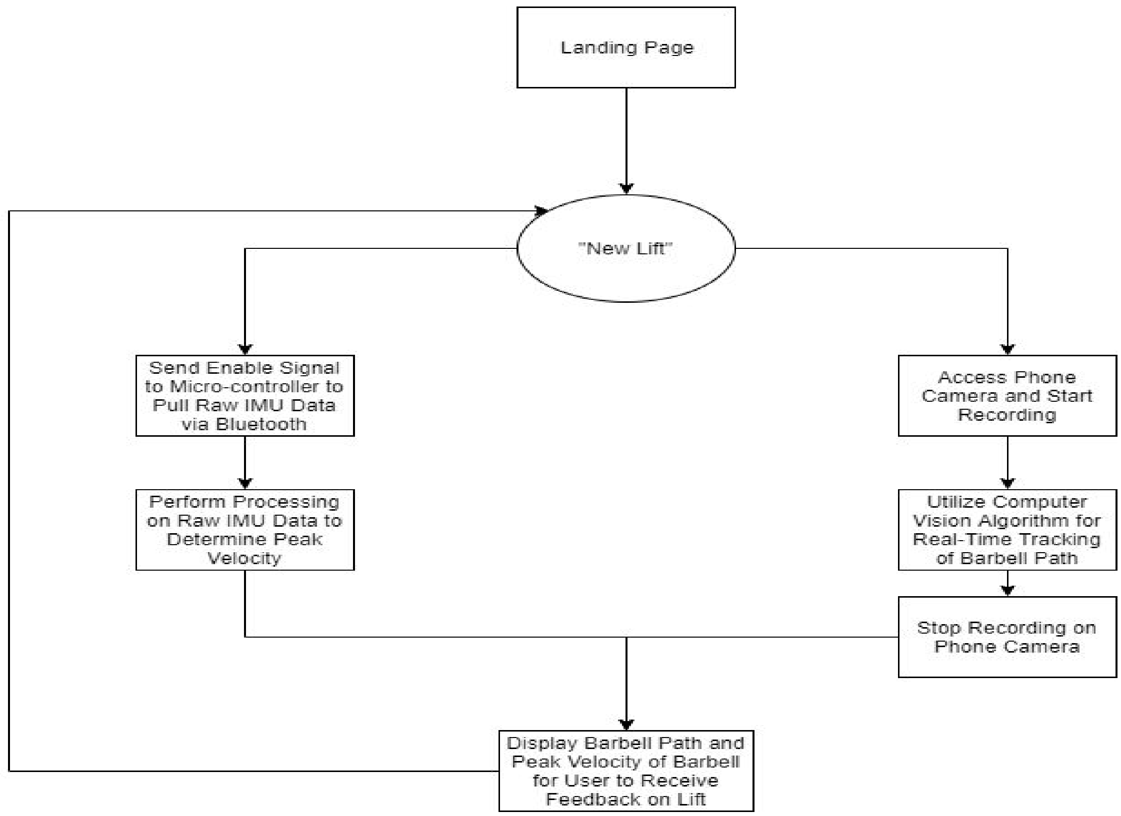


**Figure 12.** High-Level Front-End Application Flowchart

## 2.4 Tolerance Analysis

Determining the peak velocity of the barbell is critical to the success of this project. If the raw data from the IMU is unable to be processed with high precision, the Olympic weightlifter may receive a peak velocity metric with low precision. The LSM9DS1 IMU outputs a 16-bit 2's complement number for linear acceleration. If the IMU is programmed in the mode where the bounds of the acceleration are between -2g - +2g, the linear acceleration sensitivity is 0.061 mg/LSB [7]. The IMU will be programmed in this specific mode of -2g - +2g since the vertical acceleration of the barbell is usually between 0.0087-4.9000 $m/s^2$ [16].

Therefore, the linear acceleration will potentially have a precision of

$$0.061\ mg\ *\ (1\ g\ /\ 1000\ mg)\ *\ (1\ m/s^2\ /\ 0.101972\ g)\ =\ \pm 5.98\ *\ 10^{-4}\ m/s^2$$

per sample.

Assuming it takes ~1.5 seconds to complete a snatch and samples of linear acceleration are gathered every 10 milliseconds from the IMU, a total of 150 samples of linear acceleration will be gathered from the IMU per snatch.

Using the equation below to determine velocity from acceleration and the fact that 150 samples will be used per snatch in determining the peak velocity. The final velocity should be at most within

$$V_{new} = V_o + \alpha t$$

$$150\ samples * \pm 5.98 * 10^{-4}\ m/s^2 = \pm 0.08973\ m/s$$

of the actual velocity.

This error cannot be avoided due to the sensitivity of the linear acceleration for the IMU that has been chosen. The peak velocity of a well-executed snatch is between 1.52-1.67 m/s [9]. As a result, the percent error of the peak velocity from the LiftSense barbell collars should be between 5.37-5.92% from the variable of linear acceleration sensitivity.

Two other factors that will contribute to less accuracy in determining the peak velocity of the barbell is the accelerometer bias error and gyroscope bias error. For the IMU being used in this project, the linear acceleration offset accuracy is $\pm\ .09\ g's$ and the gyroscope offset accuracy is $\pm 30\ dps$ [7].

$$Velocity\ Error\ From\ Accelerometer\ Bias = (Acceleration\ Offset\ Accuracy) * (Gravity) * (Time\ in\ Seconds)$$ [17]

$$Velocity\ Error\ From\ Accelerometer\ Bias = (.09) * (9.8) * (1.5)$$

$$Velocity\ Error\ From\ Accelerometer\ Bias = 1.323\ m/s$$

$$Velocity\ Error\ From\ Gyroscope\ Bias = (1/2) * (Gyroscope\ Offset\ Accuracy) * (\pi/180) * (Gravity) * (Time\ in\ Seconds)^2$$ [17]

$$Velocity\ Error\ From\ Gyroscope\ Bias = (1/2) * (30) * (\pi/180) * (9.8) * (1.5)^2$$

$$Velocity\ Error\ From\ Gyroscope\ Bias = 5.77\ m/s$$

Although these velocity errors appear to be large in proportion to the velocity of a snatch, these sensor biases can be corrected. The IMU chosen for this project utilizes a magnetometer that plays an important role in correcting the sensor biases [7]. The specific amount of sensor bias correction is not specified by the magnetometer, but the correction should be strong enough that realistic velocities for the barbell will be able to be determined.

This mathematical analysis indicates that it is possible to feasibly implement peak velocity while meeting the requirements of this project.

# 3. Cost and Schedule

## 3.1 Cost Analysis

### 3.1.1 Labor

| 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 |

**Table 1.** Labor Costs

### 3.1.2 Parts

| 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 |
| Android Application | Google Play Store | N/A | 1 | $25.00 |
| 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** | | | | $104.00 |

**Table 2.** Parts Costs

### 3.1.3 Grand Total

| **Section** | **Total** |
|---|---|
| Labor | $48,000 |
| Parts | $104 |
| **Grand Total** | $48,104 |

**Table 3.** Grand Total Cost (Labor + Parts)

## 3.2 Schedule

| 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 Android Application Development | Rohin |

| | | |
|---|---|---|
| | Determine Processing Algorithms for Peak Velocity and Peak Acceleration | Chase |
| | Physical Packing of Components and Stress Testing LiftSense Attachments | Ethan |
| 11/11/2019 | Integrate All Modules for Final Product and Conduct Testing | All |
| | Corrections to Android 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 |

**Table 4.** Project Schedule and Task Allocation

## 4. Discussion of Ethics and Safety

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) will be properly compartmented to avoid overheating as much as possible. This means that components must be 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 adhere to 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. As indicated in the tolerance analysis, these errors should roughly be around 5%. Additionally, mathematical formulas and derivations will be utilized throughout the process of converting the raw data from the IMU to determine the peak velocity of the barbell. This will ensure that the user can be confident that the data visualized on the android 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 will be taken to minimize the chance of these attachments flying off the barbell and potentially injuring the weightlifter or any bystanders. The LiftSense barbell collars will 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 will be 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.

## Citations


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# Appendix

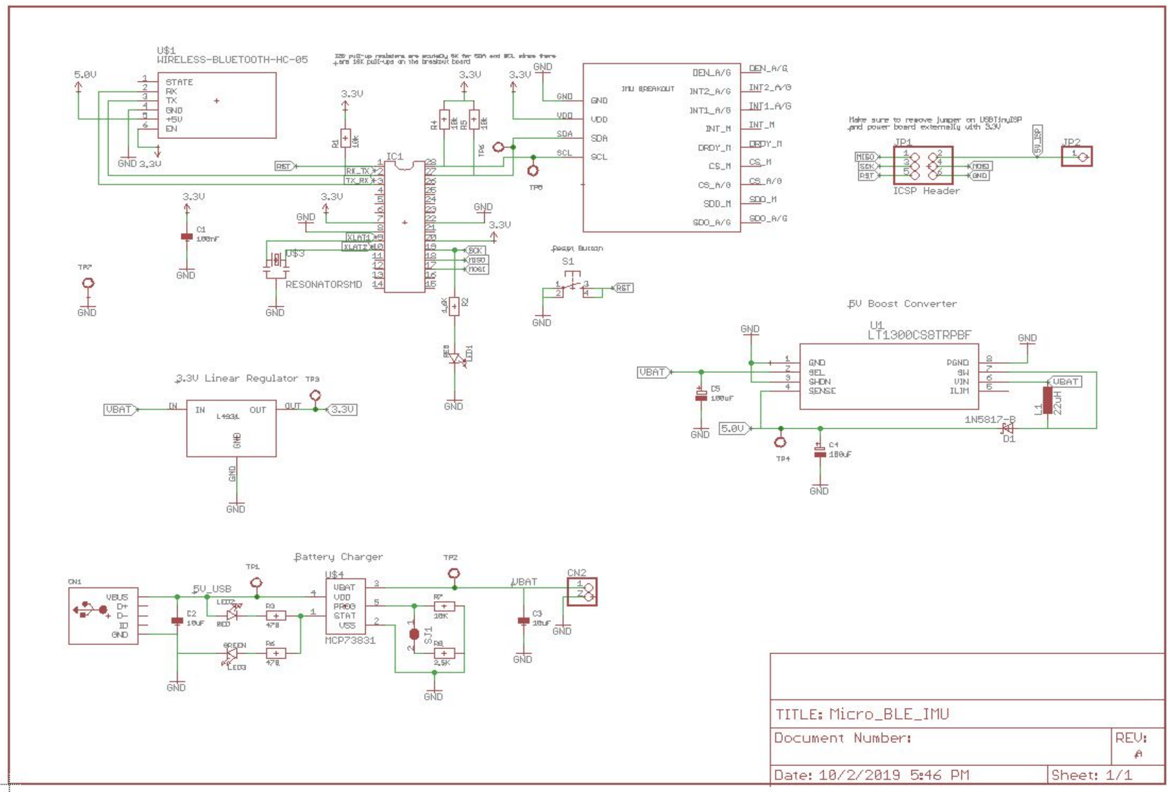


**Figure 13.** Full System Schematic

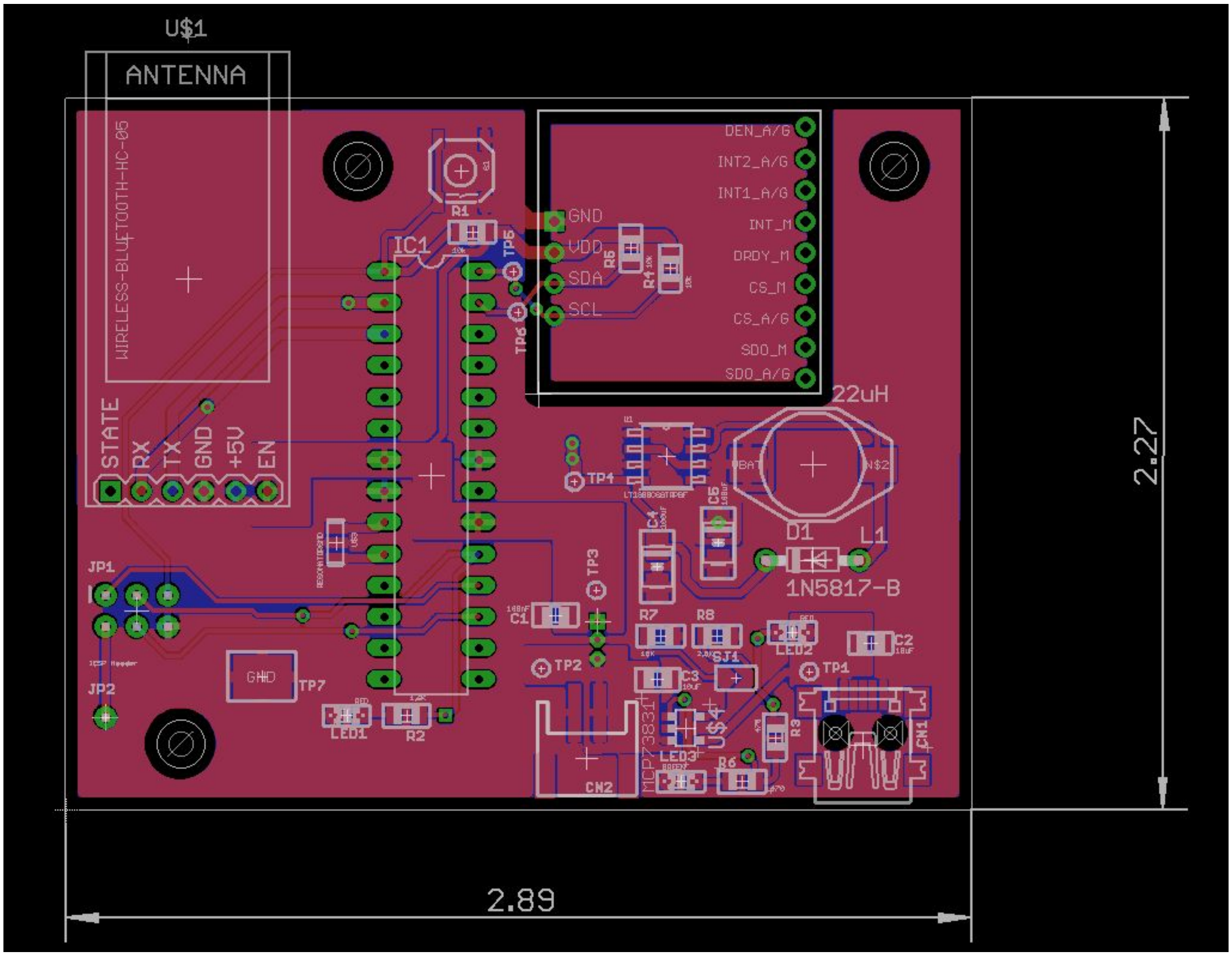


**Figure 14.** PCB Layout