Athletic Tracking Sensor Project Proposal

By

Ethan Pizzaro

JD Armedilla

Ryan Horstman

Project Proposal for ECE 445, Senior Design Spring 2025

TA: Jiankun Yang

February 15, 2025

Project No. 38

Introduction

Problem

Currently, the main metric of progress in weightlifting for everyday weightlifters is varying load and number of repetitions. But, there is also value in (and workouts designed around) moving the weight at an appropriate speed, known as Velocity-Based Training (VBT) [1]. Effective velocity-based training emphasizes lifting heavy, while simultaneously ensuring one handles the weight well and with the speed desired.

However, velocity-based training is not easily accessible because available sensors are costly and therefore infeasible for everyday weightlifters. If a lifter does buy an expensive sensor, those available lack some key features for an optimal workout. For example, some sensors assist with tracking velocity but do not assist with tracking form. Also, current sensors offer feedback that consists of the lifter doing their exercise and then checking their results on their phones. Since this feedback is not necessarily "real-time", these sensors cannot indicate to a user to adjust their velocity between each repetition. Additionally, users are not informed immediately if a bad form is used during the workout, increasing the risk of injury [2-3].

Solution

We propose a compact wearable device that takes and transmits workout data to a phone via Bluetooth. It will utilize a 9-axis sensor (acceleration, gyroscope, and magnetometer). However, in addition to sending data to a phone, it will internally process data taken during the workout and provide immediate feedback to the user through haptic signaling and LED feedback. Before starting the workout, the user can indicate on his/her phone the workout they are performing and any desired constraints. This data will be sent to the device. The device will track the user's form and acceleration, alerting him/her if a desired constraint is not being met so that it can be immediately corrected mid-set. It would be small enough to strap it to a user's wrist or neck, around a weight set, or attach it to a desired object. Using the acceleration data given by the tracking sensor, the app will display the collected velocity graphically and the lifting form so that the user can visually see his/her progress.

Visual Aid

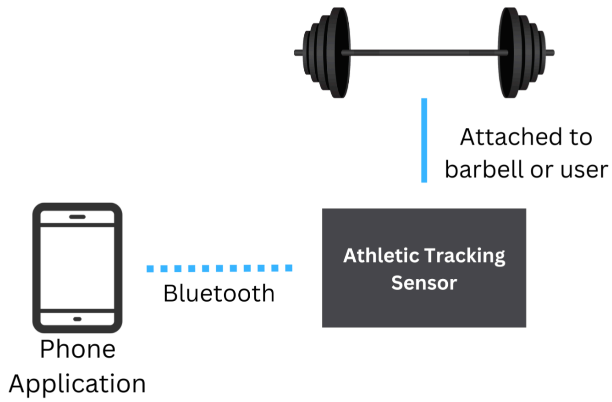

Figure 1: Usage of athletic tracking sensor.

High-Level Requirements

Our athletic tracking sensor will need to meet the following requirements:

- IMU readings on-chip will be able to determine velocity in the vertical direction with precision in the hundredths of a meter per second for bench press and back squat workouts. The device will alert the user immediately when a goal velocity is met/exceeded.
- The athletic sensor must be able to send and receive data via Bluetooth to/from our developed iPhone app, which will then use that data to graphically represent the athlete's velocity at a certain load.
- For form applications, our gyroscope will be able to detect degrees in a given direction at the precision of 3 degrees and alert the user within a half second of entering bad form.

Design

Block Diagram

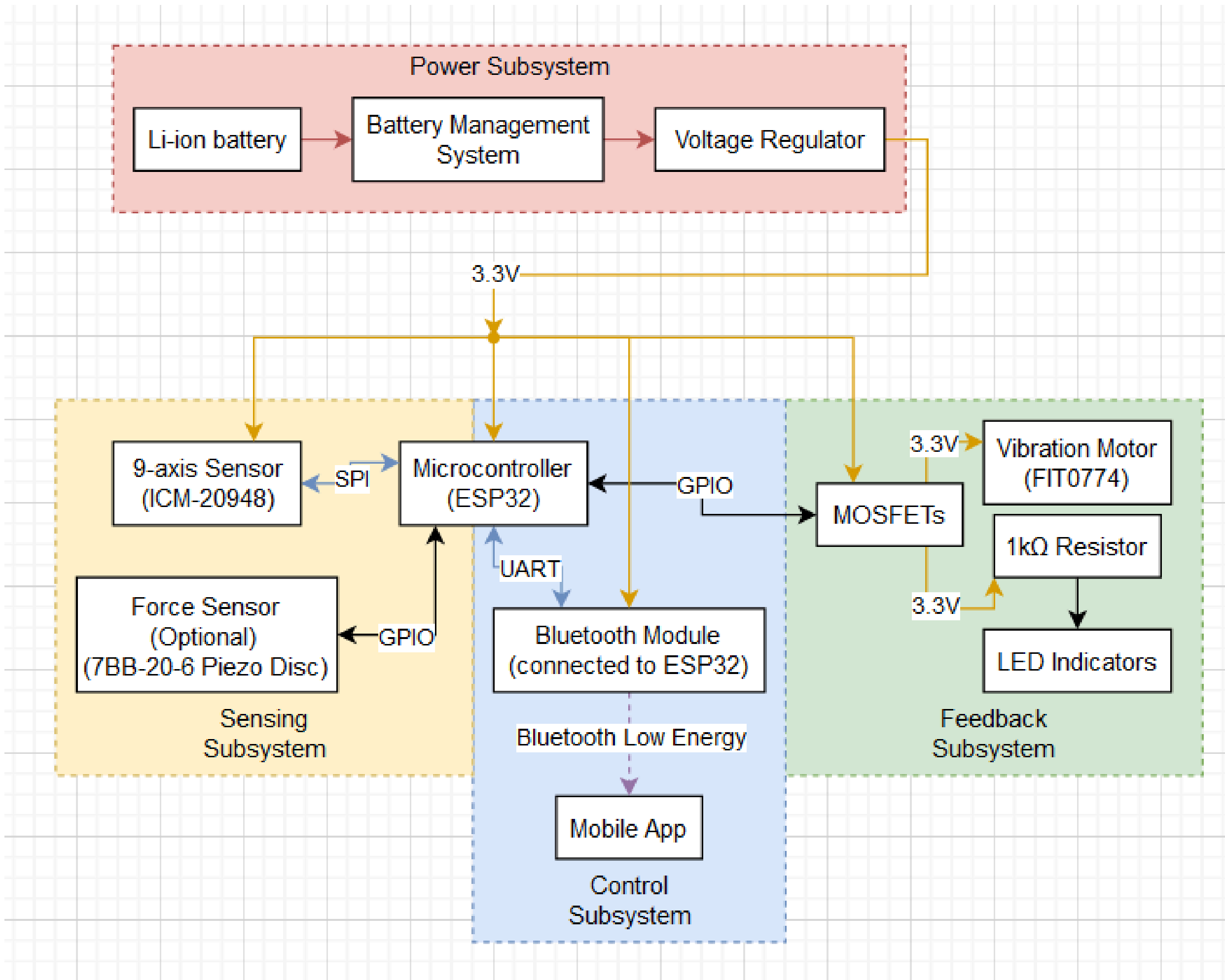

Figure 2: Block diagram for the Athletic Tracking Sensor

Subsystem Overview & Requirements

Power Subsystem

The power subsystem is responsible for supplying power to the rest of our device's components. It consists of a lithium-ion battery, a battery management system, and a voltage regulator to ensure the battery's output is set to 3.3V, which is the operating voltage of our components.

The subsystem must supply 500mA to the rest of the system continuously at 3.3V ± 0.1V. This can be verified with a voltmeter. The battery must also be rechargeable.

<u>Control Subsystem</u>

Our microcontroller will be an ESP32. This MCU was mainly chosen because of its Bluetooth Low Energy capabilities, which will be used to communicate with the accompanying mobile app. The MCU will receive workout thresholds via Bluetooth from the app. During the workout, it will take acceleration and position data from the sensing subsystem. The MCU will integrate the acceleration data to calculate velocity and compare that velocity and position data to the thresholds provided by the app. When necessary, it will send high voltage signals to the feedback system so that the user knows to correct themselves. The MCU will also transmit data to the mobile app via Bluetooth Low Energy.

The mobile app communicates with the control subsystem via its Bluetooth module. Mainly, the application will take velocity data and the user's weightlifting form data from the control subsystems and process that data to show the velocity at which the user is lifting a certain load. Other possible features that could be added include a simple rep counter, rest tracking, or other exercise-related quality-of-life enhancements.

The subsystem must be able to identify incorrect forms (exceeding/failing to meet maximum/minimum velocities, improper positioning, etc.) and actuate the feedback system within 0.5 seconds. It must also include a GUI via the mobile app to both choose the workout about to be done (pre-workout) and keep track of various statistics (post-workout) including form data and velocity data per workout. Because we want to focus on robustness, we expect our device to have a minimum range of 10 feet between the phone and the device. We will test and verify the operation with the following two workouts:

Weighted Squat:

Squat would require one sensor module on the upper back of the user. For the acceleration tracking aspect, the vertical velocity of the user would be gained (using the magnetometer data to isolate the vertical component of acceleration data). In addition to tracking and sending the data to the app, the user will input goals such as not wanting to pass a given velocity (in which case the haptics will actuate if the goal is not met), or wanting to exceed a certain velocity (in which case the haptics will actuate if the goal is met). For form tracking, the dangerous aspect of squat is back form. Often, lifters will lean too far forward at the bottom of their rep, putting themselves at risk. The microcontroller will analyze gyroscope readings to ensure the user's back stays within a safe degree from vertical.

Bench Press:

For bench press, we would have one sensor strapped to the center of the barbell or two on either end of the barbell. Acceleration tracking would be very similar to squat: isolating the vertical direction and then implementing speed goals. For form, we would additionally isolate lateral movement and haptically warn if dangerous amounts of movement occur (forward and backward, for example). Additionally, in the two-sensor mode, the levelness of the bar will be tracked to ensure one side is not higher/lower than the other.

Sensing Subsystem

Our main sensor will be an ICM-20948. This is a 9-axis sensor with an acceleration sensor, gyroscope, and magnetometer. It will receive power from the power subsystem and send the recorded data to the ESP32 for processing through the SPI protocol. Optionally, a 7BB-20-6 Piezo disc can be added to measure the force applied, which would also send data to the microcontroller.

The sensing subsystem (with or without the force sensor) must send data to the ESP32 fast enough to meet our 0.5-second responsiveness requirement. We can validate the sensor data by observing it once it is transmitted to the iPhone app. We can compare with video to ensure the data is representative of what is happening.

Feedback Subsystem

This handles haptic and visual feedback when exercise requirements are not being met. The vibration motors and LEDs will be connected to MOSFETs. The MOSFETs take in the 3.3V power from the power subsystem and output from the ESP32's GPIO pins. Thus, when the GPIO is high, it can activate the vibration motors and LEDs accordingly and default to no action when good form is being used.

The feedback subsystem must be able to provide haptic and visual feedback while an exercise is occurring, contributing to our real-time feedback requirement. We will intentionally not meet our input goals and demonstrate bad form (without heavyweight) to feedback system works.

Tolerance Analysis

Successful completion of the athletic tracking sensor hinges on the data collection from the 9-axis sensor and the processing speed of the ESP32. We must be able to collect and process data quickly enough that the device can alert the user in real-time, otherwise, the user is not getting immediate feedback. Because of the nature of the ICM-20948, there are three sensors on board and only one can be read from at a time. The maximum low noise output frequencies are 1.125kHz for the gyroscope and accelerometer and 100 Hertz for the magnetometer. We will have to alternate between the on-chip sensors with priority to acceleration since that data is integrated. Our goal will be to maximize velocity measurements while getting at least 10 gyroscope readings per second. The magnetometer readings will just be used to recalibrate the vertical axis, so it will be much less frequently read, 3 times per second. With a goal of 100 samples per second for velocity readings we spend .118 of each second sampling data, calculated in equation 1. Switching between the sensors will also take time, 20 ms according to the datasheet for the accelerometer, the rest are not given so we will assume similar. Switching 23 times per second brings that number to .46 seconds of switching per second. Combined with our sample goal we are using .578 of each second, as seen in equation 2. This proves we will have a buffer for adjustments and non-idealities in our design. For the processor, it runs at a maximum of 240MHz with a dual processor. This should be enough to maintain sensor readings, continuously integrate acceleration, maintain Bluetooth transmission, and internally monitor data.

$$(3*1/100 + 10*1/1{,}125 + 100/1{,}125) = .118 \text{ seconds} \quad (1$$

$$\text{Switching time + sampling time} = .118s + .46s = .578 \text{ seconds} \quad (2$$

Ethics & Safety

Due to our use of Bluetooth, we need to ensure that users have their exercise data secured, as per the IEEE Code of Ethics #1 [4]. Practically, this means implementing a form of encryption to protect against anyone who would want to intercept the data being sent. While the athletic tracking sensor does not explicitly require personal data, it is still imperative that we protect users' privacy in any way possible.

Because our device is wearable and will be used while performing athletic exercises, safety precautions must be taken to ensure no one is injured during testing, as per IEEE Code of Ethics #9 [4]. Since we are testing with heavy lifts, including squats and the bench press, we need to allocate adequate space for those lifts to be performed. This is especially important as testing will occur in UIUC's recreation centers available to all students, so others will be around us constantly. Additionally, we need to make sure the wearable design does not inhibit movement or cause injury. Ensuring that our design does not hurt the wearer is of utmost importance, as a device that enhances exercise should not prevent the user from doing so. We will address this by keeping the device compact and ensuring the location of the device will not interfere with workout movements.

The project itself fits #1 and #2 in the IEEE Code of Ethics [4]. The tracking sensor aims to enhance athletic training for anyone, supporting their well-being and promoting exercise for all. It also introduces users to the idea that their timing while exercising is important. Different purposes of training offer different benefits, so gaining direct knowledge of how the user's workout is going is important for both beginners and advanced lifters.

References

[1] O. Walker, “Velocity-Based Training.” scienceforsport.com. https://www.scienceforsport.com/velocity-based-training/ (accessed Feb. 10, 2025).
[2] GymAware, “GymAware RS (LPT)”, gymaware.com. https://gymaware.com/gymaware-rs/ (accessed Feb. 11, 2025)
[3] GymAware, “FLEX - Barbell Tracker for Velocity Based Training (VBT)”, gymaware.com. https://gymaware.com/product/flex-barbell-tracker/ (accessed Feb. 11, 2025).
[4] IEEE, “IEEE Code of Ethics,” ieee.org. https://www.ieee.org/about/corporate/governance/p7-8.html (accessed Feb. 11, 2025).