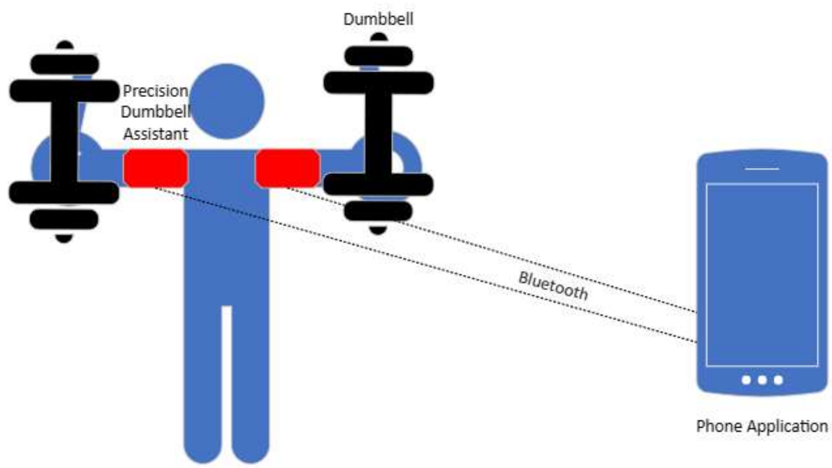
## Introduction

**Problem:** Many gym goers struggle to maintain proper form during their workouts with dumbbells, which is why they rely heavily on exercise machines. However, if you are trying to construct an at-home gym, it is not feasible to order too many machines. Hence, there should be a way to help people maintain proper form even when they just use dumbbells. To start simple, we will first make our design compatible with bicep curls. We will add more exercises depending on time constraints.

**Solution:** Our design will use 3 6-axis (accelerometer and gyroscope) IMU sensors on each arm to calculate the position of each arm and ensure that the user is performing the exercise correctly. There will be two small sensor boards located on the lower arm and shoulder, and a larger main board with another sensor on the upper arm. There will also be a battery that will be attached to the user, most likely on the upper arm or back. There will be a total of 5 subsystems in this design: sensing, processing, wireless communication, feedback, and power

**Visual Aid:**



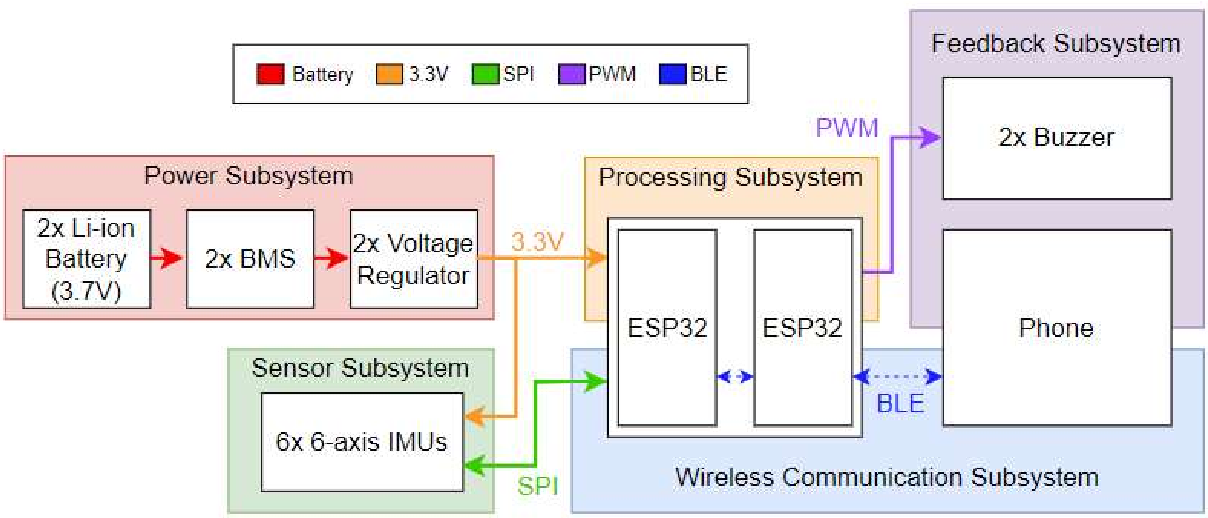

**High-level requirements list:**

- Our device needs to be accurate and consistent in motion and form analysis. To test this goal, we should be able to move our arms at the same distance and angle that we determine from our research of an online fitness expert and the feedback should be positive and repeatable.

- We also need to provide real time feedback to the user for improper form. To test this goal, we will purposely use improper form and the buzzer should sound to alert the user.
- Our device should also allow the user to do proper movements. To test this when we connect the sensors and ESP32 microcontroller, we will have to make sure that we don't have overly rigid connections or too much weight on either arm that prevents the user from moving their body parts naturally.

## Design

**Block Diagram:**




**Subsystem Overview:**

The sensing subsystem consists of 6 total LSM6DSMTR 6-axis IMUs, 3 for each arm. Each IMU will be on its own board, and connected to the processor via SPI. As mentioned before, the sensors will be located on the lower and upper arm, as well as the shoulder, which should allow us to accurately track the entire arm and dumbbell. The two small sensor boards will be connected to the main board with some kind of wire harness for power and SPI.

The processing subsystem contains the two ESP32 processors. These were chosen because of their wireless capabilities, which we will get to later. Each processor will initialize its three sensors and then read in the sensor data and make sure that they are within the threshold necessary to perform the exercise correctly.

The wireless communication subsystem will handle the communication between the two ESP32 processors, as well as to the user's phone so that they can see feedback via the feedback subsystem. We plan to use BLE (Bluetooth Low Energy), but if we run into problems with that ESP32 also should support WiFi.

The feedback subsystem will handle the audible and visual feedback needed to let the user know whether they are doing the exercise correctly or not. We plan to have a buzzer on each main board to provide audible feedback, and a phone app to provide visual feedback. We want to at least list data regarding the number of curls, speed of workout, and angle of movements. Based on the data, it will compile a report that describes the accuracy of the user's form. If we can make some sort of graphic that displays where the movement was incorrect that would be incredibly helpful, although implementing this feature seems like it would be very time consuming.

In the power subsystem, power will come from two 3.7V Li-ion battery packs, one on each arm. We plan to have these near the main board that attaches to the upper arm, but if it is too heavy it could be located elsewhere. This subsystem will also contain the circuitry needed to convert the voltage down to the voltage needed by the processor and sensors if needed.

**Subsystem Requirements:**

Sensing Subsystem:

This subsystem contains the LSM6DSMTR IMU sensors (accelerometer and gyroscope) we will use to track the motion of the user's arm. Each arm will have 3 sensors, which will send raw data over SPI to the processing subsystem. The sensors will also receive power from the power subsystem. This subsystem also includes the physical wiring from the main board to the separate sensor boards. Each connection will need at least 6 wires: 3.3V, GND, MISO, MOSI, CS, and SCLK. This block is important for all three of our high-level requirements. It must provide accurate raw data in order for our analysis to be accurate as well. It also must be able run fast enough so that we are able to provide the user with feedback almost immediately. Finally, we must design the sensor boards to be light and easy to attach to the arm, and we also must make sure that the wire harnesses used to connect the boards are lightweight and flexible enough to not restrict movement.

- Must support SPI communication speed that is fast enough for real-time motion tracking
- Must be able to sample data at a rate of at least 50 Hz to track motion (ESP32 is capable of 100 Hz)
- Each sensor must receive 3.3V +/- 0.1 V from power subsystem

Processing Subsystem:

The processing subsystem consists of two ESP32 microcontrollers. Each microcontroller is connected to three LSM6DSMTR IMUs in the sensing subsystem. We will use one SPI peripheral on each ESP32, and 3 GPIOs as chip selects to select which IMU we are talking to. The IMUs will transmit data to the ESP32s over the SPI connection and the ESP32s will process the data and determine if the data reflects that the user is using proper form or not. The ESP32 microcontrollers will also be connected to the buzzer through the PWM pin and the phone app using BLE to provide the processed data to the user.

- Each processor must read real-time data from 3 IMUs continuously
- Must receive 3.3V power supply from power subsystem
- Must process data with minimal latency

Wireless Communication Subsystem:

The ESP32s that are used in the processing subsystem will also be connected to each other with Bluetooth Low Energy, as well as to a phone app. It will send the processed data to the app so that the user can visually see feedback on their form and count their repetitions.

- Must maintain bluetooth connection between device and smartphone with minimal latency
- Should use wifi if bluetooth malfunctions
- Must successfully pair two processor boards using bluetooth

Feedback Subsystem:

The two ESP32 microcontrollers used in the processing subsystem will drive the feedback system. Each ESP32 will be connected to a buzzer through its PWM pin. When the processing subsystem determines that the user is using improper form, the ESP32 will turn on the buzzer to audibly alert the user. The PWM pin will allow us to control the pitch and duration of the buzzer. The ESP32 microcontrollers will also be connected to a phone app using Bluetooth Low Energy. The microcontrollers will send the processed data to the app where the interface will allow the user to visually see feedback on their form. The user will be able to see how many repetitions they have completed and how many of those repetitions utilized proper form. Ideally, we will create a graphic to show the proper form and how the user differs from said form.

- Buzzer should be heard within at least 1 meter
- Smartphone app should update feedback with minimal latency
- App should display number and speed of curls along with angle of movements

Power Subsystem:

The main components of the power subsystem are two 3.7V lithium. There is one battery for each arm. This subsystem will also have a voltage regulator to step down the voltage from 3.7V to the 3.3V utilized by the ESP32 and the LSM6DSMTR IMUs.

- Must supply at least 500 mA to processing subsystem at 3.3V +/- 0.1V
- Must also supply sensing subsystem with 3.3V
- Battery packs should last at least 4 hours before charging is necessary
- Voltage regulation must accurately reduce voltage supply

**Tolerance Analysis:** The accuracy of the sensors to detect the user's motion is definitely the biggest risk to this project being a success. If the detection is incorrect, the device will provide incorrect feedback to the user. We will need to use a simulation to test if the sensors are working as expected. The first step would be to generate the simulated sensor data that should include what the accelerometer and gyroscope should potentially read during a bicep curl. However, each sensor tends to have slightly incorrect readings due to noise, so that should also be accounted for in the simulation. Hence, the second step would be to apply a Kalman filter to the simulated data. This filter will both include noise and also minimize error. The filter can also estimate the actual position and angle of the arm during bicep curls based on the accelerometer and gyroscope data. This will be compared with the actual position and angle of the arm during our test to ensure that the sensors are functioning correctly.

**Ethics and Safety:** The most important ethical issue is obviously the accuracy of form enforced by our device as it could lead to injuries if inaccurate. To ensure this, we will use data from a certified online training source. The privacy of data is also a cause of ethical concern as many people who workout are sensitive about information in their fitness diaries and quality of form in exercises. We will need to ensure safe storage of our data. The main safety issue is the overheating of batteries, which is why we will carefully check our voltage regulation.