UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Athletic Tracking Sensor

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Agenda

1. Problem Statement
2. The Design
3. Final Design and Subsystems
4. Questions

Problem Statement

The Background

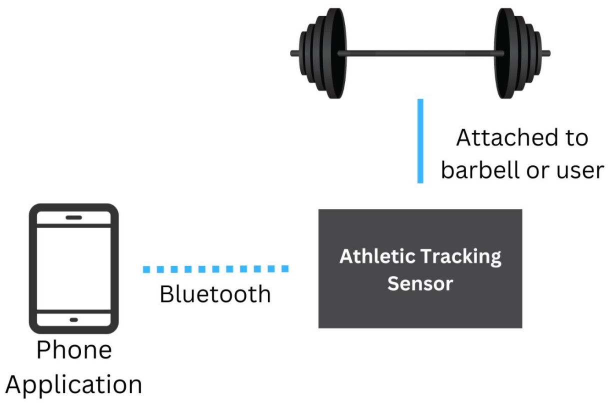
- Traditional weightlifting consists of varying heaviness of weight and number of repetitions
- Our project focuses on velocity-based training
  - The speed in which you lift weights

The Problem

- Current tracking sensors are expensive
- Current sensors convey information graphically only post-workout set
- Current sensors do not incorporate form tracking capabilities

Solution:

We created a cheap athletic tracking sensor that gives immediate feedback to the user mid-rep on both velocity goals and form safety via a vibration motor.

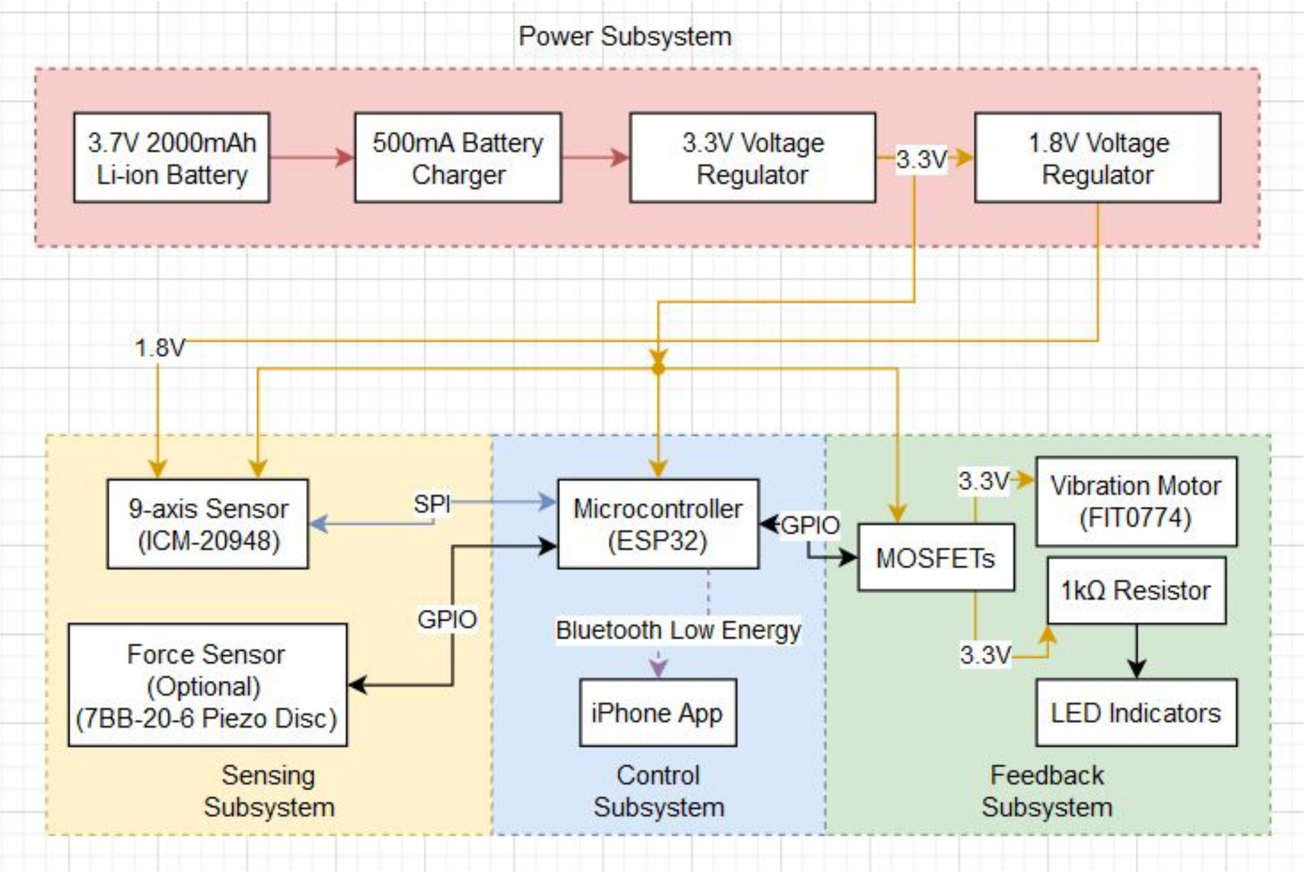


Measure Velocity, Detect Angle, and Collect Data

- Determine vertical velocity to hundredths of m/s
- Send/receive data via Bluetooth to our own iPhone app for easier processing
- Alert user immediately if velocity/angle thresholds are exceeded

The Design

Original Block Diagram



Original Block Diagram

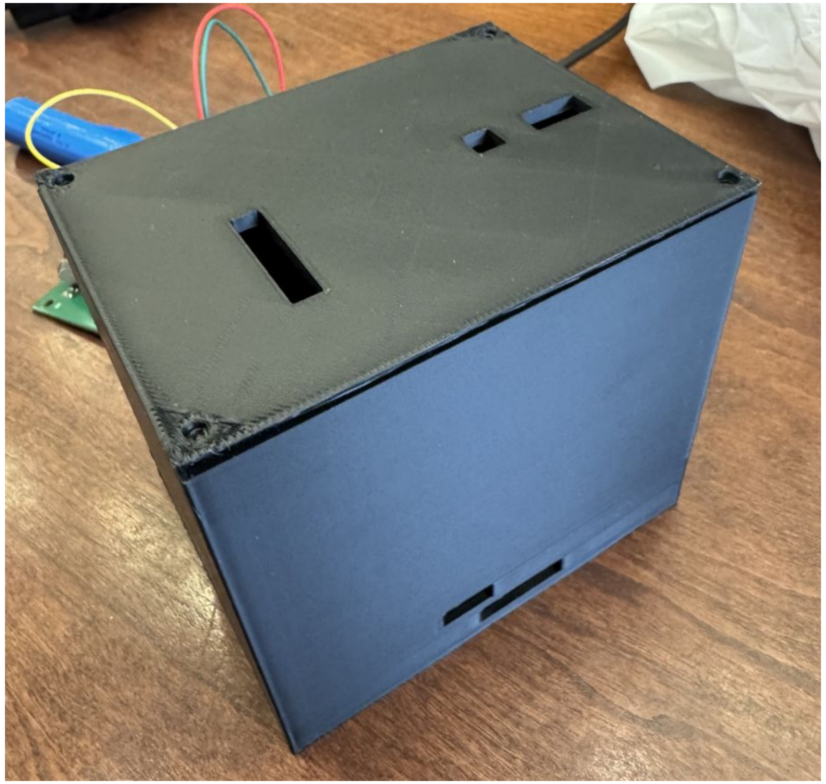
What Changed?

Sensing Subsystem

- Level shifter added (V_{DDIO} of ICM-20948 is ~1.8V while SPI pins of microcontroller output ~3.3V)

Feedback Subsystem

- MOSFET removed
- Button added to let user dictate when exercise recording starts/stops
- Switch connects/disconnects device from the battery
- 3D modeled basic PCB enclosure to allow outside access to switches, buttons, and LEDs



PCB enclosure

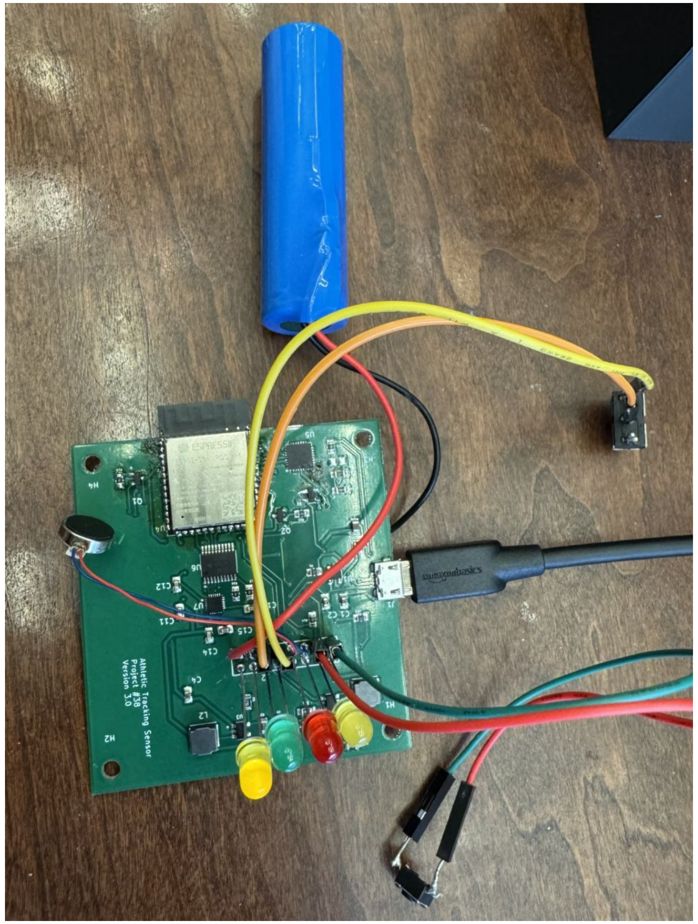
What Changed?

Power Subsystem

- Linear Li-ion charger for simpler soldering
- Buck converters for higher available current
- Micro USB port supports charging and data transfer at the same time

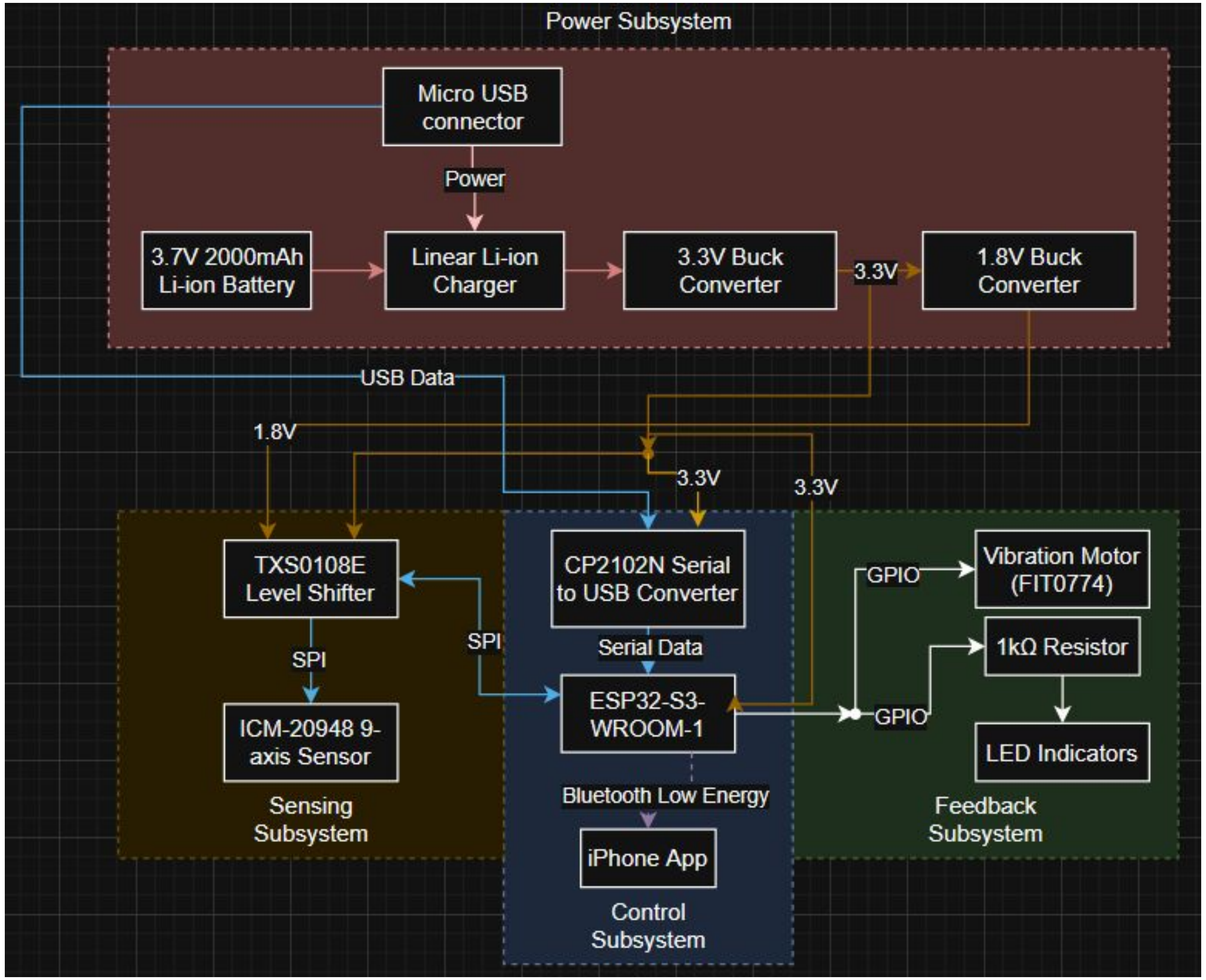
Control Subsystem

- CP2102N USB-to-Serial converter for programming
- ESP32-S3-WROOM-1 (S3 had pins too small to solder)
- iPhone app flow state changed to support Bluetooth functionality while enabling data display



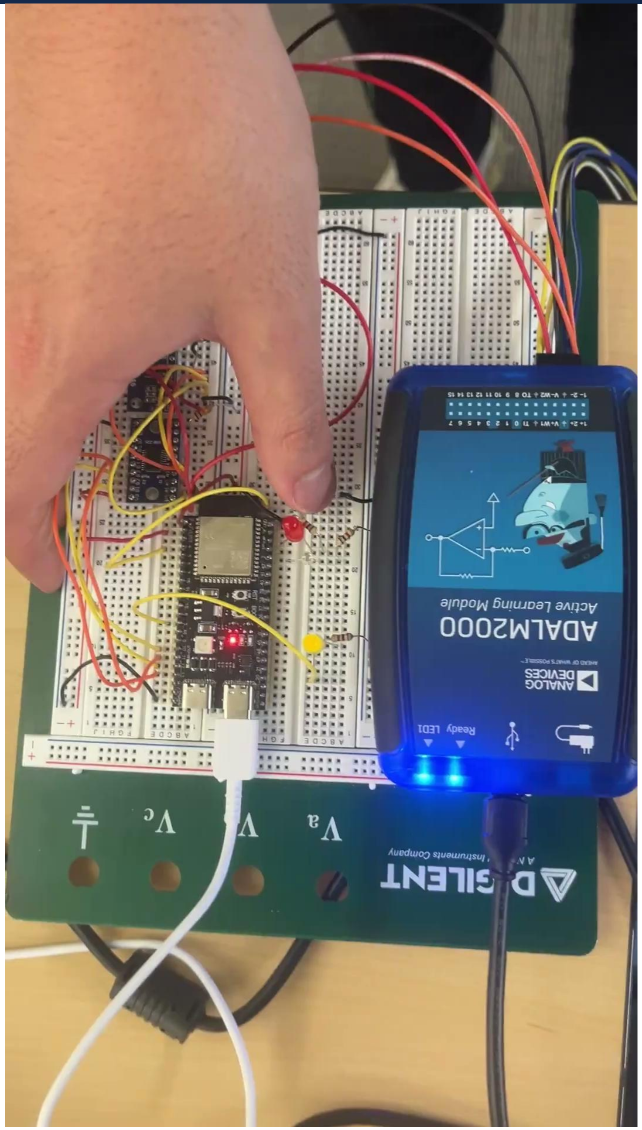
Final PCB

Final Block Diagram



Final Block Diagram

Demo Video

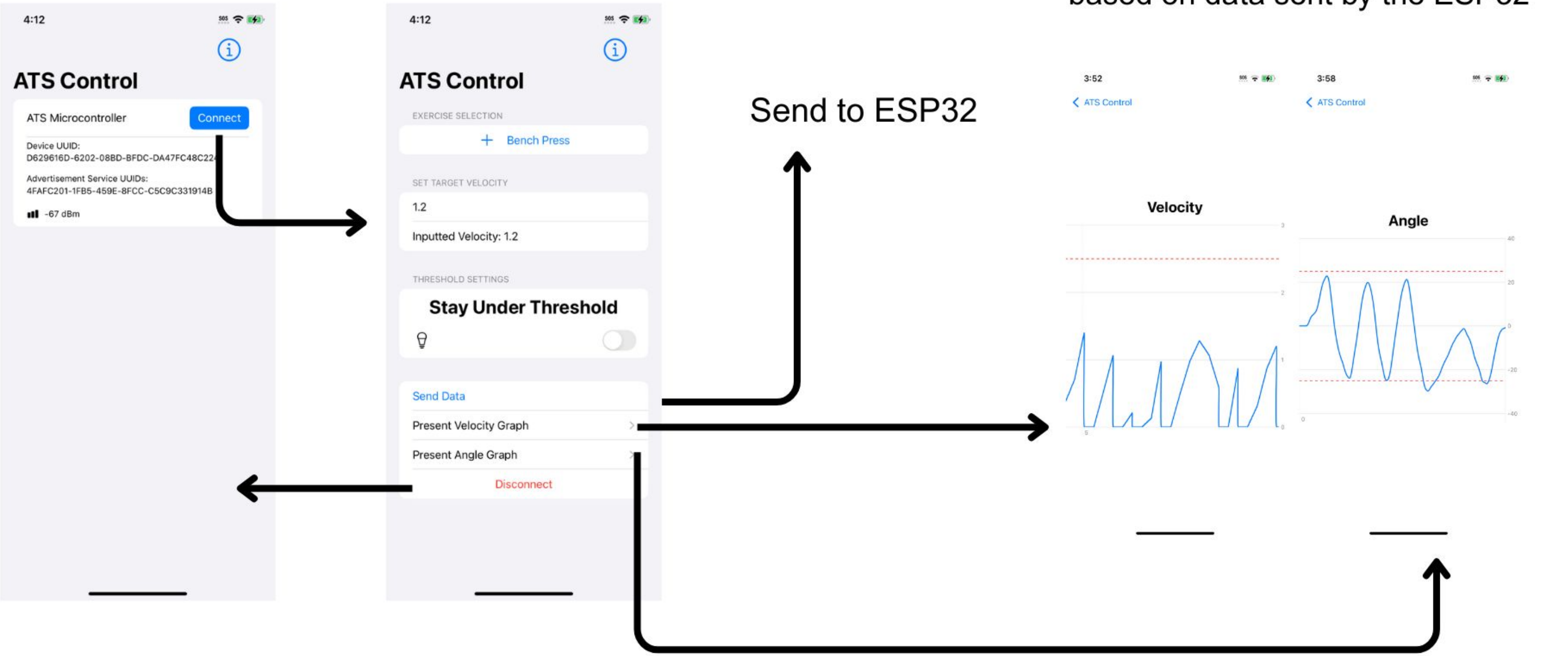


The Build: The App

Display available devices

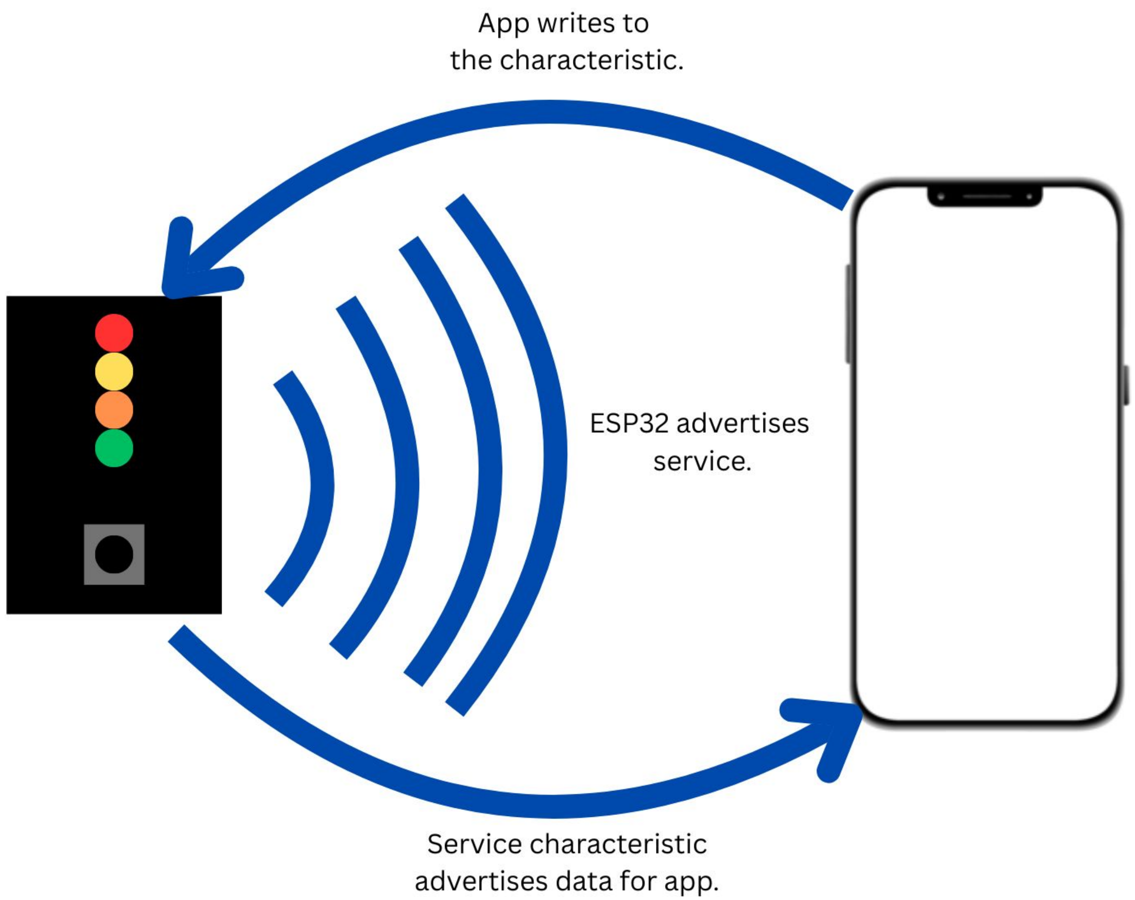
Control what information to send to ESP32

Velocity and angle/orientation graphs based on data sent by the ESP32



Connecting to ESP32

- ESP32 advertises a service
- Application searches for that service with the service UUID



Communicating Data

- Communication through a service's characteristic
  - Read and writes of the ESP32 are done through the characteristic

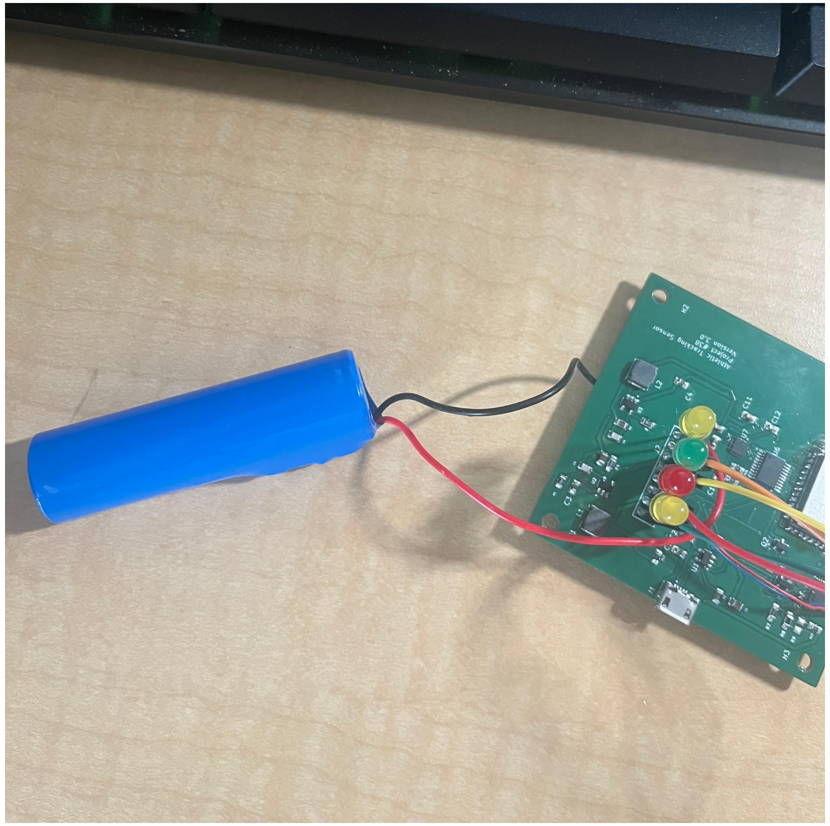
Power Supply and Delivery

Supply

- 3.7V 2000mAh Li-ion battery, linear Li-ion charger, and Micro USB port
- Charges within 6 hours with 2+ hour battery life

Delivery

- 3.3V buck converter (microcontroller, ICM-20948) and 1.8V buck converter (level shifter, ICM-20948 IO pins)



Battery connected to PCB

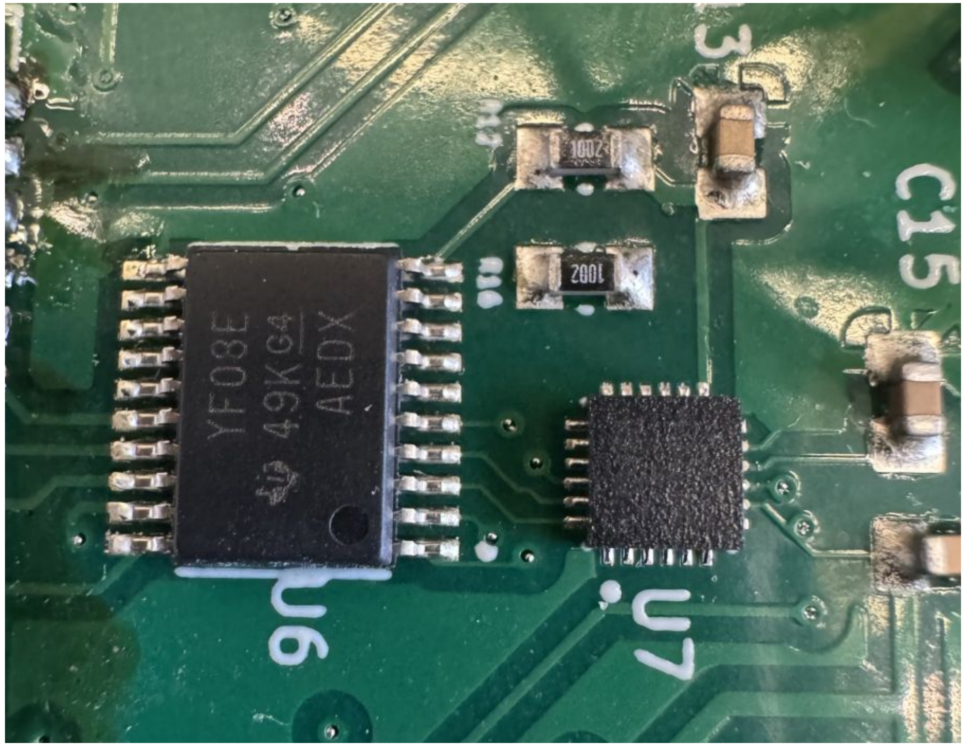
Final Design: Sensing Subsystem

9-Axis Sensor: ICM-20948

- Includes accelerometer, gyroscope, and magnetometer
- Communication via SPI protocol

Level Shifter

- SPI pins operate at 3.3V and ICM-20948 operates at 1.8V
- Level shifter makes SPI signals compatible with the IMU



Final Design: Data Analysis

Integration of Sensor Outputs

- Both Angle and Velocity values are calculated by integrating angular velocity and acceleration, respectively
- For acceleration, vertical acceleration due to gravity is picked up by the sensor, and had to be accounted for
- The magnitude of total change in velocity change is used instead of a particular direction for output velocity

Deadband Filtering

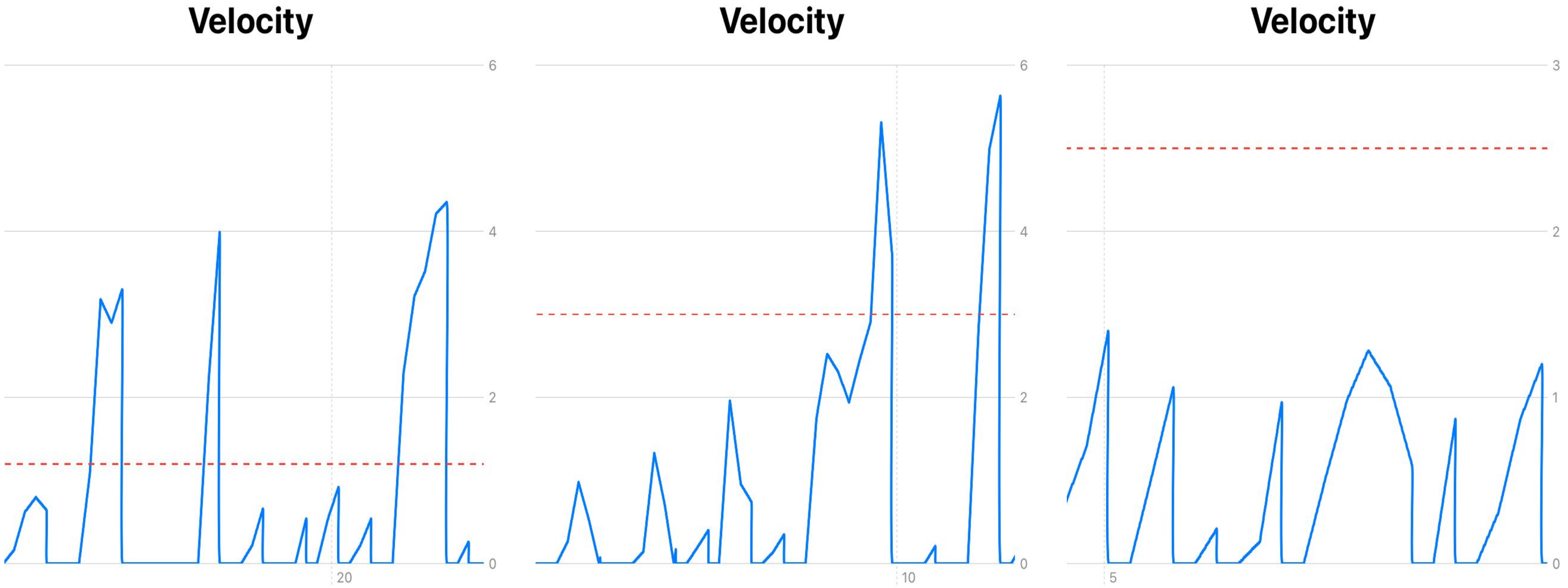
- Both accelerometer and gyroscope are sensitive to vibration noise that produces drift in angle and velocity outputs

```
myIMU.getGyrValues(&gyr);

float currentTime = millis();
float deltaTime = (currentTime - gyr_lastTime) / 1000.0;
gyr_lastTime = currentTime;

// Apply deadband to gyroscope raw data
float gyrDeadband = 2;
if (abs(gyr.x) < gyrDeadband) gyr.x = 0;
if (abs(gyr.y) < gyrDeadband) gyr.y = 0;
if (abs(gyr.z) < gyrDeadband) gyr.z = 0;

// Integrate gyro readings to get angles
angleX += gyr.x * deltaTime;
angleY += gyr.y * deltaTime;
angleZ += gyr.z * deltaTime;
```

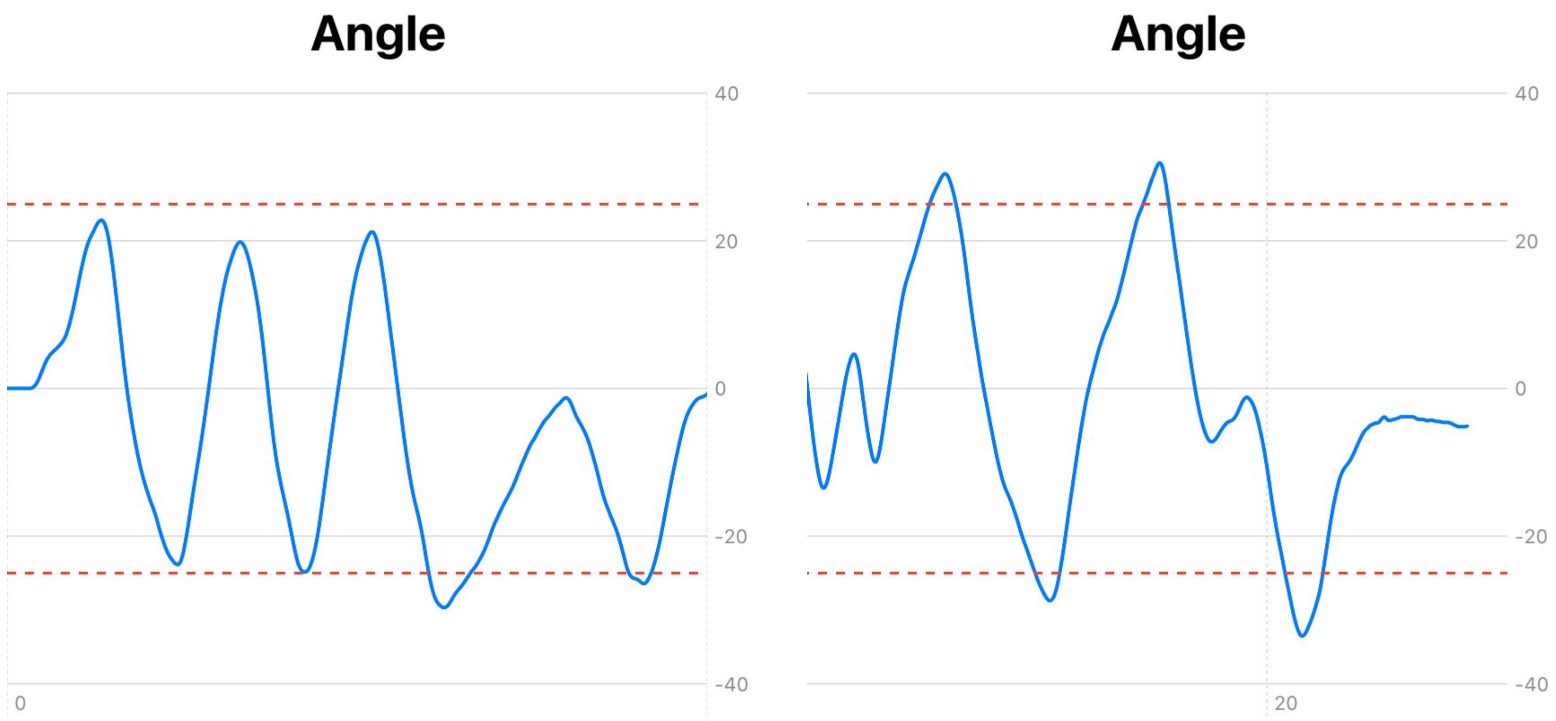
$$v = v_0 + a\,t$$

$$|v| = \sqrt{x^2 + y^2 + z^2}$$

Results: Velocity Tracking



Results: Form Tracking



Final Design: Control Subsystem

Sensor Processing and Programming

- Utilizes native SPI and Bluetooth Low Energy functionality to work with ICM-20948 and iPhone app
- Determines when GPIO pins activate, driving feedback subsystem
- Listens for “Record Data” button input to start monitoring velocity/angle thresholds

Figure 11: USB-to-Serial converter (U5) and microcontroller

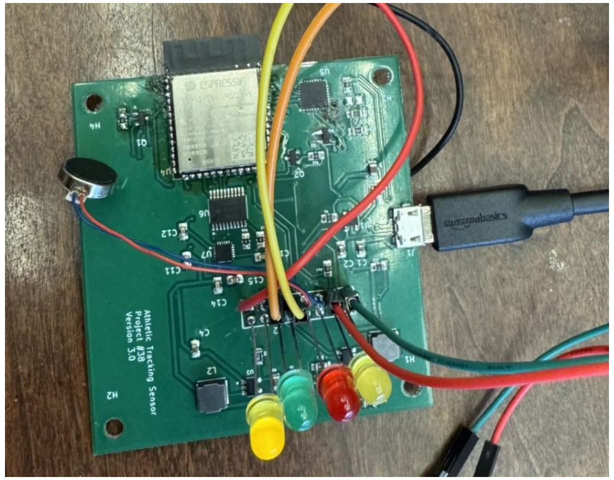
Microcontroller Tasks

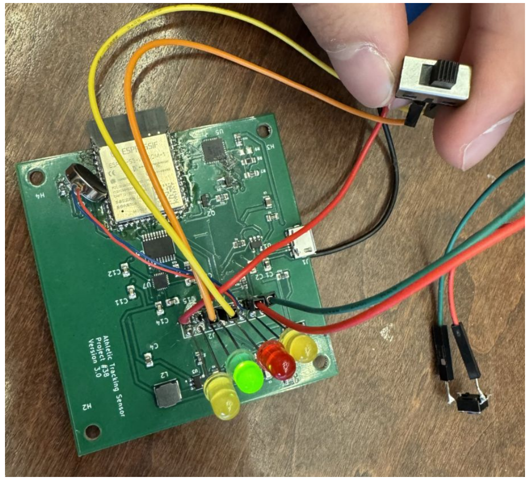
- Read/write to ICM-20948
- Activate LEDs and vibration motor
- Send/receive data to/from iPhone app

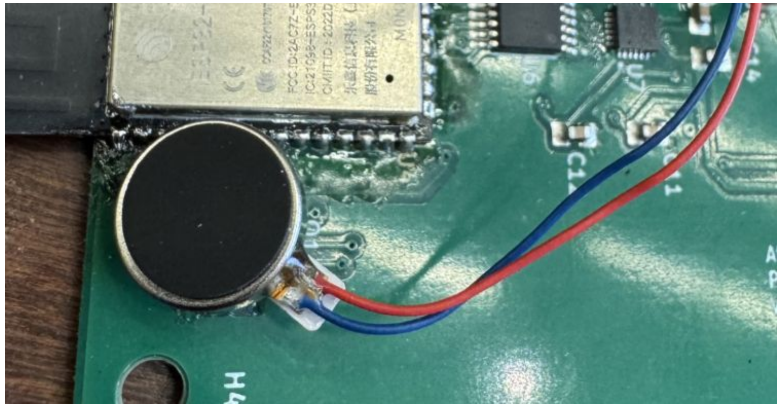
Final Design: Feedback Subsystem

Haptic Feedback

- Vibration Motor actuating with user notification LED







Indication LEDs

- Power-ON
- Device Charging
- State of Device (waiting or taking data)
- User Notification

Issues with Programming the ESP32-S3-WROOM-1

- V_{REGIN} and V_{DD} left unconnected in the PCB's schematic on the USB-to-Serial converter
  - Misunderstood from datasheet that V_{BUS} would provide its power
- Solution: connect 3.3V power to V_{REGIN} and V_{DD}

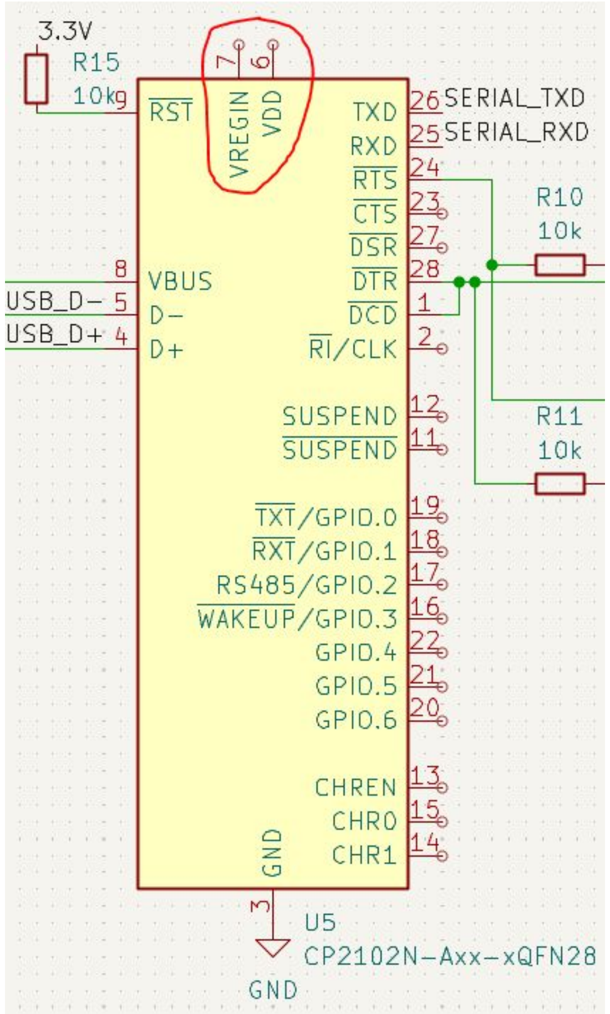


Figure 16: V_{REGIN} and V_{DD} pins

Protecting Users and Their Data

- Bluetooth Low Energy encryption
- Preventing Injuries While Testing
- Ensuring User Movement
- Dissipating Heat
- Makes Velocity-Based Training More Accessible

Conclusion

Accomplishments & Future Work

Summary of Accomplishments

- Created a working rechargeable battery power supply for a wearable device
- Calculated velocity and angles from a 9-axis sensor's raw data
- Provided live feedback during exercises, beating out industry standards
- Developed an app that utilizes bluetooth communication to display data

Future Work

- Get PCB fully functional
- Optimize space usage (decreasing enclosure size)

Questions

References

[1] T. T. C.S.C.S, “What You Need to Know About Spotting in the Gym,” Men’s Health, Jul. 20, 2020. https://www.menshealth.com/fitness/a33366411/how-to-spot-weight-lifting/

[2] “Barbell Bench Press Overview,” fitnessprogramer.com. https://fitnessprogramer.com/exercise/bench-press/ (accessed May 1, 2025).

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