UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Running Cadence Monitor Belt

Electrical & Computer Engineering

April 24, 2024

Background

The Problem

Current Devices on the Market do Not Provide Hands-Free, Eyes-Free Feedback on Cadence

- Running Watches
- Smartphones
- Foot-mounted Solutions
- All very expensive

Goal: Engineer a Device to Alert a User When Their Cadence Falls Outside of an Optimal Range

High Level Requirements

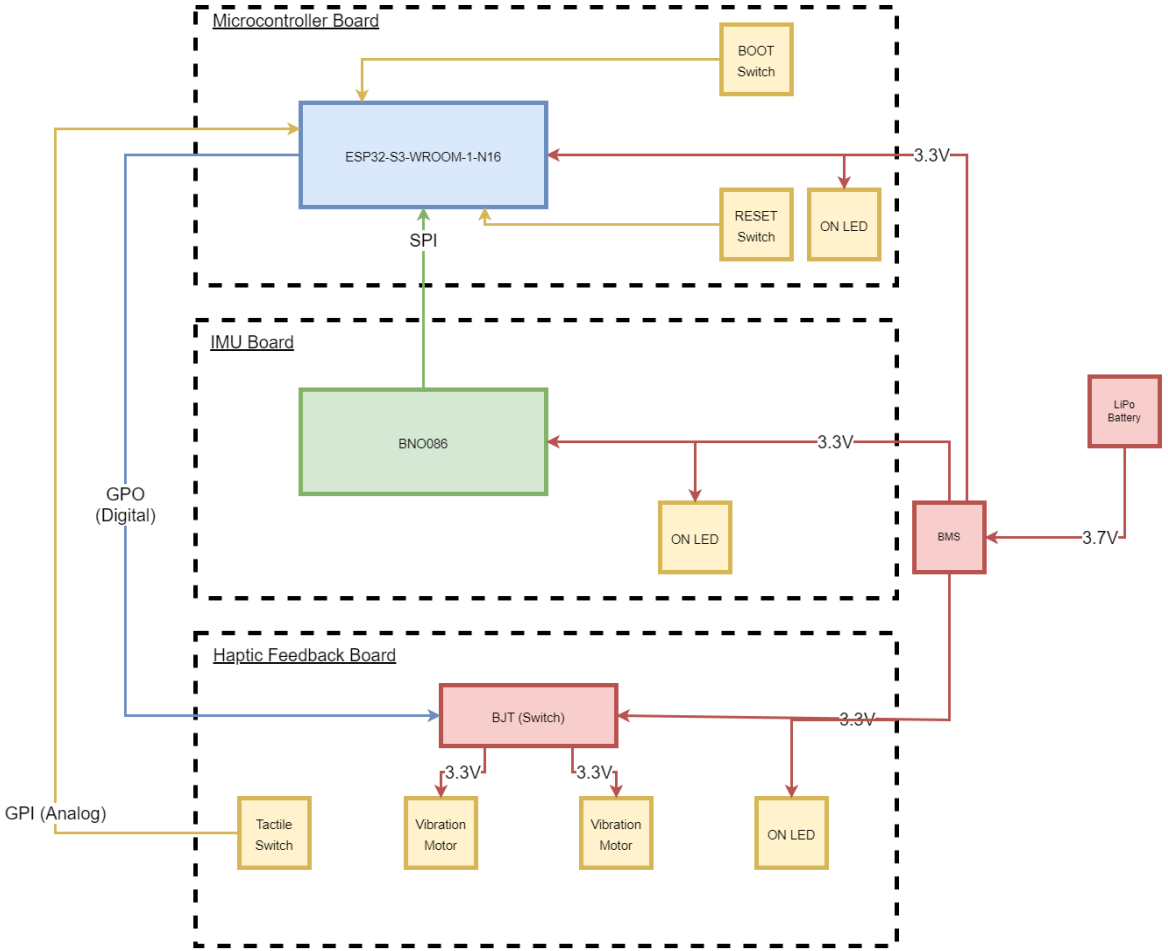
1. The product shall detect the strides of the user through an Inertial Measurement Unit (IMU) and derive from them a strides per minute (SPM) metric. The default SPM goal is 180.

2. The product shall notify the user of a measured SPM outside of the set limit (+/- 5) of a user-adjustable goal SPM via vibration motors located on the device.

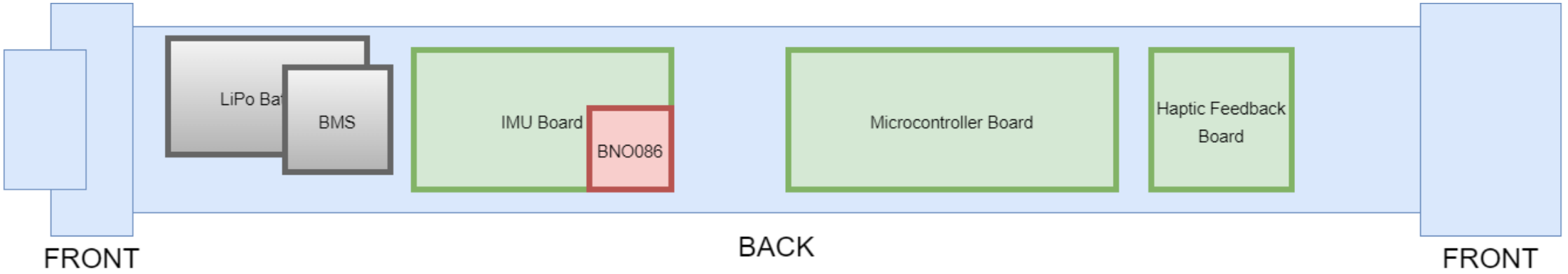
3. The product shall have the goal SPM be user adjustable in increments of 5 through a tactile switch located on the Haptic Feedback board.

4. The product shall be solely powered by a portable 3.7V Lithium Polymer (LiPo) battery capable of 1.5A current output.

Block Diagram



Belt Mounted Device With Haptic Feedback Motors Physical Diagram



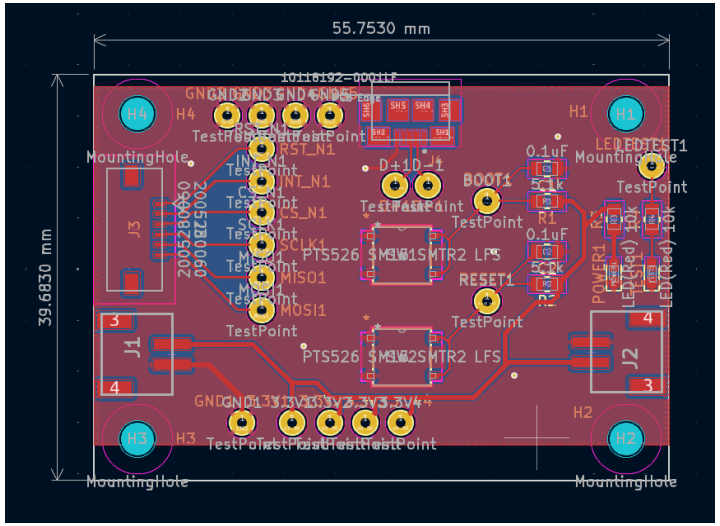
Microcontroller (MCU) Board Requirements

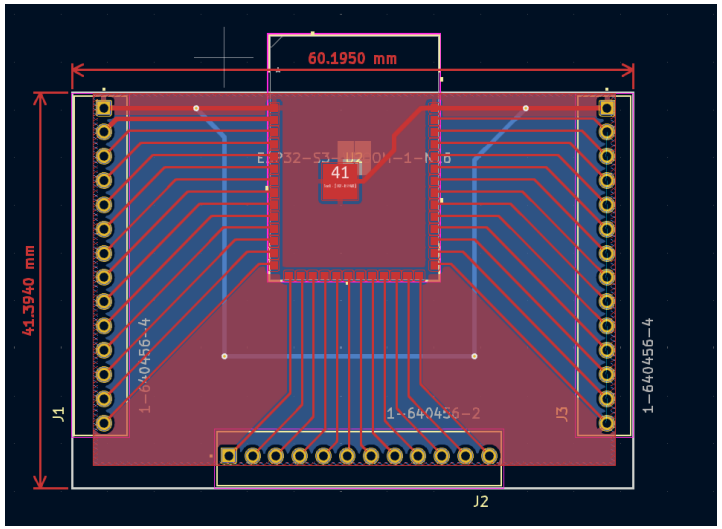
Requirements

- The Microcontroller Board shall connect the supplied 3.3V power line from the BMS to the ESP32 MCU.
  (Verified, DMM measured voltage)

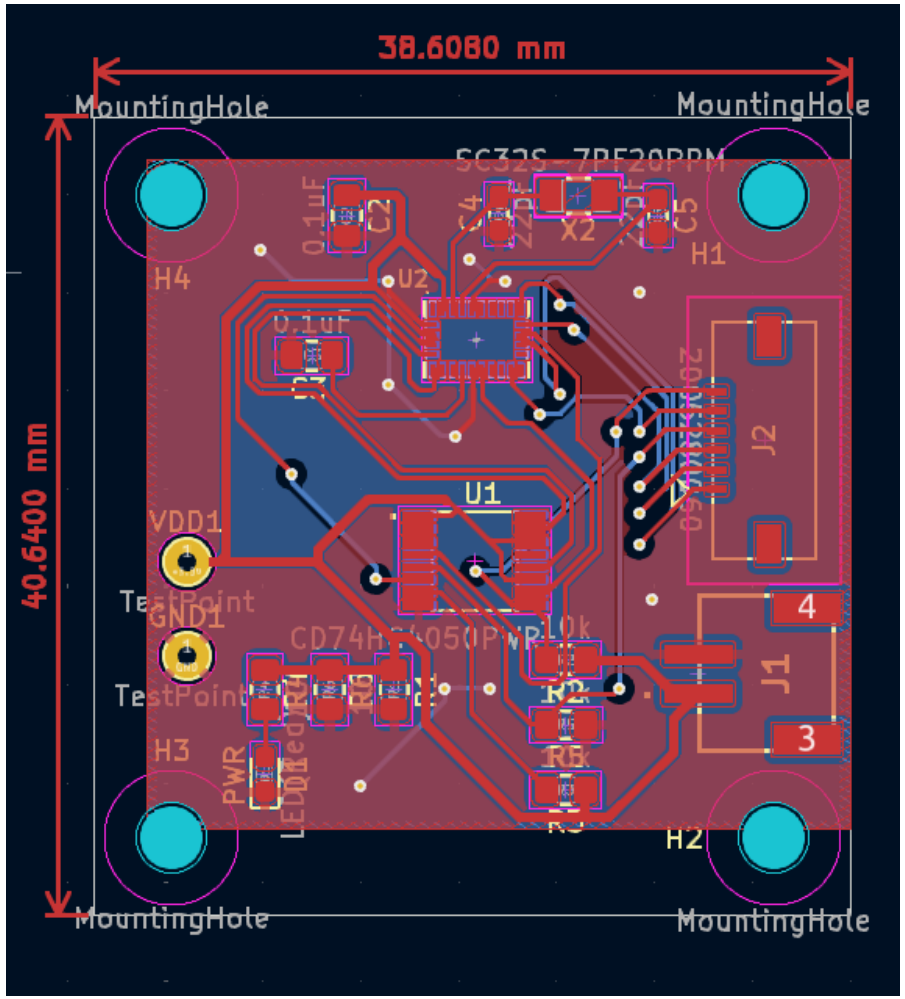
- The Microcontroller Board shall allow the ESP32 MCU to communicate on the HSPI SCK (P14), HSPI MISO (P12), and HSPI MOSI (P13) pins, which shall be routed to the IMU Board.
  (Verified, SPI comm. from IMU observed)

- The Microcontroller Board shall allow the ESP32 MCU to communicate on the GPIO25 (P25), GPIO26 (P26), GPIO32 (P32), and GPIO33 (P33) pins, which shall be routed to the Haptic Feedback Board.
  (Verified, HF Board operates w/ GPIO pins)





IMU Board Requirements



Requirements

- The BMS shall supply up to 1.5 A at 3.3 +- 0.1V to the IMU Board, Microcontroller Board, and Haptic Feedback Board. (Verified, DMM measured voltage)

- The BNO086 IMU shall supply Linear Acceleration Vectors, Absolute Orientation Vectors, and other metrics to the Microcontroller Board through a SPI interface. (Verified, SPI comm. from IMU observed)

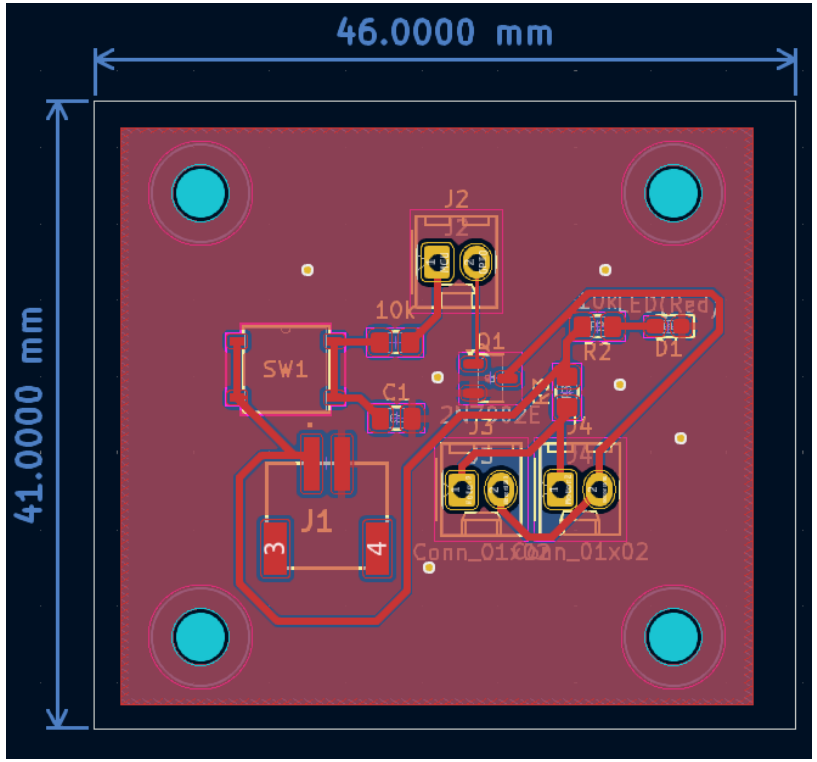
Haptic Feedback Board Requirements

Requirements

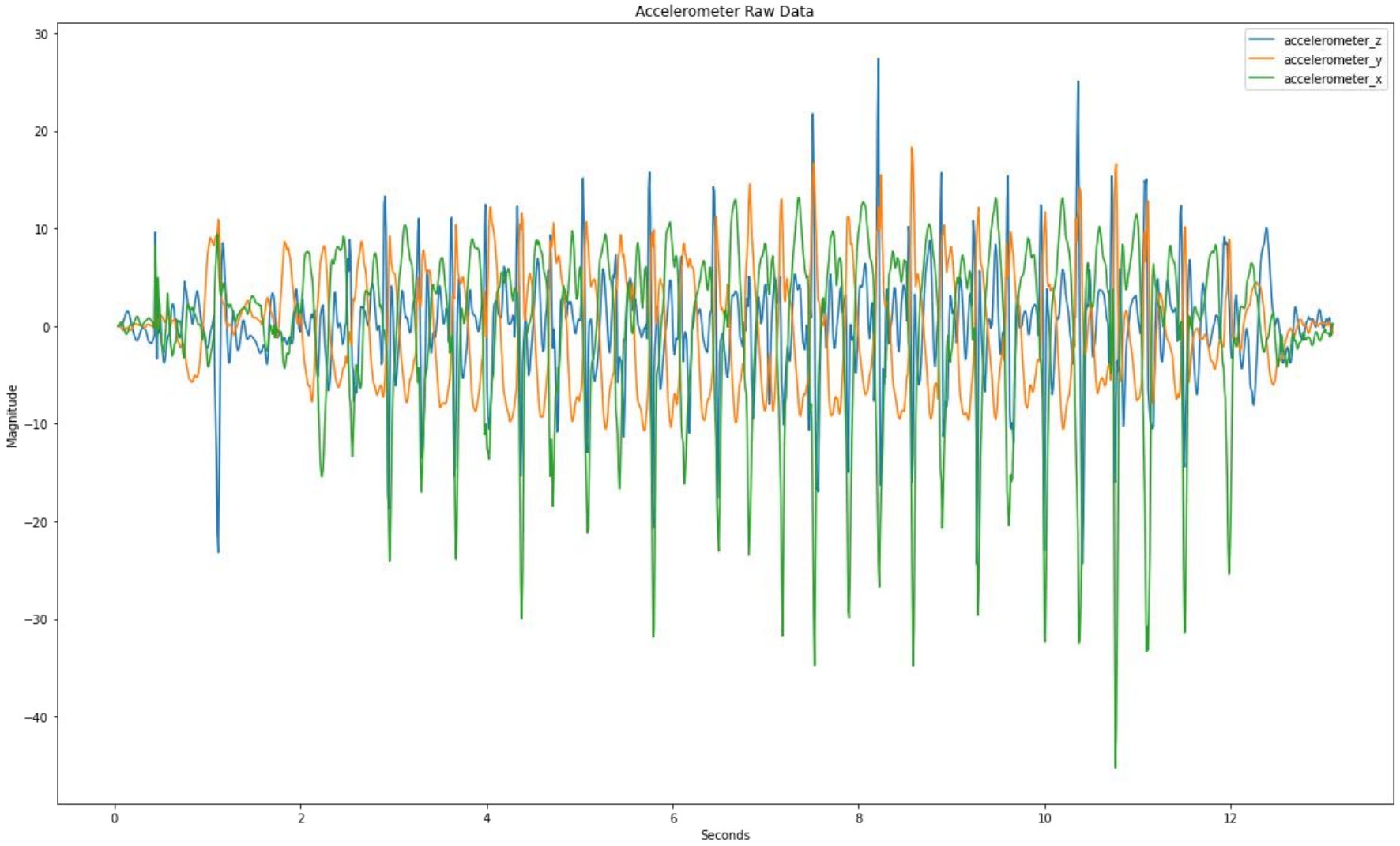
- The Haptic Feedback Board shall connect the supplied 3.3V power line from the BMS to the 2N7002ET7G MOSFET and the PTS526 SM15 SMTR2 LFS tactile switch.
  (Verified, DMM measured voltage)

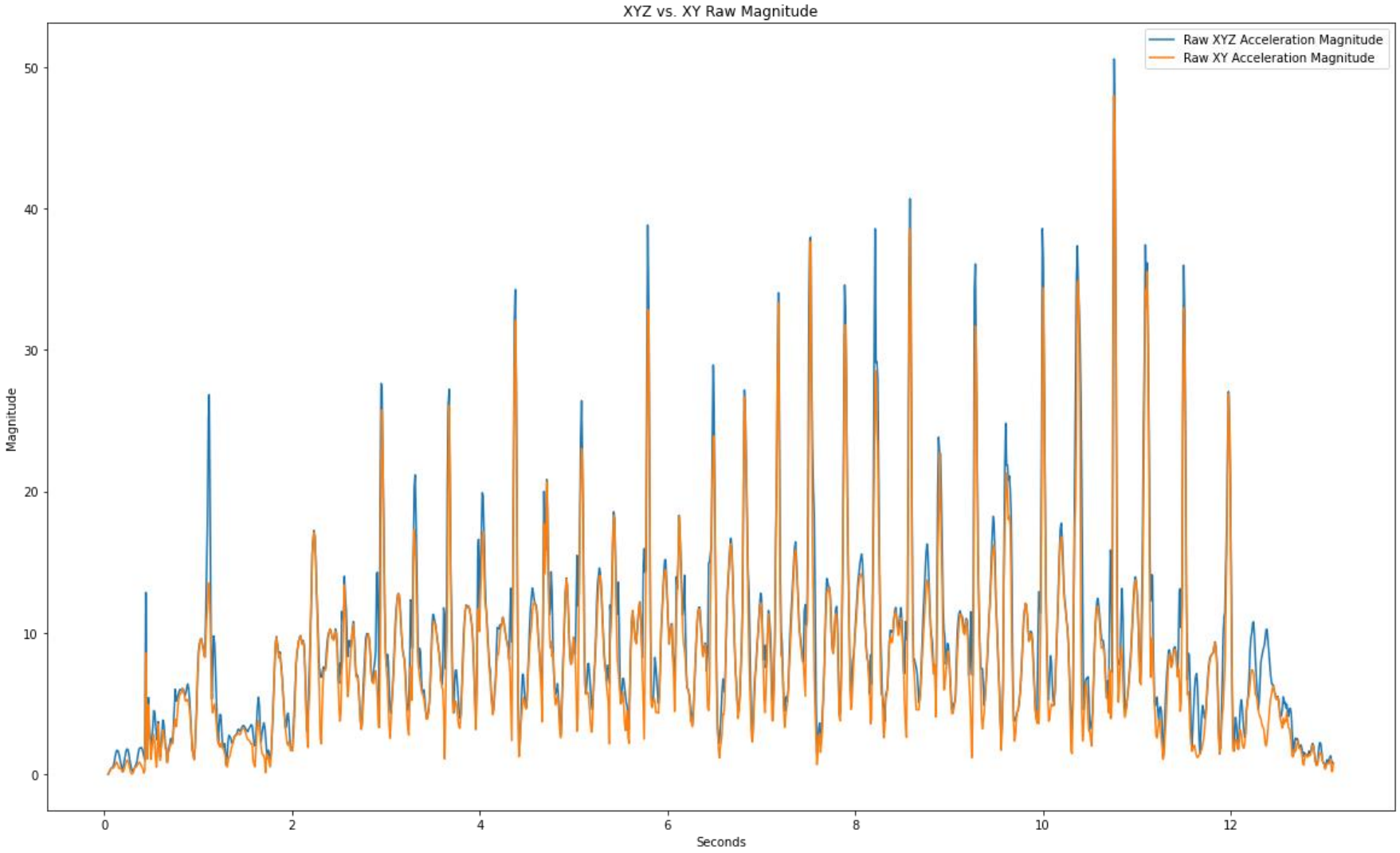
- The PTS526 SM15 SMTR2 LFS tactile switch shall connect to the Microcontroller Board via signals connected to the GPI pins of the ESP32 MCU.
  (Verified, MCU able to lower SPM with button press)

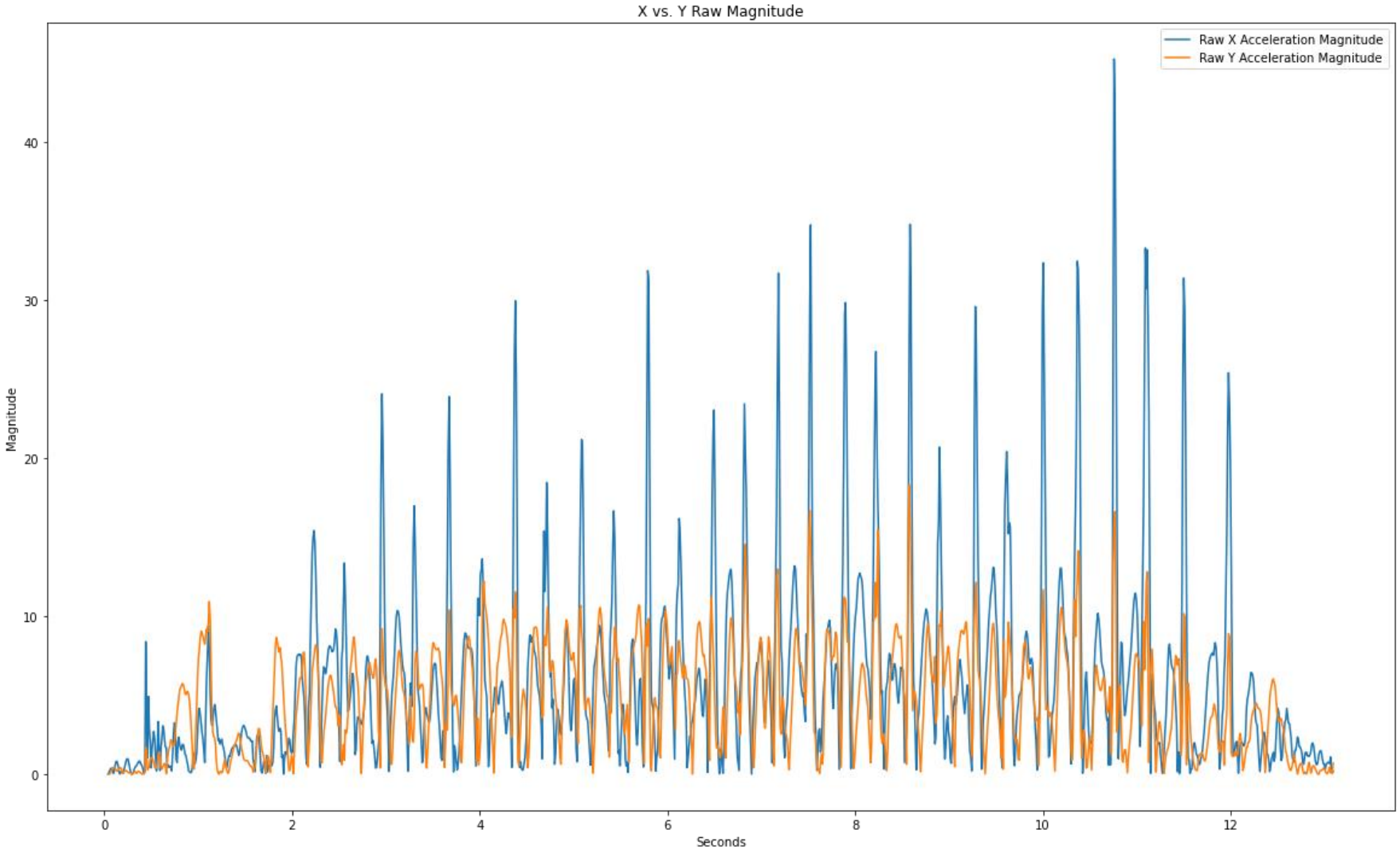
- The 2N7002ET7G MOSFET shall provide the supplied 3.3V power line to both SEEED STUDIO 2.0MM MINI vibration motors when sufficient voltage is applied to its gate via the GPO signal from the Microcontroller Board.
  (Verified, motors fire when and as expected)

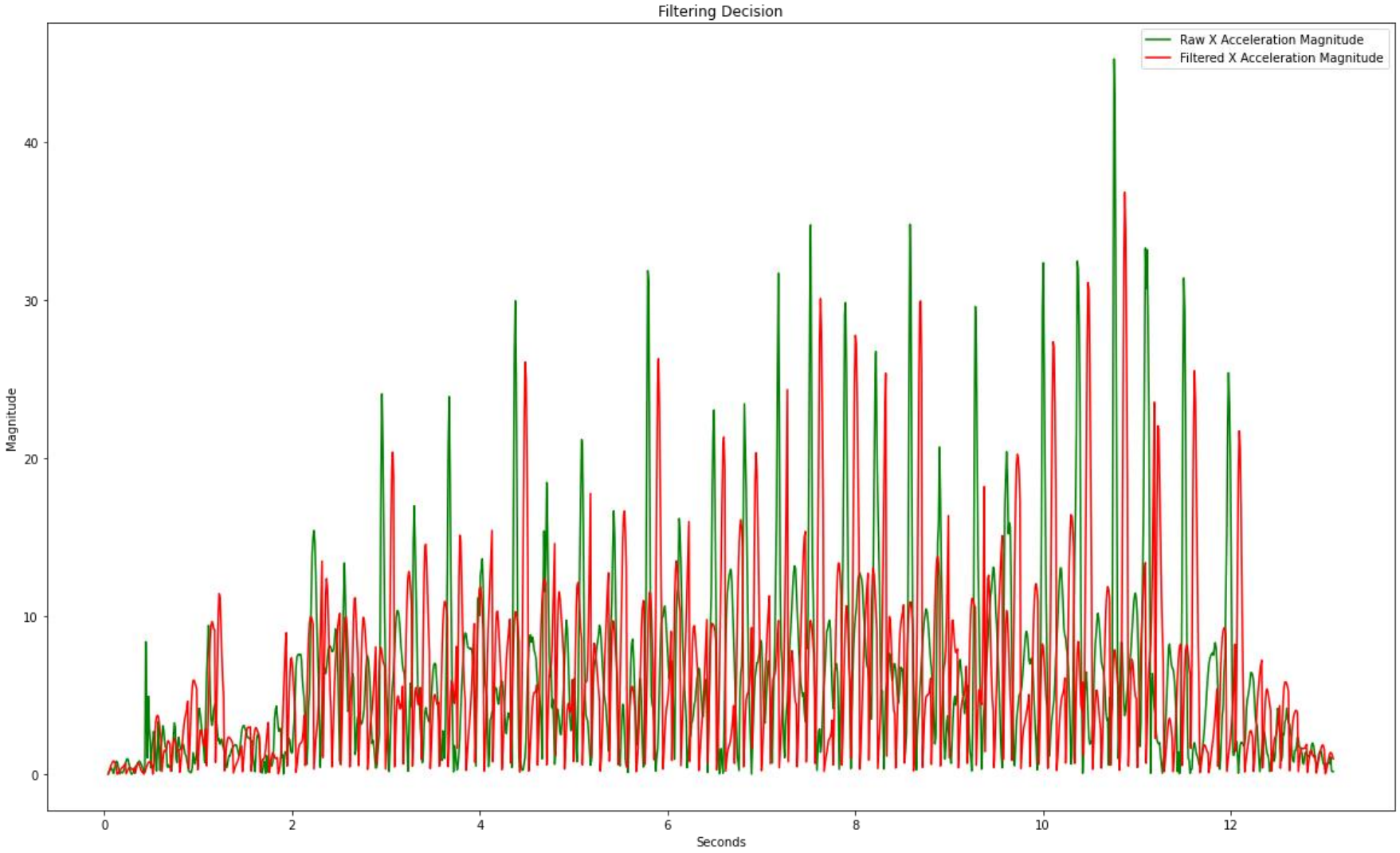


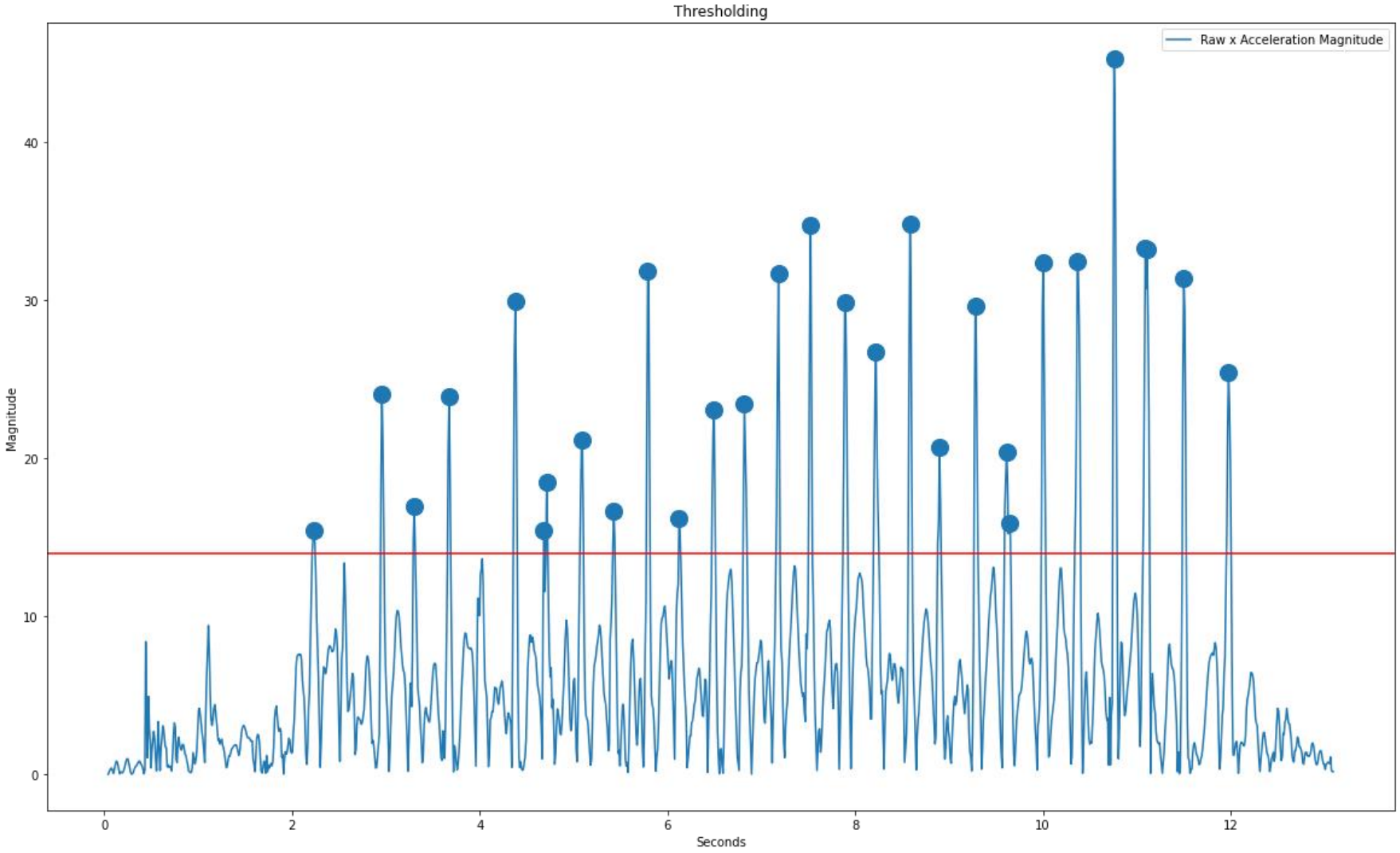
Algorithm Rundown

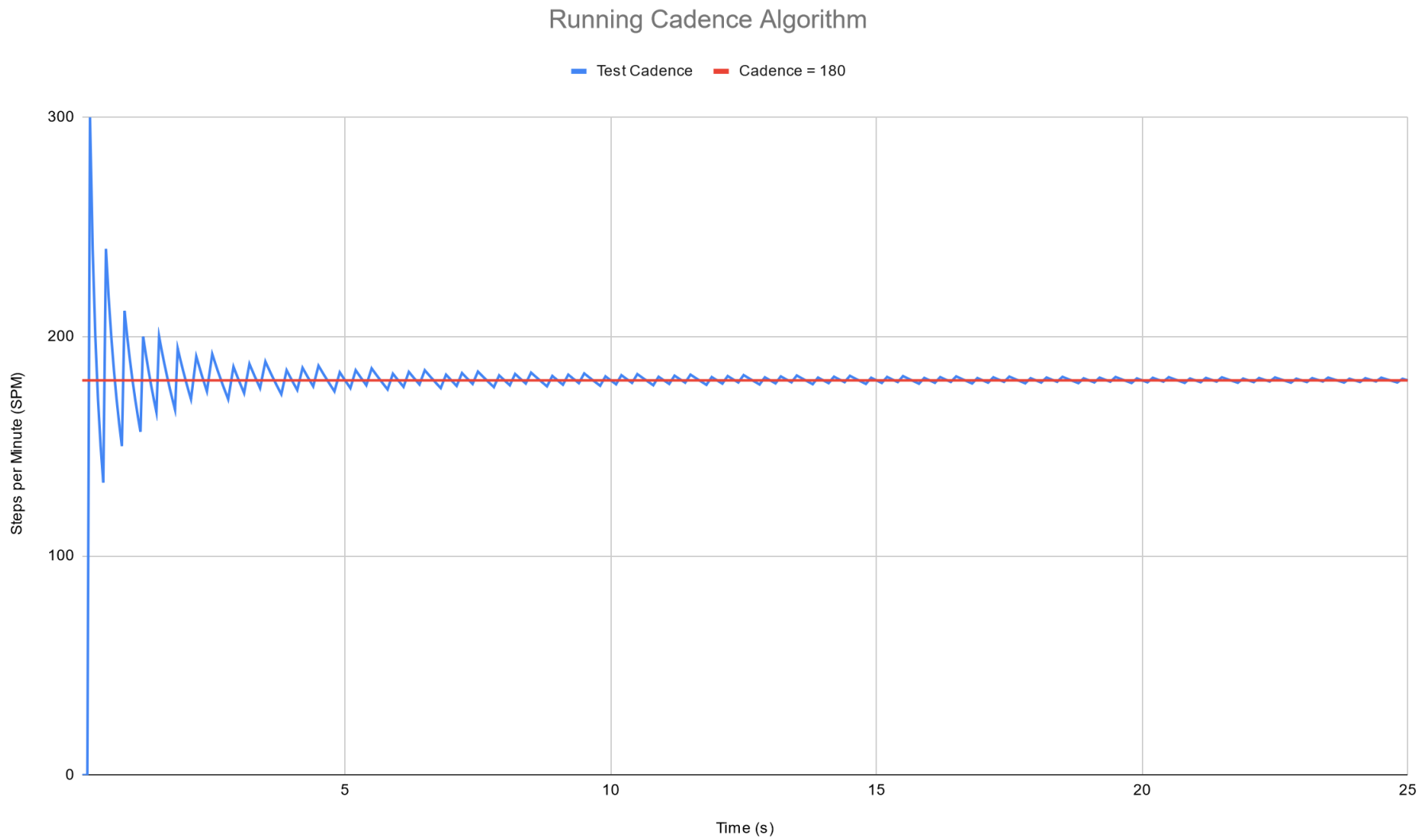



XYZ vs. XY Raw Magnitude
Raw XYZ Acceleration Magnitude
Raw XY Acceleration Magnitude
Magnitude
Seconds
0
10
20
30
40
50
0
2
4
6
8
10
12


X vs. Y Raw Magnitude
Raw X Acceleration Magnitude
Raw Y Acceleration Magnitude
Magnitude
Seconds
0
10
20
30
40
0
2
4
6
8
10
12

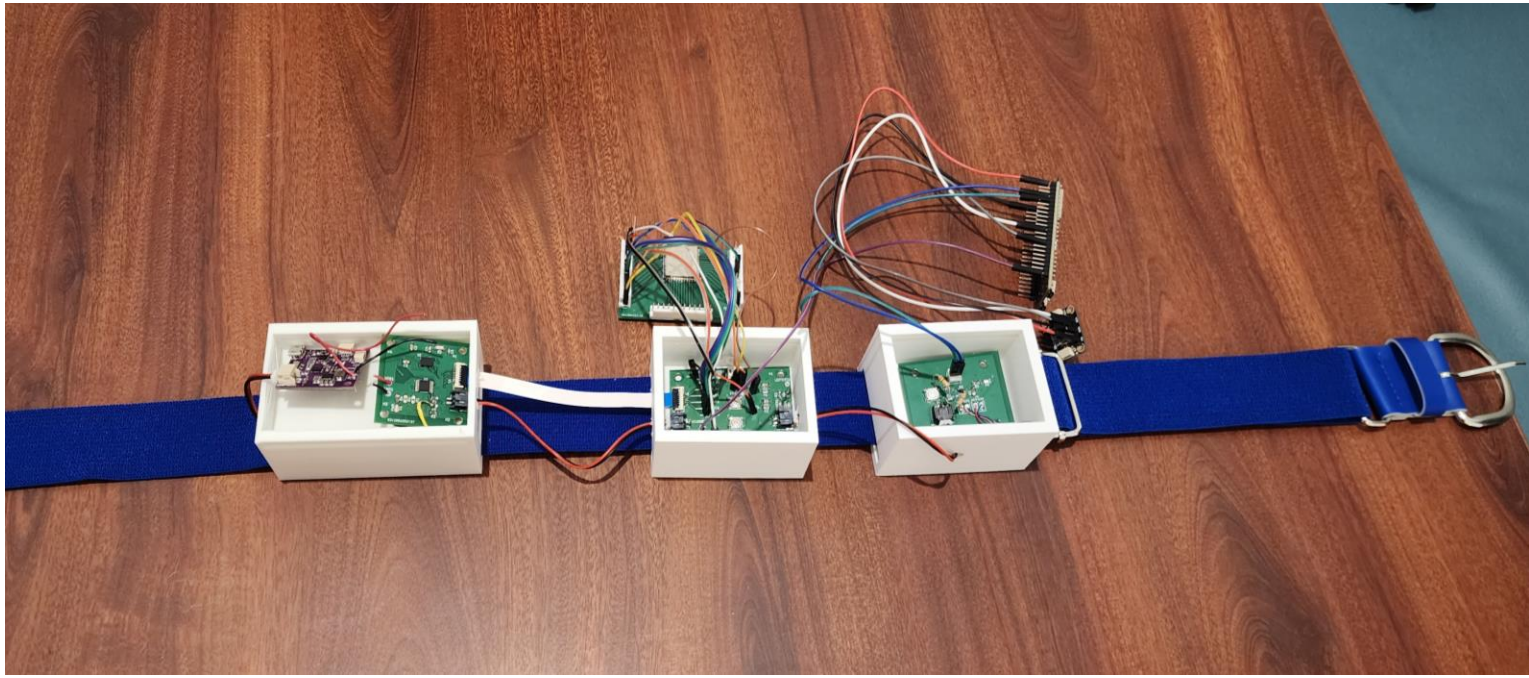

Filtering Decision
Raw X Acceleration Magnitude
Filtered X Acceleration Magnitude
Magnitude
Seconds
0
10
20
30
40
0
2
4
6
8
10
12


Thresholding
Raw x Acceleration Magnitude
Magnitude
Seconds
0
10
20
30
40
0
2
4
6
8
10
12

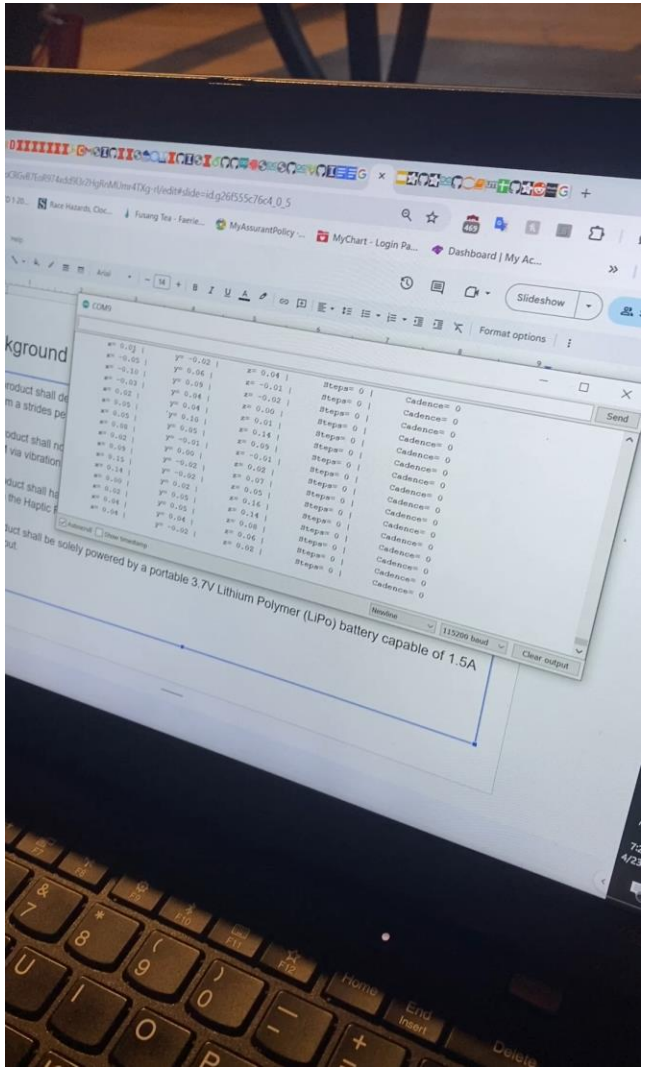

Running Cadence Algorithm
Test Cadence
Cadence = 180
300
200
100
0
Steps per Minute (SPM)
5
10
15
20
25
Time (s)

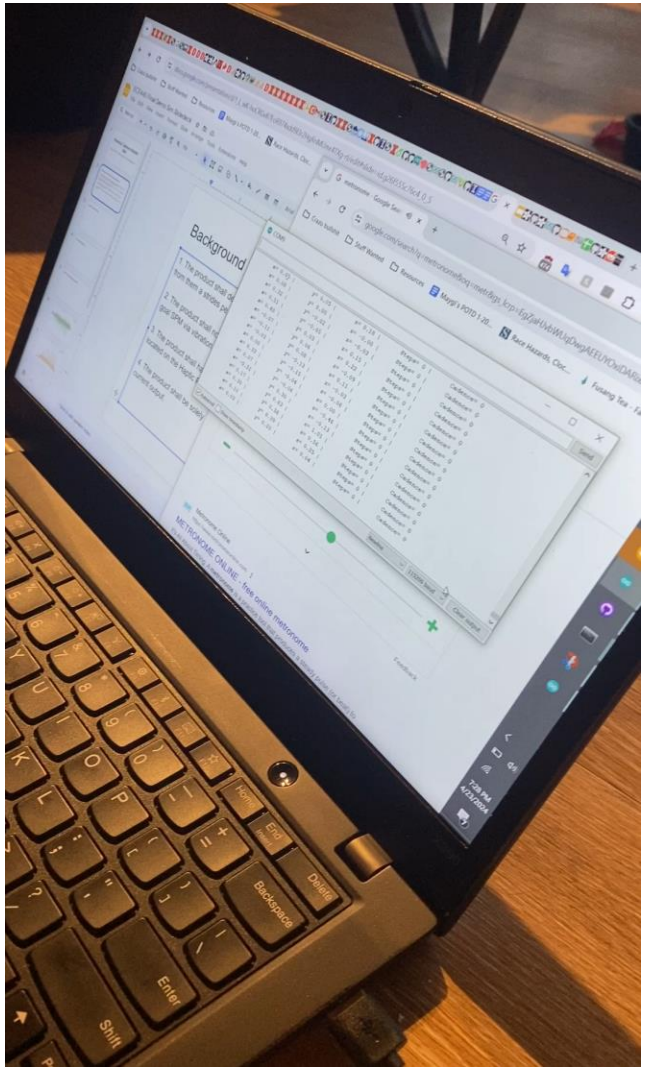
Results

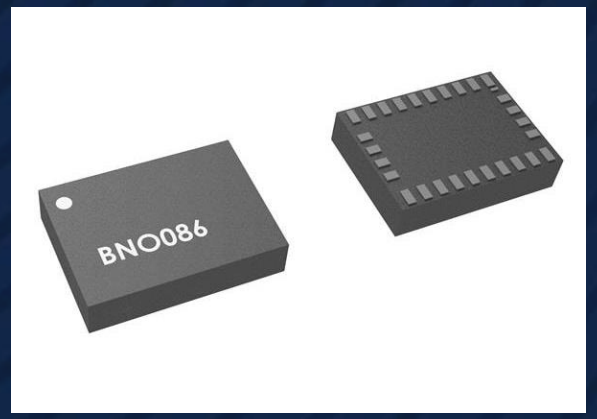
- Able to demonstrate all 4 high level requirements
- IMU and Microcontroller had problems, so dev boards were required

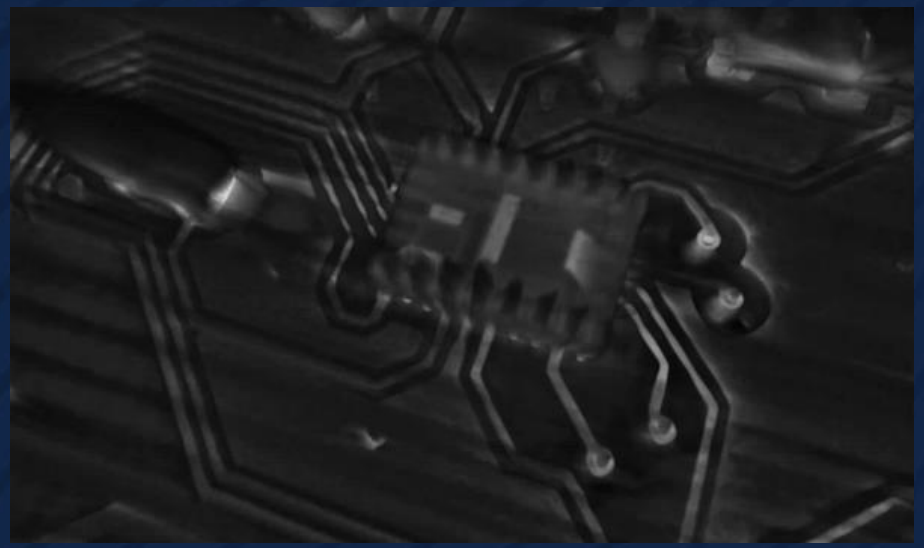


Results


Slideshow
Format options
Send
Clear output
powered by a portable 3.7V Lithium Polymer (LiPo) battery capable of 1.5A


Background

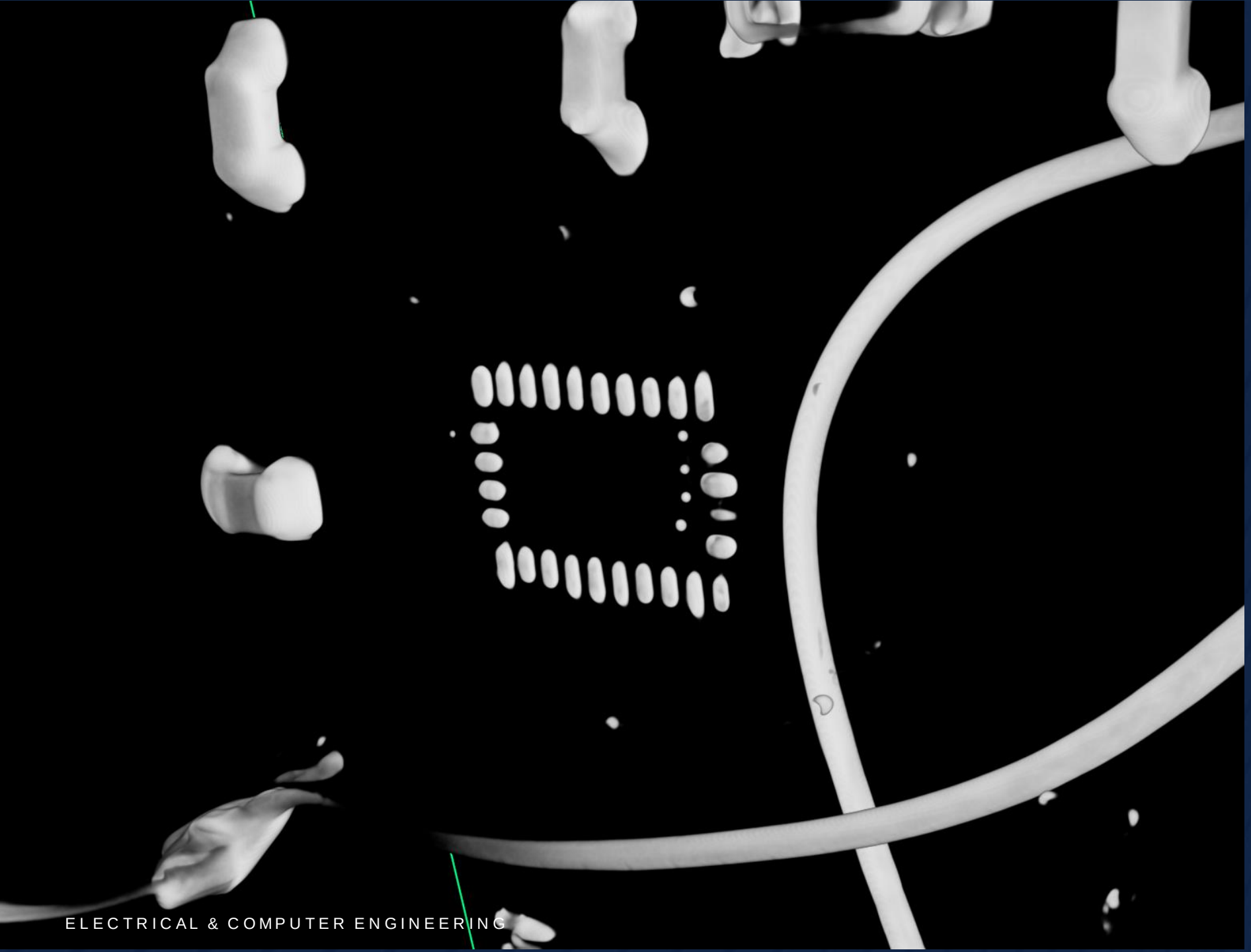




IMU Subsystem Shortfalls

Problem: IMU Chip Consistently Sending Interrupt Requests, Ignoring Inputs

Possible Causes: Poor Solder Joints (TFLGA), Incorrect Hardware Configuration



Investigation: TFLGA Package Solder

Post-Demo CT scan of IMU Board

MCU Subsystem Shortfalls

Problem: ESP32-S3 MCU Programs, Doesn't Execute Programs

Possible Causes: Faulty MCU, Incorrect Hardware Configuration (Unlikely)

```
esptool.py v4.5.1
Serial port COM4
Connecting...
Chip is ESP32-S3 (revision v0.1)
Features: WiFi, BLE
Crystal is 40MHz
MAC: 68:b6:b3:52:87:4c
Uploading stub...
Running stub...
Stub running...
Configuring flash size...
Flash will be erased from 0x00000000 to 0x00003fff...
Flash will be erased from 0x00008000 to 0x00008fff...
Flash will be erased from 0x0000e000 to 0x0000ffff...
Flash will be erased from 0x00010000 to 0x0005cfff...
Compressed 15088 bytes to 10374...
Writing at 0x00000000... (100 %)
Wrote 15088 bytes (10374 compressed) at 0x00000000 in 0.3 seconds (effective 369.7 kbit/s
Hash of data verified.
Compressed 3072 bytes to 146...
Writing at 0x00008000... (100 %)
Wrote 3072 bytes (146 compressed) at 0x00008000 in 0.1 seconds (effective 373.7 kbit/s)..
Hash of data verified.
Compressed 8192 bytes to 47...
Writing at 0x0000e000... (100 %)
Wrote 8192 bytes (47 compressed) at 0x0000e000 in 0.1 seconds (effective 498.1 kbit/s)...
Hash of data verified.
Compressed 312752 bytes to 178878...
Writing at 0x00010000... (9 %)
Writing at 0x0001c34b... (18 %)
Writing at 0x00024b9b... (27 %)
Writing at 0x0002a5d5... (36 %)
Writing at 0x0002fca7... (45 %)
Writing at 0x00034f35... (54 %)
Writing at 0x0003a58a... (63 %)
Writing at 0x00042c1f... (72 %)
Writing at 0x0004adf4... (81 %)
Writing at 0x00051643... (90 %)
Writing at 0x00056dd7... (100 %)
Wrote 312752 bytes (178878 compressed) at 0x00010000 in 2.8 seconds (effective 898.6 kbit
Hash of data verified.

Leaving...
Hard resetting via RTS pin...
```

Remaining Work

Make the microcontroller and IMU functional

Make the overall build smaller

Design the belt to be more of a product than a prototype

Conclusions

Learned how to work in a team on a large project

Applied skills acquired from our ECE curriculum

Thank You!

Questions?

The Grainger College of Engineering

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