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EK 210
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EK 210 Final Report

Executive Summary

This report describes the development of a compact biometric sensing device designed for professional tennis players to monitor wrist acceleration and rotation during swings. The primary goal was to create a device that provides mechanical feedback to improve performance by helping players refine their swing mechanics. The prototype integrates an Arduino Nano 33 IoT, rotary encoder, MPU-6050 sensor, OLED display, and a haptic feedback mechanism, all powered by a rechargeable 3.7V LiPo battery.

Our coding efforts extended beyond data analysis, as we aimed to code the device to enable users to input acceleration and rotation ranges, track real-time data, and view maximum recorded values via a user-friendly interface controlled by the rotary encoder. Complementing our software components, we created housing for all components that were a drastically minimized size from our prototype on CAD. The goal was to develop a wristwatch-sized product that prioritizes durability and user comfort.

The haptic feedback mechanism provides immediate buzzing alerts when measured values exceed the user-defined thresholds, helping players refine their swings. Testing confirmed that the device meets its key objectives of accurate measurement and user-configurable feedback. Future improvements could focus on further minimizing the housing and customizing a PCB board.

Introduction

The client has asked for a biometric sensing device to help athletes train better and monitor their performance throughout an activity for a specific athlete or sport. More specifically, the client works for a company that manufactures training devices for high-level performance athletes. A biometrics sensor of our choice (acceleration and position) excluding blood pressure and heart rate and mechanical feedback (vibration) excluding sound or light based on a threshold (user set) were asked to be integrated into our project. Lastly, our housing must be smaller than a shoe box and should have a power source of choice (battery).

According to our research, biometric devices come in various forms, each with different objectives. Common types of biometric devices are Identification Biometric Devices (such as Fingerprint, face recognition, or DNA), Medical Biometric Devices (continuous glucose monitors), and the third most common biometric device is a Training Biometric Device (movement sensors, ex. Catapult® Sports Bras). This design will be based on the Training Biometric Device, which uses sensors to measure and track an athlete's physiological characteristics and physical performance. The device provides real-time data and feedback to the user to improve athletic performance, enhance efficiency, and prevent injuries. As stated above, our device will use the mechanical feedback of vibration to alert the user when they have met their input threshold of acceleration and rotation to improve performance overall. Finally, another considerable constraint is cost. The maximum budget for this project was $200, and our final total spending was $87.23.

Problem Statement

The goal was to design a wearable biometric device for professional tennis players that monitors swing acceleration and rotation, provides mechanical feedback when measurements exceed user-defined thresholds, and helps improve performance through measurable insights.

Key Objectives

- Measure swing acceleration (m/s^2) and rotation (°/s) using compact, accurate sensors.
- Provide a customizable interface to set and adjust acceleration and rotation range thresholds.
- Deliver real-time mechanical feedback when thresholds are exceeded.

Metrics

- Real-time data monitoring with a refresh rate suitable for fast tennis swings.
- Feedback accuracy within ±5% of input thresholds.
- Measured acceleration and rotation accuracy within ±5%

Description of Final Products/Evaluation of Results

Our primary aim was to create a user-friendly wearable device designed to capture swing acceleration and rotation from a user input threshold that would provide mechanical, vibrational feedback to improve tennis performance. We were able to meet all of our core objectives. However, our device has gone into shambles in the past day since our final presentation, and we are still determining why. This will be evaluated in the lessons learned section of our report.

Regarding hardware, careful consideration and integration of components—such as Arduino nano 33 IoT, MPU-6050, rotary encoder, haptic feedback motor, and OLED 128x64—was done through precise soldering to perfboards and CAD design. See Appendix F for the circuit. Our chosen rechargeable 3.7 V lithium polymer battery paired with a 5V boost converter proved reliable in maintaining the necessary voltage throughout the time of use, as well as an NMOS MOSFET with a 1k ohm resistor to control the current flow. See Appendix G for power consumption of each component.

Our software code ensures smooth device operation and captures swing acceleration and rotation data to provide vibrational feedback for tennis performance improvement. With the help of our code, the rotary encoder offers an intuitive user experience for navigation and data adjustment. Our code prevents thresholds from exceeding preset limits, ensuring logical adjustments. The activation of the motor is if the measured values are within the user's input thresholds, underscoring our achievement of delivering responsive feedback, as outlined in our project objectives. See Appendix H for the code flow chart.

We selected the MPU-6050 sensor for its compact size, versatility, and reliability. Initially, it provided incorrect readings because the pins were not soldered, causing unstable connections. Once soldered, the sensor performed reliably. For our biometric sensor device for tennis players, we increased the acceleration range to 8g (78.48 m/s^2) and the rotation range to 1000 degrees/second to capture wrist motion during hits accurately and serves. Calibration, performed using the Arduino IDE library for the MPU-6050, ensured precise measurements.

As for external design and housing, CAD iterations resulted in a broader casing to try and minimize bulkiness as best as possible while having enough room to enclose all of our internal parts. Our prototype was too large, using wood and finger joints from the wire cutter. Using CAD allowed us to value durability for things such as the LCD and other internal components while also aiding in the minimization of housing. Additionally, using perfboards to solder all components down reflected a strategic trade-off between width and height, prioritizing user comfort in the long run.

To acknowledge limitations, we recognized that troubleshooting efforts during perfboards implementation and issues with our boost converter added complexity to the project timeline. Future work would explore alternative solutions to minimizing size, such as ordering a custom PCB for a smoother integration process. Further user testing and feedback collection could refine the user interface and overall experience.

Integrating hardware, software, and design elements has yielded a wearable device that effectively fulfills its objectives. Our watch can track acceleration (0.0 to 78.45 m/s^2) and rotational velocity (0.0 to 1000.0 °/s) using an MPU6050 sensor and provides real-time feedback via a haptic motor when measurements fall within user-defined thresholds. The device features customizable thresholds, an OLED display for live data and metrics, and modes for monitoring, threshold adjustment, and maximum value tracking. All of this was done in a compact as possible, durable, and accurate casing and wristband. See Appendix J for the demonstration video.

The significance of our work is to provide athletes with a practical device that will make their game actively better. The collaborative efforts and problem-solving skills demonstrated throughout this project emphasize the importance of teamwork, overcoming challenges, and achieving project goals.

Lessons Learned

This project taught us that the engineering design process takes much time, effort, and teamwork. As most groups have said, they would consider the time constraint more. Our group effectively handled the time constraint. However, everyone can always start earlier; for example, we could have ordered a custom PCB earlier. The main thing we learned is always to have duplicates of parts and strong soldering connections. We had to resolder constantly and had many issues in the past day, with parts breaking and going on a goose chase to find more. Overall, being more prepared is what we learned for the future.

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Appendix

A. Full List of Objectives and Metrics

Hardware

- Arduino Nano 33 IoT microcontroller.
- MPU-6050 IMU for acceleration and gyroscope measurements.
- OLED display (128x64) for user interface and data visualization.
- Rotary encoder for mode navigation and threshold adjustments.
- 3.7V LiPo battery with a 5V boost converter for power.
- MOSFET with 1k ohm resistor and haptic motor for feedback.
- Perfboards for component assembly.

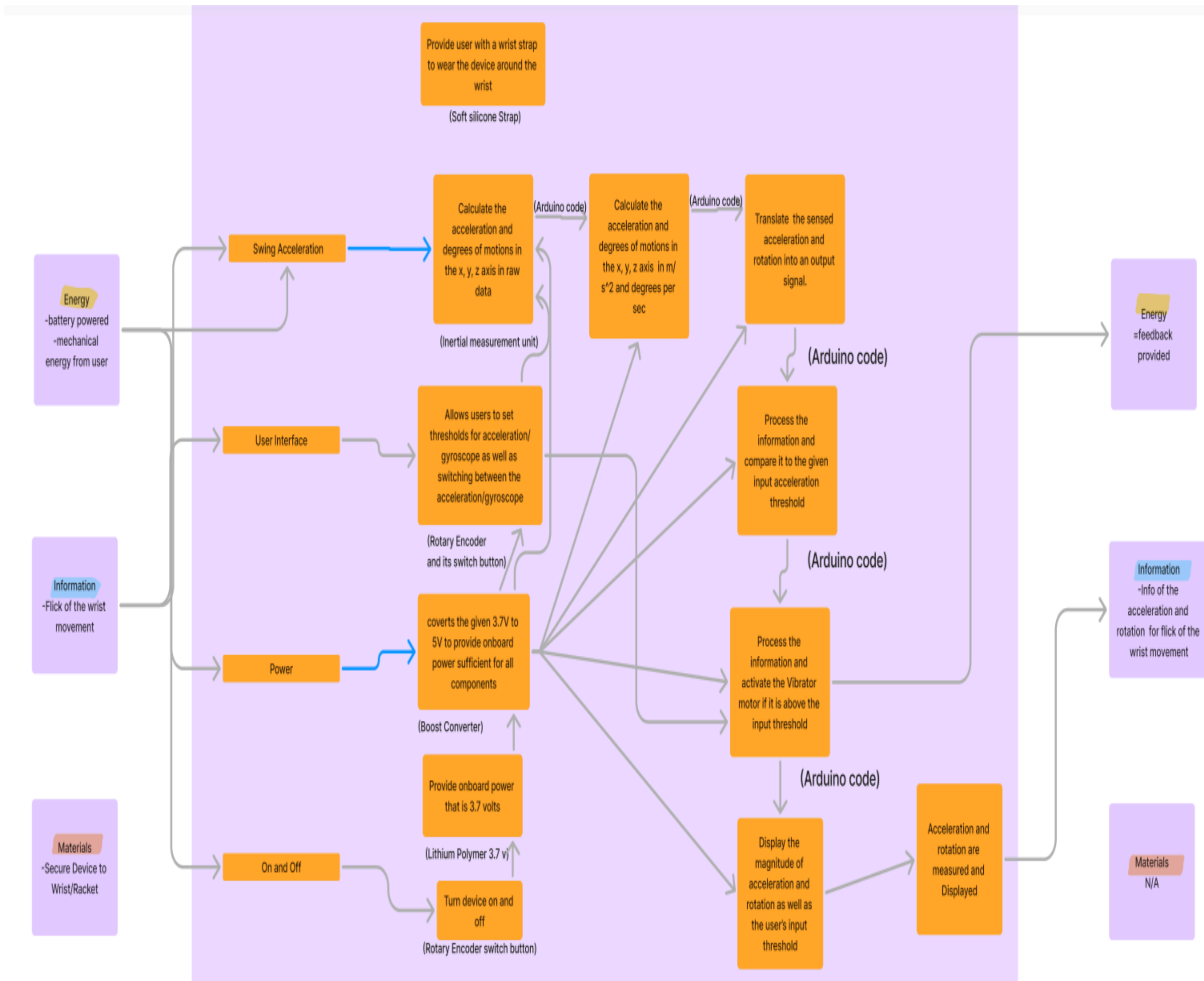
Functionality

- Modes
    - **Main Menu:** Displays real-time acceleration and rotation data.
    - **Acceleration Range:** Allows users to set low and high thresholds for acceleration (0–78.89 m/s^2).
    - **Rotation Range:** Allows users to set low and high thresholds for rotation (0–1000 °/s).
    - **Max Data:** Displays maximum recorded acceleration and rotation values.
    - **Navigation**: Controlled via the rotary encoder with single, double, and long presses.
    - **Power Management:** The OLED screen can be toggled on/off by holding the encoder button.

Safety and Cost

- Be safe
    - Everything is enclosed within the box, and no open circuit
- Be accurate at reading relevant biometrics
    - Read acceleration and rotation with ±5% accuracy
- Be affordable
    - Cost less than $200

B. Glass Box



Provide user with a wrist strap to wear the device around the wrist
(Soft silicone Strap)
Energy
-battery powered
-mechanical energy from user
Swing Acceleration
Calculate the acceleration and degrees of motions in the x, y, z axis in raw data
(Inertial measurement unit)
(Arduino code)
Calculate the acceleration and degrees of motions in the x, y, z axis in m/s^2 and degrees per sec
(Arduino code)
Translate the sensed acceleration and rotation into an output signal.
(Arduino code)
Energy
-feedback provided
User Interface
Allows users to set thresholds for acceleration/ gyroscope as well as switching between the acceleration/gyroscope
(Rotary Encoder and its switch button)
Process the information and compare it to the given input acceleration threshold
(Arduino code)
Information
-Flick of the wrist movement
Information
-Info of the acceleration and rotation for flick of the wrist movement
Power
coverts the given 3.7V to 5V to provide onboard power sufficient for all components
(Boost Converter)
Process the information and activate the Vibrator motor if it is above the input threshold
(Arduino code)
Provide onboard power that is 3.7 volts
(Lithium Polymer 3.7 v)
Materials
-Secure Device to Wrist/Racket
On and Off
Turn device on and off
(Rotary Encoder switch button)
Display the magnitude of acceleration and rotation as well as the user's input threshold
Acceleration and rotation are measured and Displayed
Materials
N/A

C. PCC

	Precision + Accuracy	Vs. Durability	Vs. Cost	Vs. Size/Weight	Vs. Power Supply	Vs. Feedback Mechanism	Total
Precision + Accuracy	—	1	1	0	1	1	4
Durability	0	—	1	0	0	1	2
Cost	0	0	—	0	0	0	0
Size /Weight	1	1	1	—	1	1	5
Power supply	0	0	1	0	—	1	2
Feedback Mechanism	0	0	1	0	0	—	1

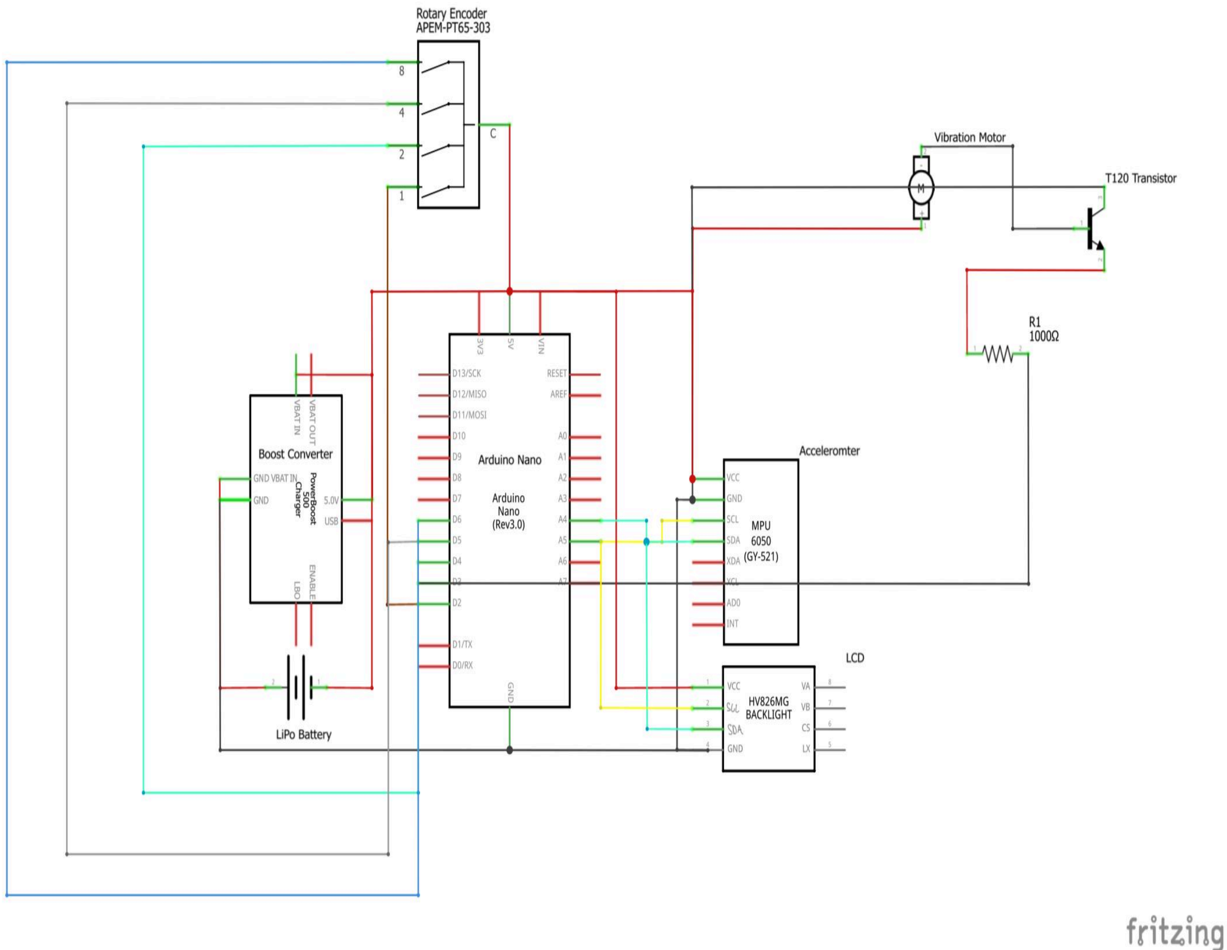
D. Morph Chart

Size/Weight	1	2	3
Durability	Rubber	Metal	Plastic
Power Supply	Solar Power	Disposable Battery	Rechargeable Battery
Data Collection/Transmission	Bluetooth	USB	MicroSD Card
Feedback Mechanism	Haptic Feedback	A flag	Color changing cards

E. Bill of Materials

Part Number	Components	Price
VIBRATION ERM MTR 11000 RPM 5V	Vibration motor	1.95
Arduino Nano 33 IoT [ABX00027]	Arduino nano	25.9
OL-HLS	Velcro roll	7.99
TIP 120 power Darlington Transistors (976)	TIP 120 power Darlington Transistors -3 pack	0.83
Product ID: 2465	Boost converter	19.95
Adafruit I2C Stemma QT Rotary Encoder	Rotary Encoder	7.95
1568-1496-ND	Lithium-ion battery	4.95
3647-OLED128x640.96" SPI	OLED LCD screen	4.76
Adafruit MPU-6050 6-DoF Accel and Gyro Sensor	IMU sensor	12.95
	Total	**87.23**

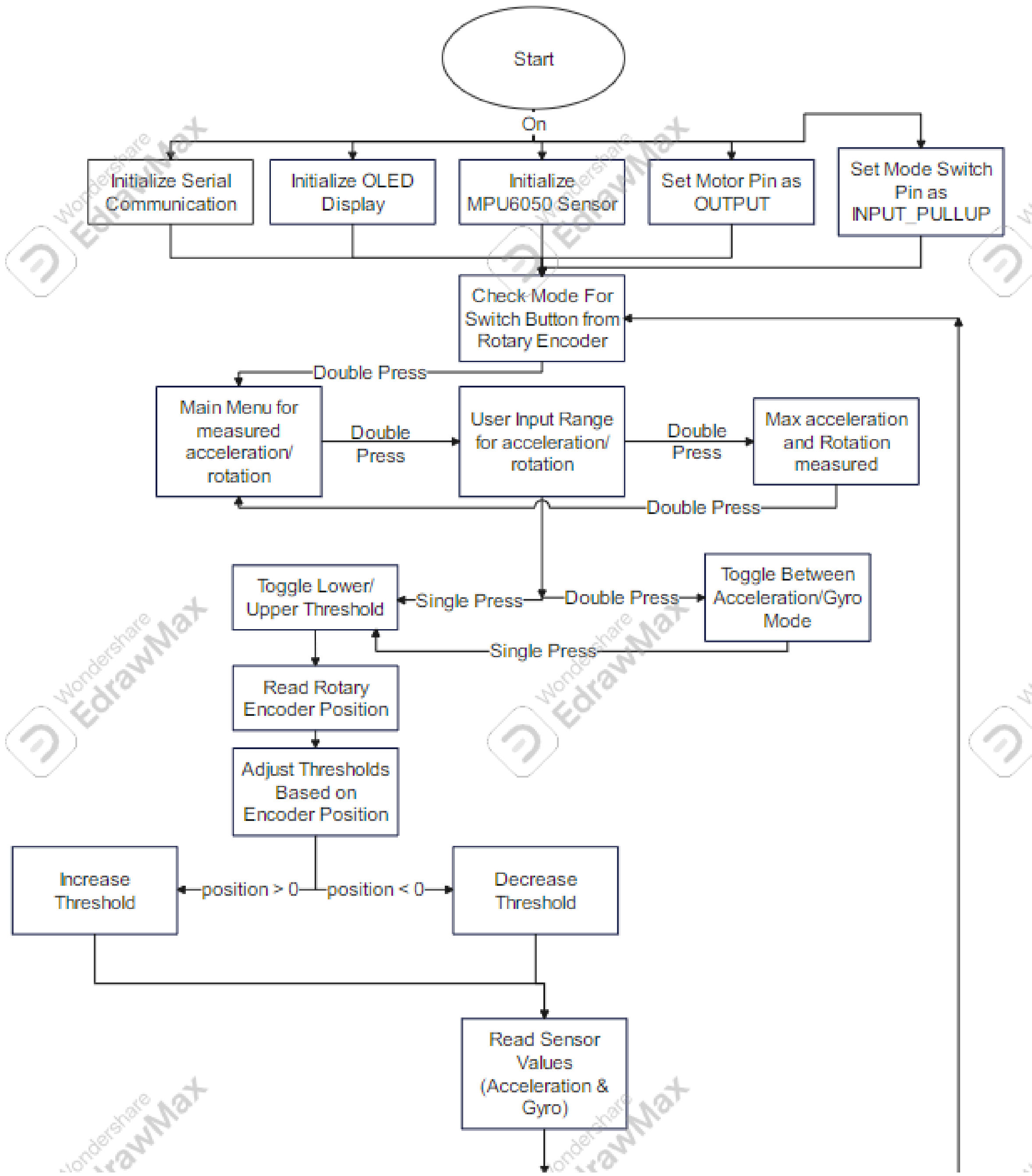
F. Electronics Sketch/Circuit

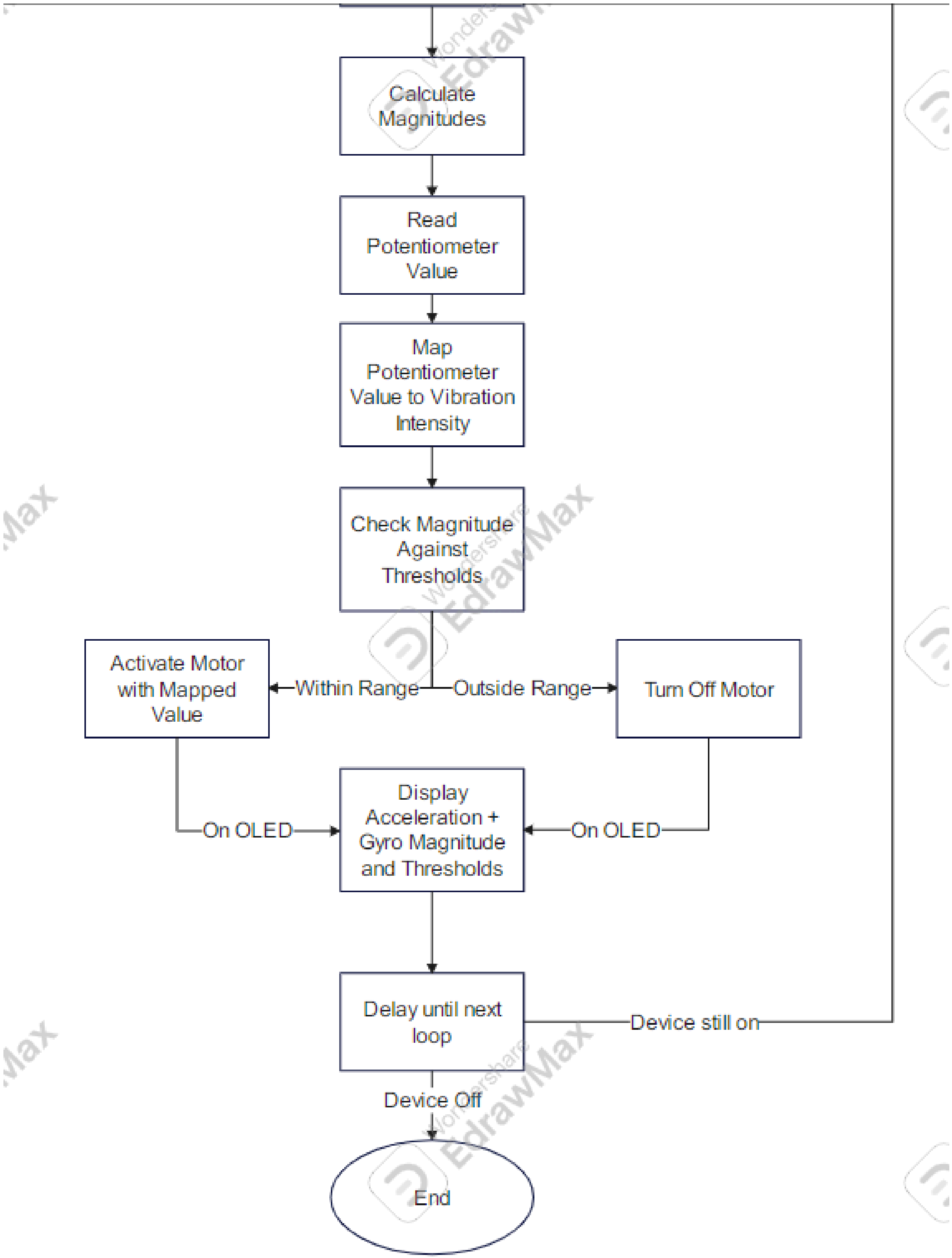


G. Power Consumption

Components	Supply Current (mA)	Supply Voltage (V)	Peak Power Consumption (W)
3.7 LiPo Battery	1000 mA	3.7 V	3.7 W
5V Boost Converter	1500 mA (from battery)	5 V	5.56 W (90% efficiency)
OLED 128x64	8 to 20 mA	3.3 to 5.0 V	0.04 to 0.08 W
KY-040 Rotary Encoder	10 mA (contact rating)	5 V	0.05 W
MPU-6050	3.8 mA (gyro + accel full power)	2.375-3.46 V	~0.013 W
Vibrating Mini Motor Disc	≤75 mA (rated current)	2.5-3.8 V	~0.225 W (at 3.0V)

H. Code Flow Chart

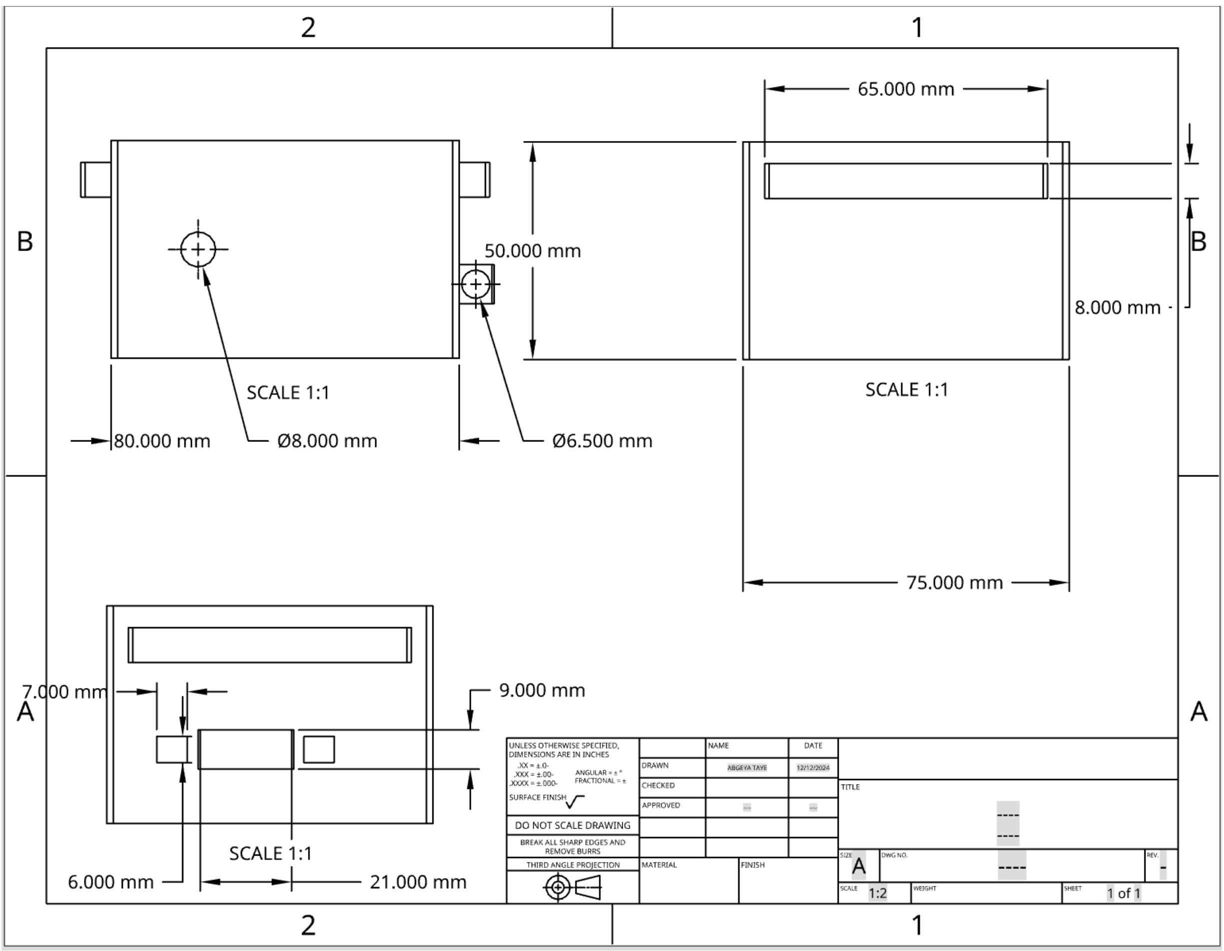


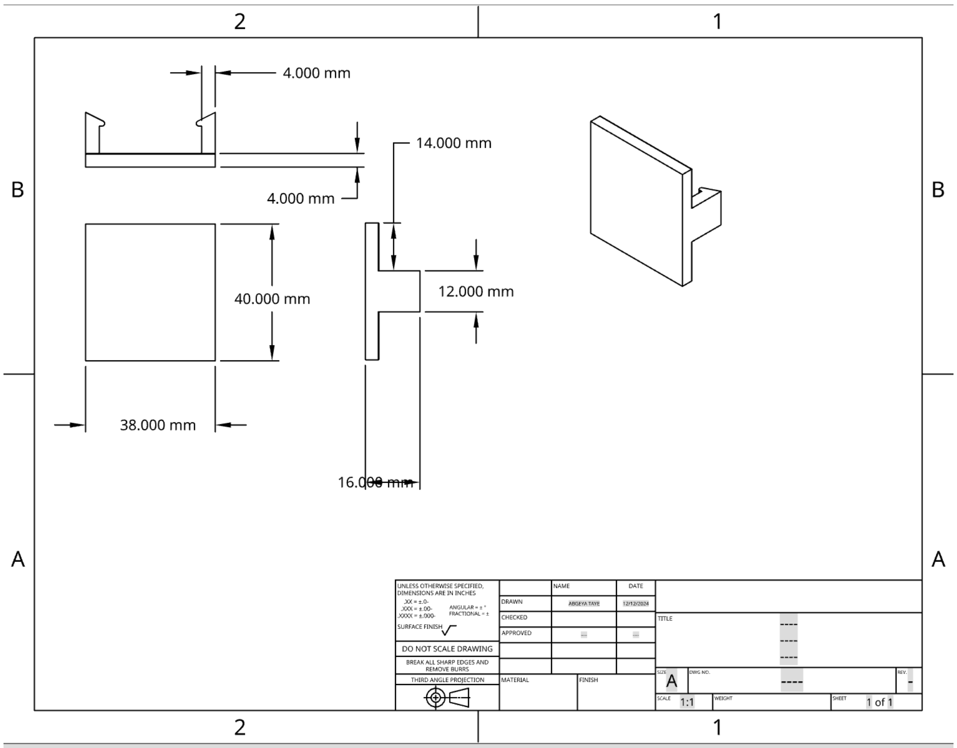


Calculate Magnitudes
Read Potentiometer Value
Map Potentiometer Value to Vibration Intensity
Check Magnitude Against Thresholds
Within Range
Outside Range
Activate Motor with Mapped Value
Turn Off Motor
On OLED
On OLED
Display Acceleration + Gyro Magnitude and Thresholds
Delay until next loop
Device still on
Device Off
End

I. Housing design

BOX: 80mm X 75mm X 50mm
LID: 80mm X 75 mm X 3mm
Battery holder : 40mm X 16mm X 38mm




4.000 mm
14.000 mm
4.000 mm
40.000 mm
12.000 mm
38.000 mm
16.000 mm
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
DRAWN
CHECKED
APPROVED
NAME
DATE
TITLE
MATERIAL
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SIZE
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DWG NO.
REV.
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WEIGHT
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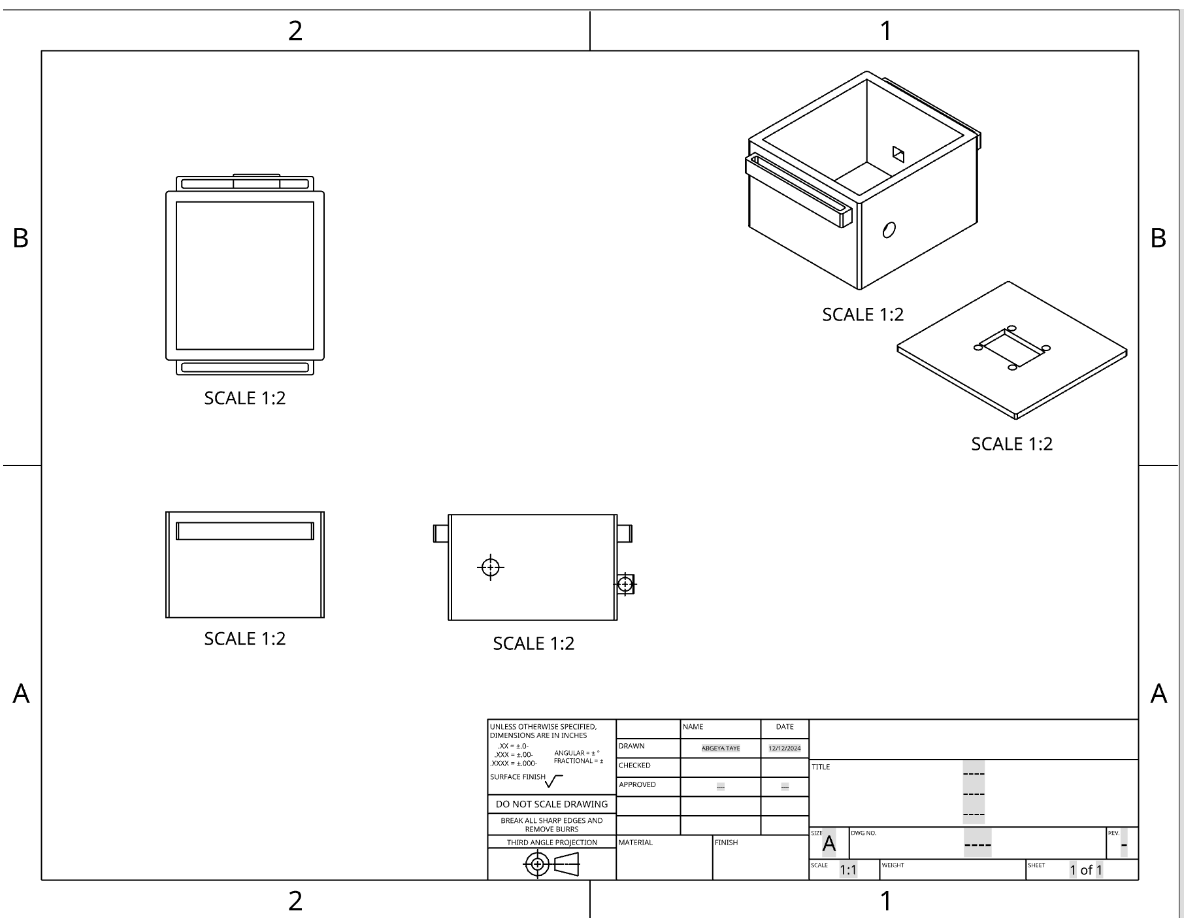
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UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
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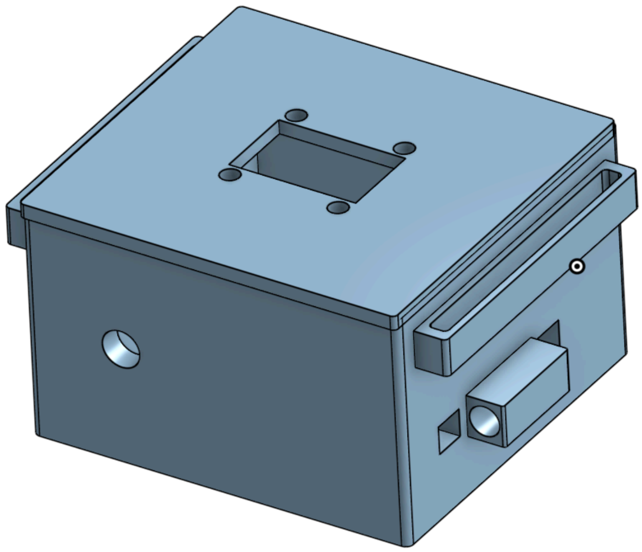
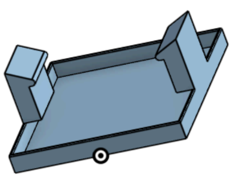
Final BOX

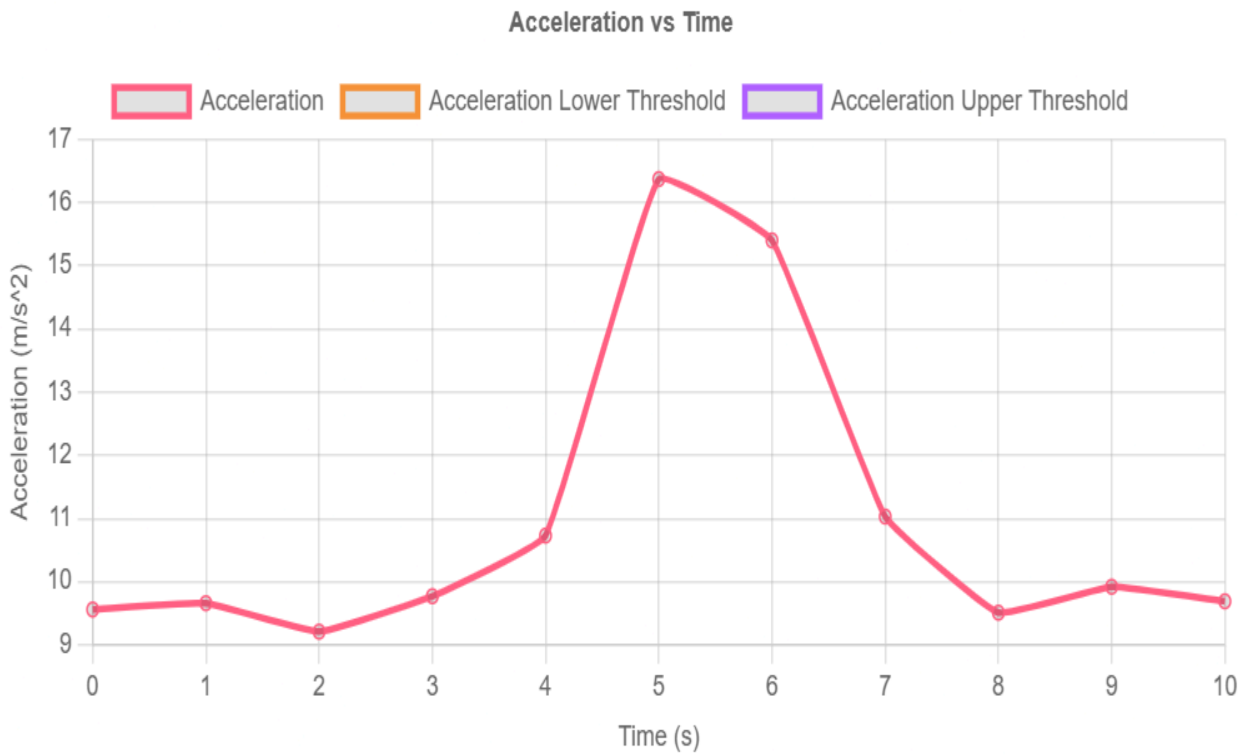


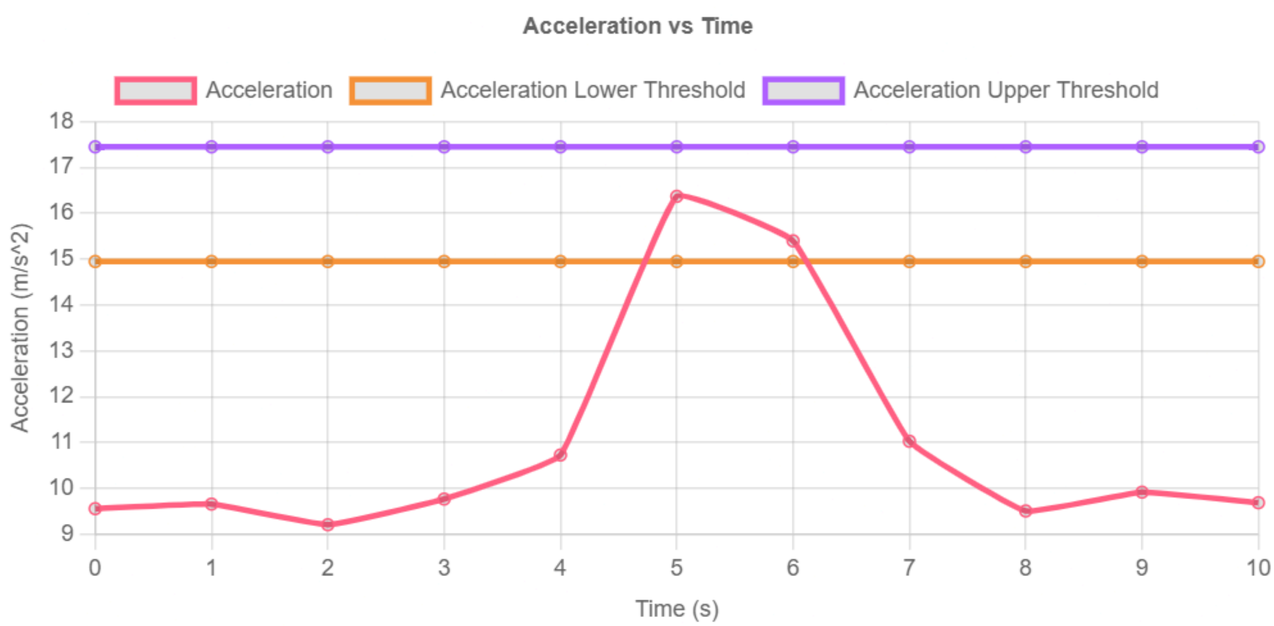


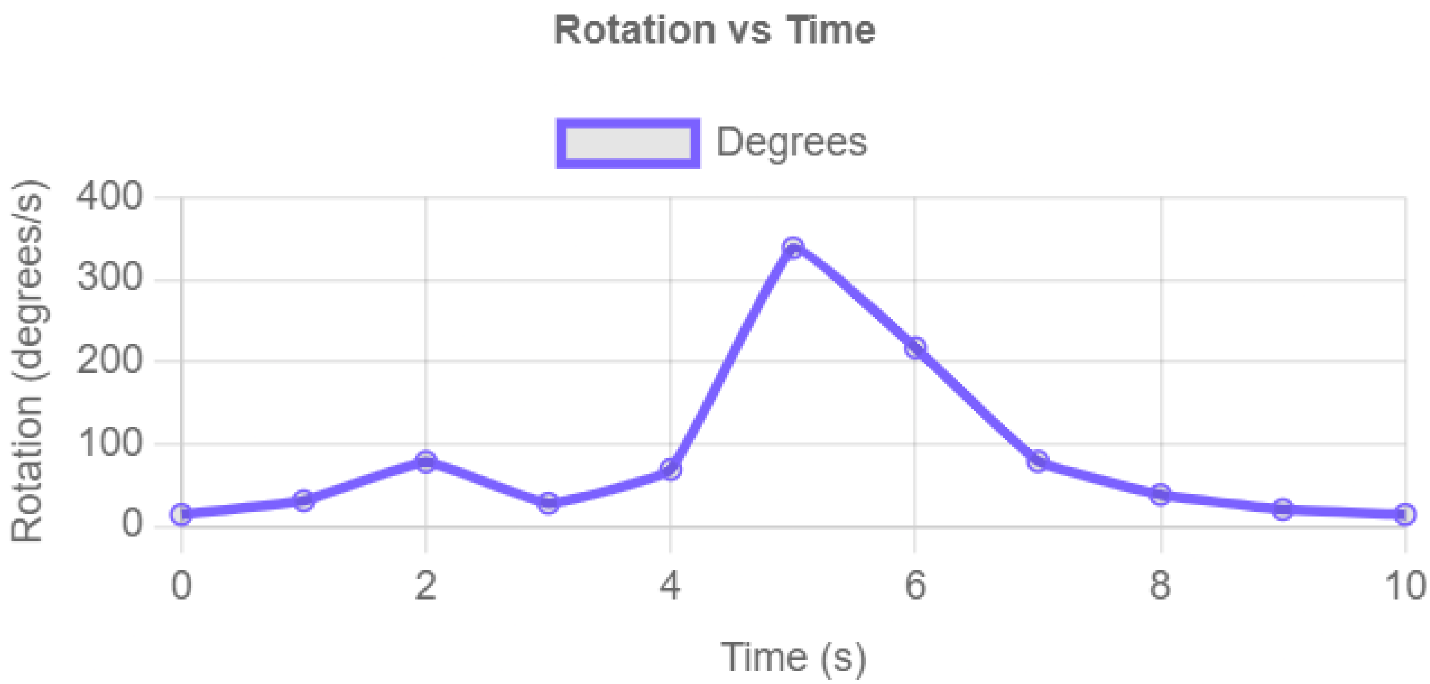
J. Demonstration of Working Product

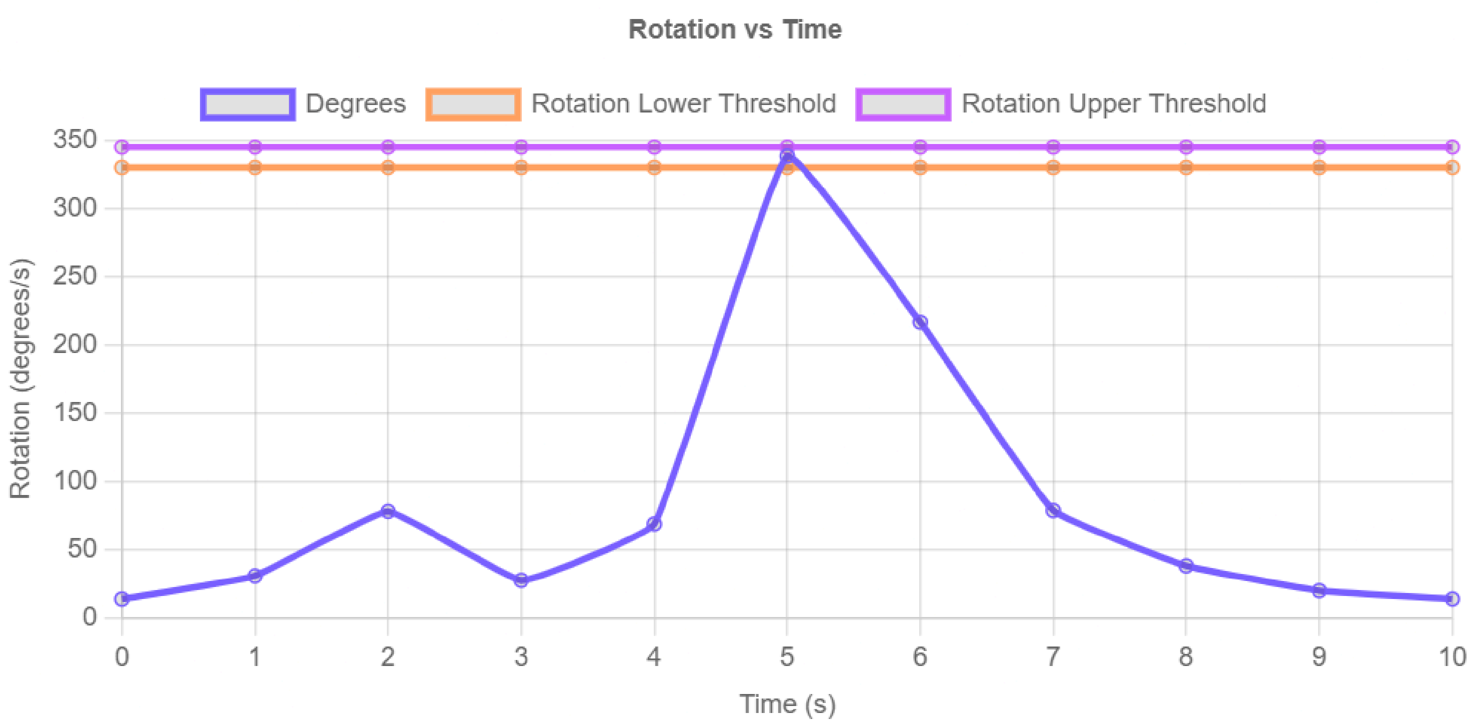
https://drive.google.com/file/d/1da2H64FBbh-MOOYr5yrfvkrewvc04shX/view?usp=sharing

K. Sensory specifications






Rotation vs Time
Degrees
Rotation (degrees/s)
400
300
200
100
0
0
2
4
6
8
10
Time (s)


Rotation vs Time
Degrees
Rotation Lower Threshold
Rotation Upper Threshold
Rotation (degrees/s)
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
Time (s)