Github link: https://github.com/bluesparrow09/TECHIN515-magic-wand/tree/main

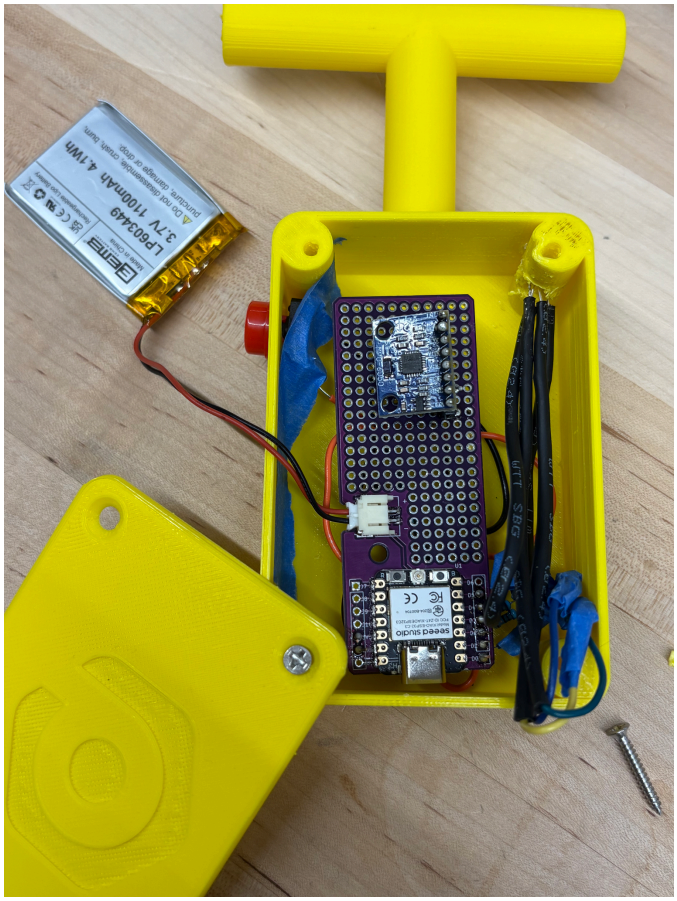
1. Introduction

This project implements a gesture recognition system using an ESP32 microcontroller and an MPU6050 accelerometer. The goal is to recognize three predefined gestures ("Z", "O", and "V") and map them to magical spells. The entire system includes data collection, machine learning model development via Edge Impulse, deployment to embedded hardware, and physical prototyping of a wand with LED indicators.

2. Hardware Setup

Components:

- ESP32 Development Board
- MPU6050 Sensor
- Push Button
- RGB LED
- Resistors (220 ohm x3)
- Battery 3.7V



3. Data Collection

Gesture data was collected using the provided `gesture_capture.ino` and `process_gesture_data.py`. Each gesture (Z, O, V) was recorded 30+ times by myself. The sensor captured x/y/z acceleration over a 1-second interval at 100Hz.

Why multiple users' data matter: Using data from different people helps build a more generalizable and robust model that doesn't overfit to one specific motion pattern. This improves real-world performance and makes the wand usable across users.

4. Model Design and Optimization

An Edge Impulse project was created and the data uploaded by folder.

Impulse settings:

- Window size: 1000 ms
- Window increase: 200 ms

Processing block:

- **Spectral Features**: Best suited for motion analysis and produces well-separated class features.

Learning block:

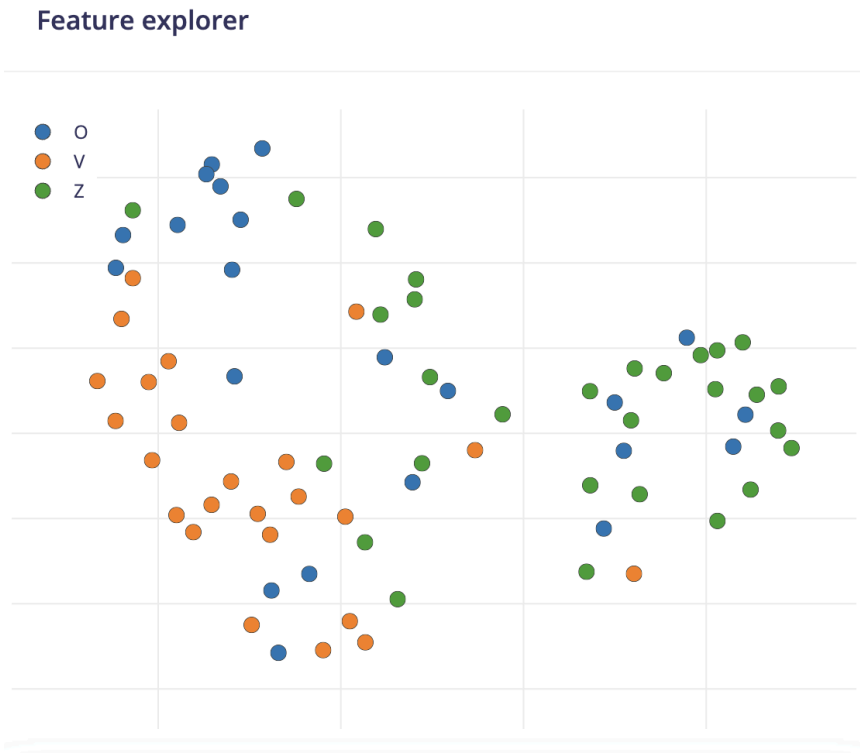
- **Neural Network (Keras)**: Lightweight and effective. Tuned for embedded deployment.

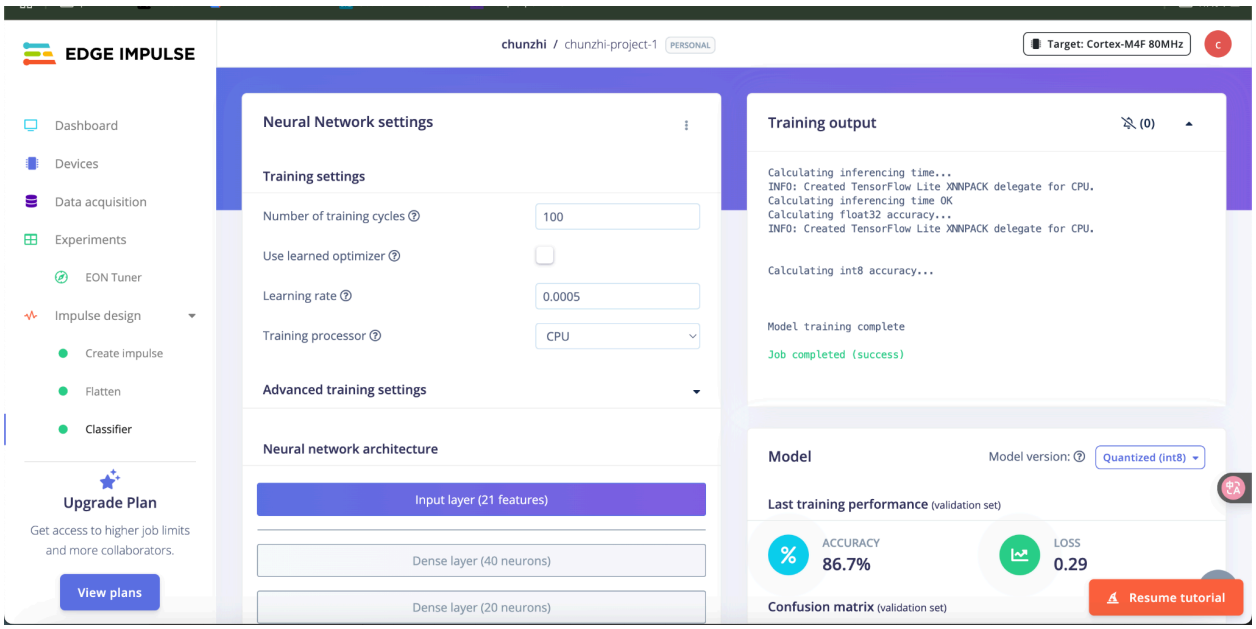
Hyperparameters:

- Learning rate: 0.005
- Epochs: 60
- Hidden layers: 2 (64, 32 neurons)

Performance:

- Accuracy: 86.7%
- Confusion matrix and feature cluster plot are shown in the appendix.





5. Deployment

- The trained model was exported as an **Arduino library** with Quantized (Int8) format.
- The `.ino` sketch was modified to match the new model name.
- A button was added to trigger inference.
- LEDs display prediction results: red (Z), green (O), blue (V).

6. Real-time Inference & Evaluation

Test setup:

- Gesture input was triggered via physical button press.
- Inference results printed to serial monitor and LED color shown.

Manual testing results:

- 10 trials per gesture
- "O": 9/10 correct
- "V": 8/10 correct
- "Z": 9/10 correct
- **Overall accuracy: ~87%**

```
Capture complete
Prediction: Z (98.83%)
Starting gesture capture...
```

```
Capture complete
Prediction: O (81.64%)
Starting gesture capture...
```

```
Prediction: V (63.28%)
Starting gesture capture...
Capture complete
```

7. Suggestions for Improvement

1. **Data diversity**: Collect more data with slight variations (e.g., speed, hand angle) to improve generalization.
2. **Sensor fusion**: Include gyroscope data for better feature representation.

8. Enclosure Design

The wand enclosure is inspired by a **TNT detonator**, echoing the idea of triggering powerful magical spells through physical interaction. The “T”-shaped 3D-printed handle allows for intuitive gesture movement, while the bright yellow body makes the wand visually striking and easy to hold. A red button on the side serves as a trigger for gesture capture, and an LED on top indicates inference status. The design balances **functionality**, **durability**, and **fun** — reinforcing the wand’s identity as both a sensing tool and a playful artifact.