# SafeDrive

**Real-Time Embedded Driving Behavior Scoring on XIAO ESP32S3**

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## Problem & Motivation

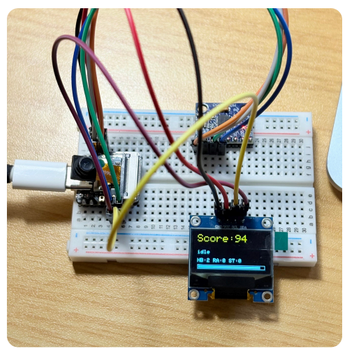
Unsafe driving behaviors — sharp turns, hard braking, rapid acceleration — are leading causes of road accidents. Existing fleet-monitoring systems are expensive, cloud-dependent, and inaccessible for individual drivers.

SafeDrive deploys a **TinyML neural network on the XIAO ESP32S3**, using a **MPU-6050 IMU** to classify driving behavior in real time, scoring each trip entirely on-device with no cloud dependency and under tight embedded resource constraints.



| 5 | 50Hz | 2s |
|---|---|---|
| behaviour classes detected | IMU sampling rate | sliding window per inference |

## System Overview



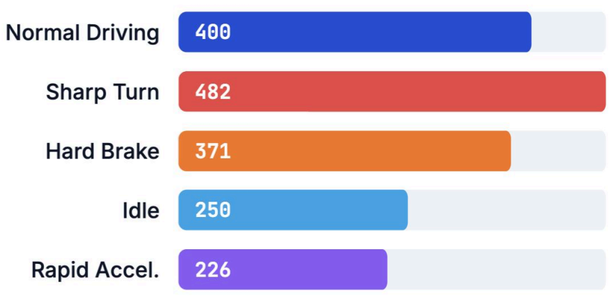



**IMU** → **Features** → **TinyML** → **Score** → **Display**

- **IMU**: MPU-6050, 50Hz · 6-axis
- **Features**: Spectral Analysis, 2000ms window
- **TinyML**: Neural Network, INT8 quantized
- **Score**: 0 to 100, live update
- **Display**: SSD1306 OLED + Serial

## Data Collection

Collected **1,729 labeled windows** across 5 behaviour classes using the MPU-6050 IMU at 50Hz. 80/20 train-test split; 2000ms sliding window per sample.

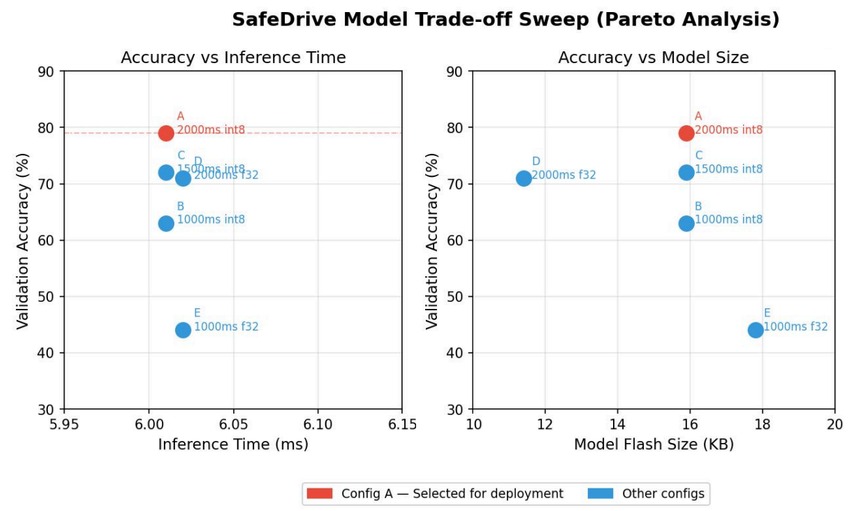



Total: **1,729 windows** · Uploaded to Edge Impulse

## Model Trade-off Sweep

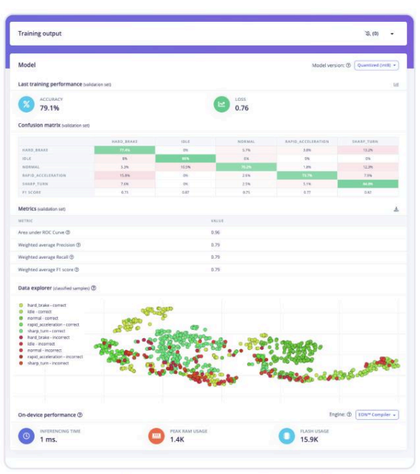
Swept 5 configurations varying window size and quantization to find the best accuracy–latency trade-off.

| Config | Window | Quantization | Val. Acc. | Latency | Flash |
|---|---|---|---|---|---|
| A ★ Deployed | 2000ms | int8 | 79% | 6.01ms | 15.9KB |
| B | 1000ms | int8 | 63% | 6.01ms | 15.9KB |
| C | 1500ms | int8 | 72% | 6.01ms | 15.9KB |
| D | 2000ms | float32 | 71% | 6.02ms | 11.4KB |
| E | 1000ms | float32 | 44% | 6.02ms | 17.8KB |

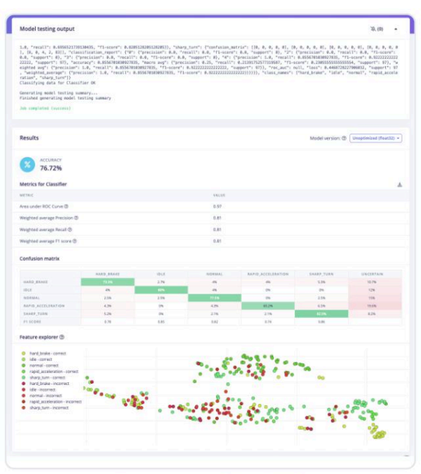



## Results

Config A · Neural Network INT8 · **79.1% validation** · **76.72% test accuracy**



Validation Set (79.1%)



Test Set (76.72%)

Key metrics — Config A

| | |
|---|---|
| Val. Accuracy | 79.1% |
| Test Accuracy | 76.72% |
| Flash Used | 13% |
| RAM Used | 8% |
| Battery Life | 10hr |

## Resource Budget

Config A (int8, 2000ms) runs well within the ESP32S3's resources, leaving substantial headroom for future class expansion.

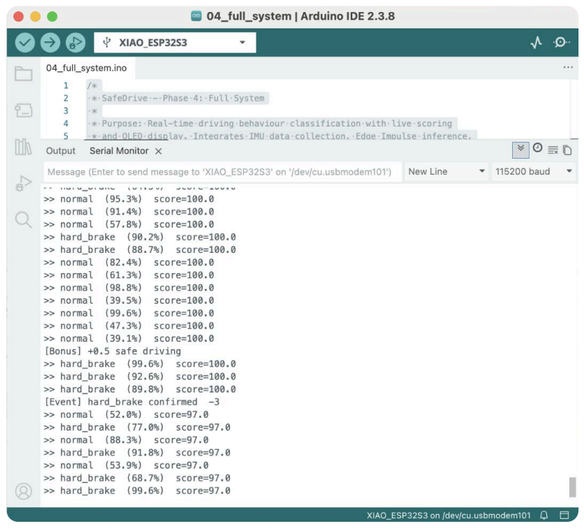


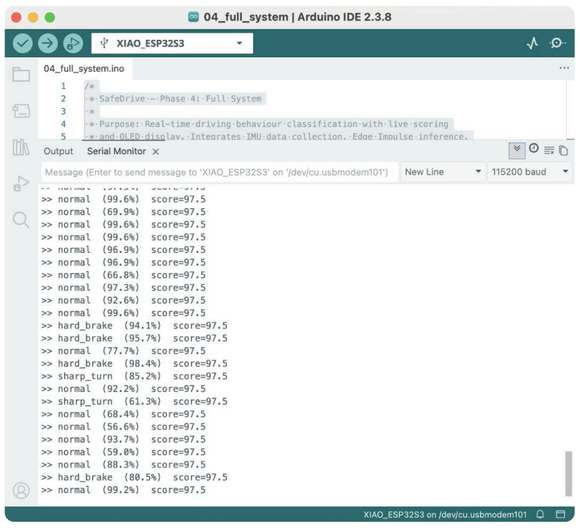

## Live Demo










### Driving Score Rules

| | |
|---|---|
| 100 | Start score — resets at trip begin |
| -3 | Hard brake confirmed (3× debounce) |
| -2 | Rapid acceleration confirmed |
| -2 | Sharp turn confirmed |
| +0.5 | Safe driving per minute (max 100) |

Serial output streams predicted class, confidence, and driving score. Score starts at 100; 3 consecutive predictions required to confirm an event (debounce).

## Conclusion & Future Work

### Key Takeaways

**01**
A 6-axis IMU runs five-class driving behaviour classification entirely on-device, with no cloud and no data leaving the hardware.

**02**
The deployed model achieves 79% accuracy in 6ms inference time, using only 13% Flash and 8% RAM on the ESP32S3.

**03**
Sweeping window size and quantization across five configurations shows that larger temporal context consistently wins over faster sampling.

### Future Work

- Expand dataset with more participants and road conditions to improve generalization
- Add GPS fusion for route-aware scoring and per-segment breakdown
- Deploy BLE companion app for real-time score visualization on mobile
- OBD-II integration for vehicle speed context and richer feature extraction



https://github.com/GIX-Luyao/individual-project-deliverables-yuwennnnnnnnnnn.git