TinyML-Powered Edge AI Hand Band for Sudden Fall Detection

1. Problem Statement

Accidental falls are a common safety concern, especially for elderly people, patients, and individuals who work alone. In many cases, the main problem is not only the fall itself but the delay in receiving help. If no one is nearby, the injured person may remain unattended for a long time.

Most existing fall detection systems depend only on motion sensors or require the user to manually press an emergency button. This can lead to false alarms or delayed response. There is a need for a smart wearable device that can automatically detect falls, verify the danger condition, and send alerts immediately.

2. Objective

The main objectives of this project are:

- To develop a wearable hand band for fall detection.
- To use TinyML for intelligent motion analysis.
- To implement Edge AI for real-time on-device decision making.
- To reduce false alarms using recovery detection.
- To confirm danger condition using a microphone sensor.
- To send emergency alerts instantly through Wi-Fi.
- To provide a compact and low-cost safety solution.

3. Existing Work

Several fall detection solutions are already available in the market. These include smartphone applications, smart watches with SOS features, CCTV monitoring systems, and hospital patient monitoring devices.

Smartphone-based systems require the user to keep the phone nearby at all times. Smart watches are effective but often expensive. CCTV systems are limited to indoor locations and cannot provide portable monitoring. Many motion sensor devices detect falls but cannot confirm whether the user is actually in danger.

Because of these limitations, a more reliable and affordable wearable solution is needed.

4. Gap Analysis

Current systems mainly focus on fall detection only. They do not verify the situation after a fall. This often creates false alarms during activities such as running, sudden hand movement, or jumping.

Another limitation is that many systems require manual user response. If the person becomes unconscious or unable to move, manual systems become ineffective.

Our project addresses this gap by combining motion sensing, TinyML prediction, and microphone-based danger confirmation in a single wearable device.

5. Novelty of the Project

The uniqueness of this project lies in the combination of multiple technologies in a wearable form.

This project uses TinyML to classify motion patterns directly on the device. Edge AI enables fast processing without depending on cloud computing. After a fall is detected, the system activates a microphone sensor to confirm whether the person may still be in danger.

This two-stage verification method improves reliability and helps reduce false alerts. The project also includes both automatic and manual emergency alert options.

6. Project Description

The project is a smart hand band designed for safety monitoring. It continuously tracks hand movement using the MPU6050 motion sensor. The collected data is processed by an ESP32 controller running a TinyML model.

When sudden abnormal movement is detected, the system identifies it as a possible fall. Instead of sending an alert immediately, the system waits for a short period to check whether the person resumes normal movement.

If normal movement is detected, the system considers the user safe and turns on the green LED. If no recovery movement is observed, the system enters danger mode.

In danger mode, the red LED and buzzer are activated. The T5848 microphone is turned on to further confirm whether the user is in distress. After confirmation, an emergency alert is sent through Wi-Fi.

A push button is also provided so the user can manually request help at any time.

7. Components Used

The following hardware components were used in this project:

GLYPH S3 – Main controller
MPU6050 – Motion sensing module
T5848 Microphone – Audio confirmation sensor
Push Button – Manual emergency trigger
Red LED – Danger indication
Green LED – Safe indication
Active Buzzer – Audible alert
Li-Po Battery (500mAh) – Portable power supply
GMOD lithium- Ion charging module

8. Software Used

- Arduino IDE was used for programming and testing.
- TinyML tools such as Edge Impulse is used for model development.
- KiCad 9.0 is used for PCB design.
- GitHub was used for source code management.
- Fusion 360 is used for enclosure design.

9. Methodology

The project was developed in multiple stages. First, motion data was collected from the MPU6050 sensor. This data was used to identify normal and abnormal movement patterns.

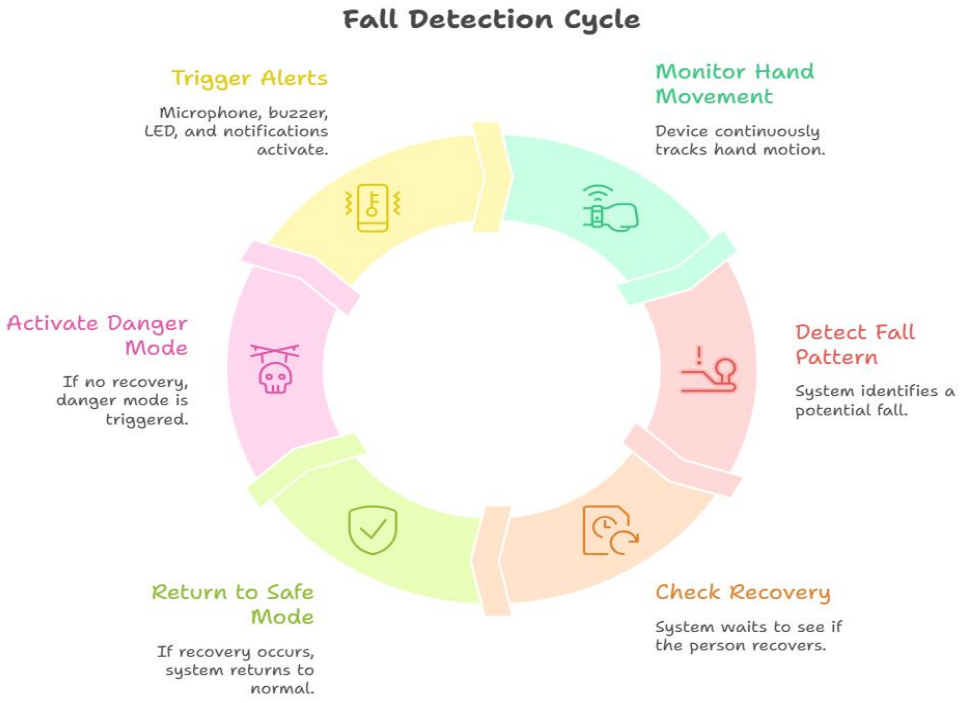
A TinyML model was then trained to classify possible fall events. The model was deployed on the ESP32 for real-time inference.

During operation, the system continuously monitors movement. If a fall is detected, a recovery check is performed. If the user does not recover normal movement, the system activates the microphone, buzzer, and LED alerts.

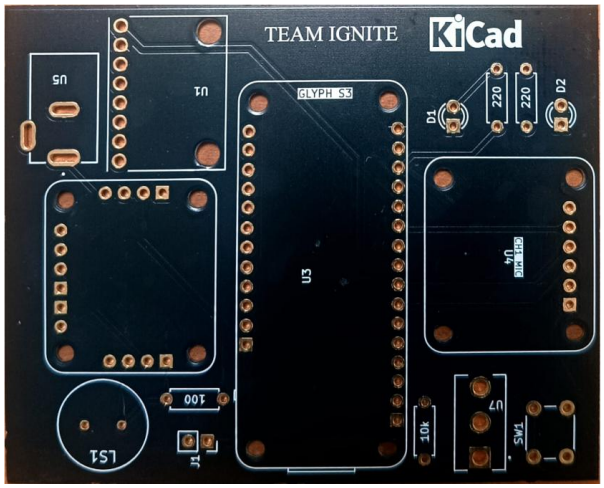
Finally, an emergency message is sent through bluetooth.

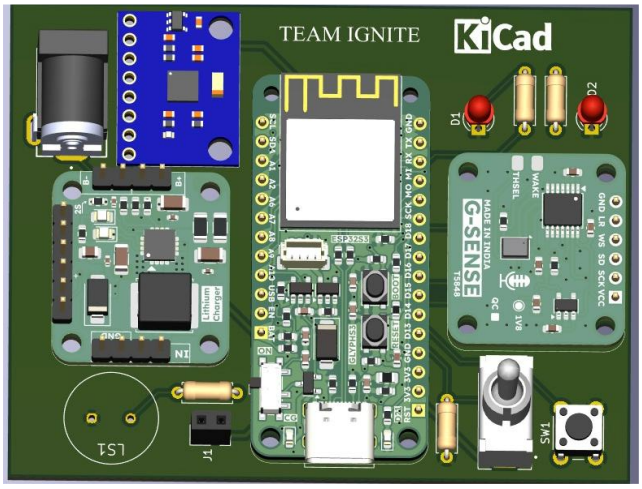
10. Workflow

- The device starts by monitoring hand movement continuously.
- If no abnormal motion is detected, it continues normal monitoring.
- When a fall pattern is detected, the system waits briefly to check recovery.
- If the person starts moving normally again, the system returns to safe mode.
- If no movement is detected, danger mode is activated.
- The microphone turns on, the buzzer sounds, the red LED glows, and an emergency alert and notification is transmitted.

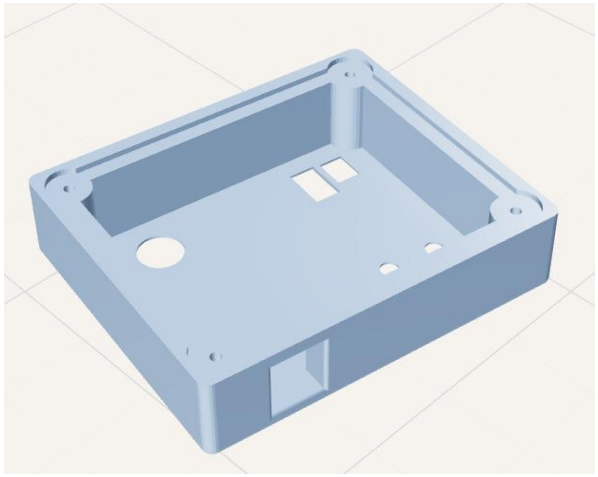


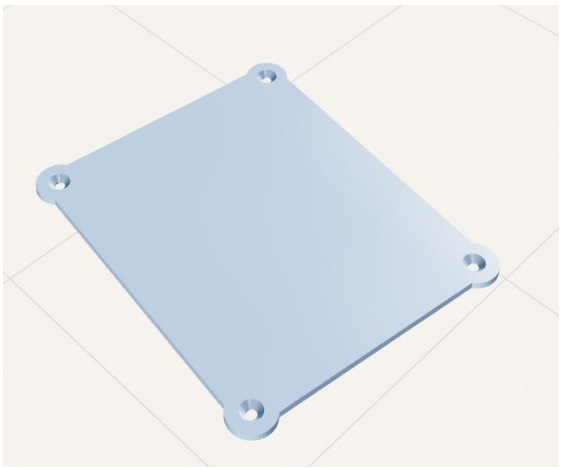
11. PCB design





12. 3D model of the PCB Enclosure





13. Fall Detection Model Performance

Last training performance (validation set)

ACCURACY	LOSS
92.7%	0.24

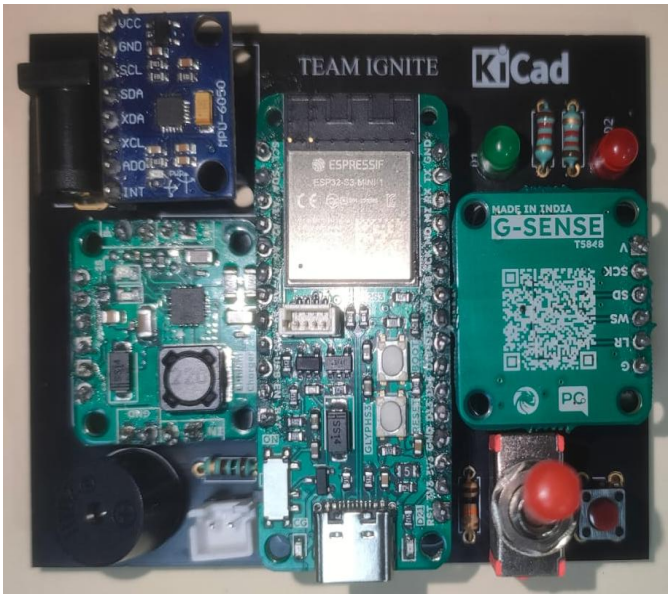
Confusion matrix (validation set)

	FALL DETECTED	SAFE
FALL DETECTED	84%	16%
SAFE	0%	100%
F1 SCORE	0.91	0.94

Metrics (validation set)

METRIC	VALUE
Area under ROC Curve	0.92
Weighted average Precision	0.94
Weighted average Recall	0.93
Weighted average F1 score	0.93

13. Prototype



14. Demo Video of Prototype

https://drive.google.com/file/d/1SyCoSZdOWGMMtq8KlIbUYnV40B3C36ju/view?usp=sharing

15. GitHub Repository Contents

https://github.com/sushanthkulal/TinyML-Powered-Edge-AI-Hand-Band-for-Sudden-Fall-Detection.git

16. Applications

This system can be used in elderly care monitoring.

It can help patients who require regular supervision.

It is useful for industrial workers working in isolated areas.

It can also be adapted for personal safety wearable devices.

17. Conclusion

This project presents a practical and affordable wearable safety solution using TinyML and Edge AI. By combining motion sensing with audio confirmation, the system improves the reliability of fall detection and reduces false alarms.

The device is compact, battery-powered, and suitable for real-time emergency monitoring. With further development, it can become a valuable tool in healthcare and personal safety applications.

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