University of Moratuwa

Faculty of Engineering

Department of Electronic & Telecommunication Engineering

EN 1190: Engineering Design Project

Team HyperTronics

Workplace Safety Device

Project Report

Group Members

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1 Problem Description

1.1 Problem

Mining is one of the most dangerous industries worldwide, including in Sri Lanka. In mining, workers are regularly exposed to extreme conditions such as unstable terrain, falls, limited visibility and the accumulation of toxic gases. Accidents involving falls and toxic gas exposure often occur unnoticed, especially during night shifts or when workers operate alone, leading to dangerous delays in response due to limited communication in the mining environment.

Despite existing safety regulations, the Sri Lankan mining sector continues to report a significant number of workplace accidents, leading to serious injuries that could be prevented with timely detection and response. Traditional safety systems within mines rely on manual supervision and reporting. These approaches are often delayed and ineffective in accidents such as falls or gas leaks.

Existing solutions in Sri Lanka are often too expensive, non-portable, or lacking integration with real-time alert systems. This makes them inaccessible to small-scale and medium-scale mines, where most of the workers are employed.

1.2 Motivation

The frequent occurrence of unnoticed accidents and the limitations of existing safety systems in mining environments inspired the development of an affordable, portable, and real-time monitoring device. Our motivation is to increase worker safety in mining environments by reducing response times to hazardous incidents to prevent serious injuries.

1.3 Expected Goal

Our objective is to design and develop a wearable safety device that can detect and report accidents in mining environments in real time. The system is intended to identify falls and exposure to hazardous gases and to immediately notify the responsible person through an automated alert system with live location.

1.4 Solution

Our solution is a workplace safety device designed for mine workers. Workers are continuously monitored for sudden falls and exposure to hazardous gases. When a dangerous event is detected, the device automatically sends an SMS alert to a supervisor or safety officer with the location where the accident occurred. It is lightweight, battery-powered, and easy to wear throughout a work shift. This system ensures that accidents are identified immediately and an alert with live location is sent without delay, improving safety and reducing risks in the mining industry.

1.5 Justification of Selection

The initial scope of our project was to develop a wearable device capable of detecting worker falls in mining environments. However, during an interview with a mining officer, we were informed that toxic gas exposure is another major concern in underground operations. Based on this insight, we extended our solution to integrate a gas sensor, enabling the system to detect both falls and environmental hazards in real time.

The device is designed to be portable, durable, and easy to use throughout a worker's shift since it is powered by a rechargeable battery and housed in a compact, strong enclosure, making it suitable for harsh mining environments. Based on feedback from a survey, the device form factor was decided to be belt-worn rather than wrist-worn to ensure minimal interference with work activities. Additionally, since most mines do not have internet connectivity, we use a GPS/GPRS module to send immediate SMS alerts with location.

This approach offers a more practical alternative to existing systems, such as camera-based monitoring or wireless sensor networks, because of its cost effectiveness, ease of installation and maintenance, and resistance to mining conditions.

2 Technical Feasibility

We have successfully made our project technically viable and obtained all the necessary resources. We used an MPU-6050 accelerometer to detect sudden falls and an MQ-5 gas sensor to monitor the presence of hazardous gases. An STM32 microcontroller was used for processing sensor data and controlling the system. Development and programming were carried out using STM32CubeIDE, which allowed efficient configuration, debugging, and firmware development. The device uses a GPS/GPRS module to send SMS alerts with live location to a safety officer without the need of internet connectivity, to address the connectivity limitations in underground environments. The device is powered by a 3.7V 1600mAh LiPo battery, with a TP4056 module for safe charging to ensure device portability. Also, the device uses Texas Instruments' TPS61022 regulator to deliver a stable 2A output.

We collaborated with professionals to design and print the PCB. The outer casing was 3D printed using white PETG, which can withstand harsh mining conditions, to house the internal circuits. Rysera Innovations managed the 3D printing process. Component soldering was performed in our lab.

The device can meet its performance targets, including accurate fall detection, reliable gas sensing, and sending real-time alerts with correct GPS location. Sensor specifications, existing research, and communication protocols are supported for these. Prototype testing and calibration have confirmed the system's ability to detect critical events with minimal false alerts and deliver timely SMS to safety officers.

3 Product Architecture

3.1 Block Diagram

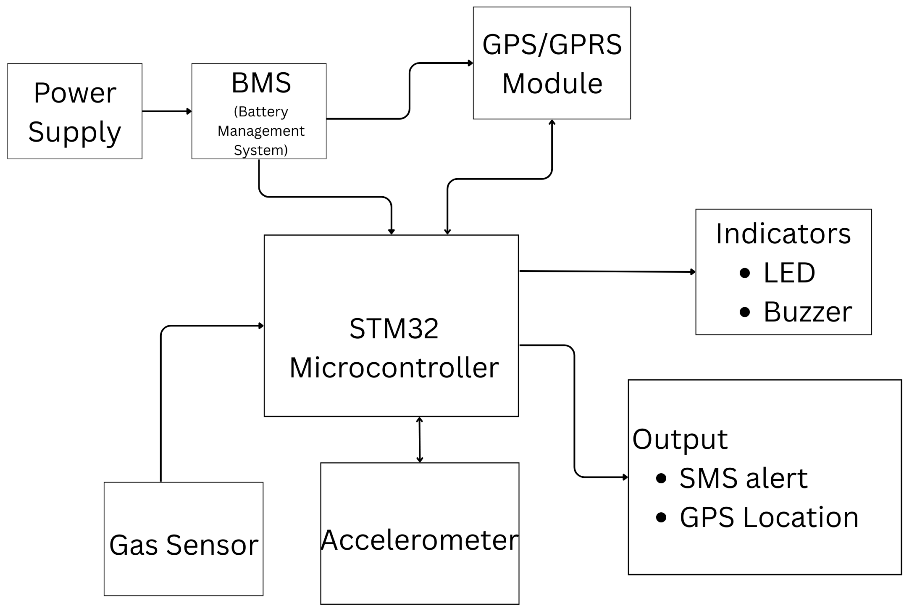

Figure 1: Block Diagram of the Workplace Safety Device

- **STM32 Microcontroller:** Acts as the central processing unit that collects data from sensors (falls and accumulation of gases), processes it using programmed algorithms, and makes decisions based on threshold values. The MCU also controls the buzzer and LED indicators to provide immediate local alerts. Moreover, when an accident is detected, it commands the GPS/GPRS module to transmit an SMS alert with the GPS location to the safety officer. To reduce false alarms, the device includes a user-operated button that allows the wearer to cancel accidental alerts within a predefined time window. When pressed, the MCU silences the buzzer, stops the alert process, and prevents the SMS notification from being sent, minimizing unnecessary emergency responses.

- **MPU-6050 Triple Axis Analog Accelerometer:** Detection of sudden changes in motion to identify falls or impacts. Data from this sensor are processed by the STM32 to distinguish falls from normal motion.

- **MQ-5 Gas Sensor:** Identifying the presence of hazardous gases such as methane, LPG, and butane. It provides an analog voltage output proportional to gas concentration. If that exceeds the threshold, the device sends an SMS with location, notifying about the gas leak.

- **GPS/GPRS Module:** Sends SMS alerts with GPS location to a safety officer when an accident is detected. Communication done through cellular networks ensures reliable alerts in underground mining sites where internet connectivity is unavailable.
- **Power Supply:** The device is powered through a 3.7V 1600mAh LiPo battery. It was selected because of its compact size, high energy density, and rechargeability. This battery provides sufficient energy to power the device continuously for up to 24 hours.
- **Battery Management System:** The BMS, implemented using the TP4056 5V 1A Type C charging module, which manages safe charging and discharging of the LiPo battery. It protects the battery from overcharge, overdischarge, and short circuits. So, it extends battery life and ensures user safety.
- **Buzzer and LED Indicators:** Provides immediate onsite alerts to the worker in case of a fall or gas hazard.

Based on the practical challenges and technical constraints, several changes were made during development.

- Initially, we planned to use 0402-sized components to reduce PCB area. Since these components are very small and difficult to solder, we shifted to 0603 and 1206 components for better reliability and ease of assembly.
- Although the device was compact in size, the PCB layout was complex due to multiple components and routing requirements. Therefore, we opted for a 4-layer PCB
- Due to the device's compact design and the requirement to supply up to 2A of current, a power regulator was essential. After considering multiple options, the TPS61022 regulator was selected as the most reliable and efficient solution to meet these performance and size constraints.

4 Sketches of Product Designs

4.1 Initial Sketch

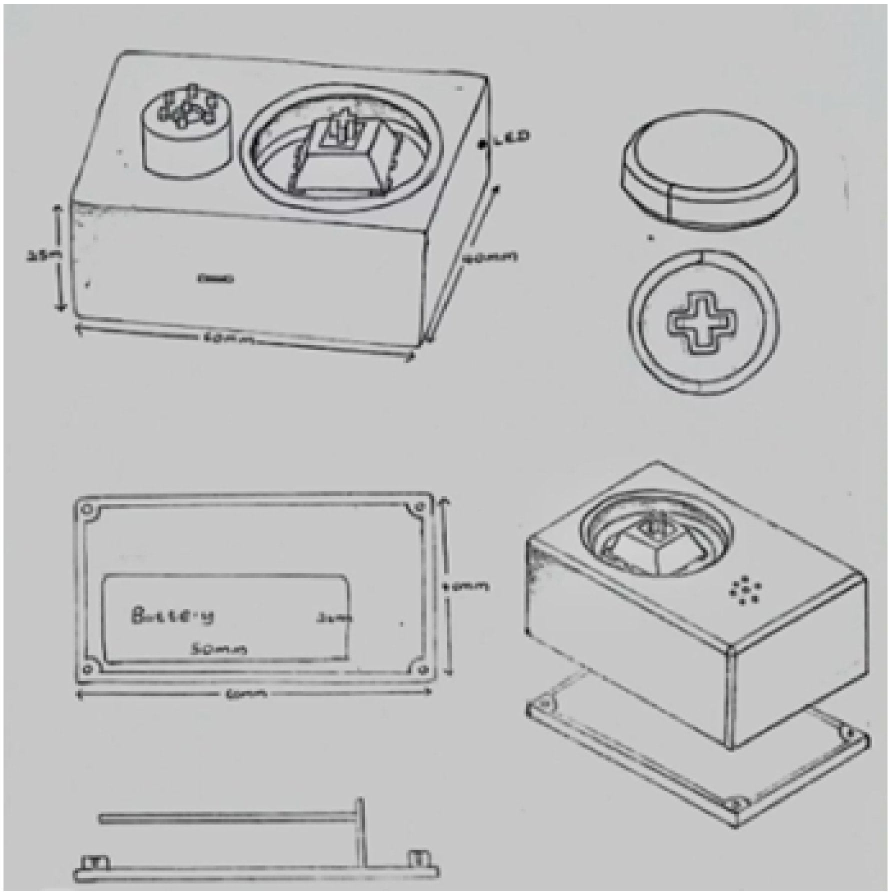

Figure 2: Initial Sketch of the Product

In the initial design, we included both a belt clip and a hook to provide flexible mounting options. However, considering the discomfort during prolonged use and its proneness to mechanical failure compared to the hook in rough working conditions, we reasoned that the belt clip was unnecessary. Therefore, it was removed from the final design to simplify the device. Moreover, based on ergonomic needs, ease of access, and internal layout, we centered the tactile switch which cancels alerts manually.

4.2 Final Sketch

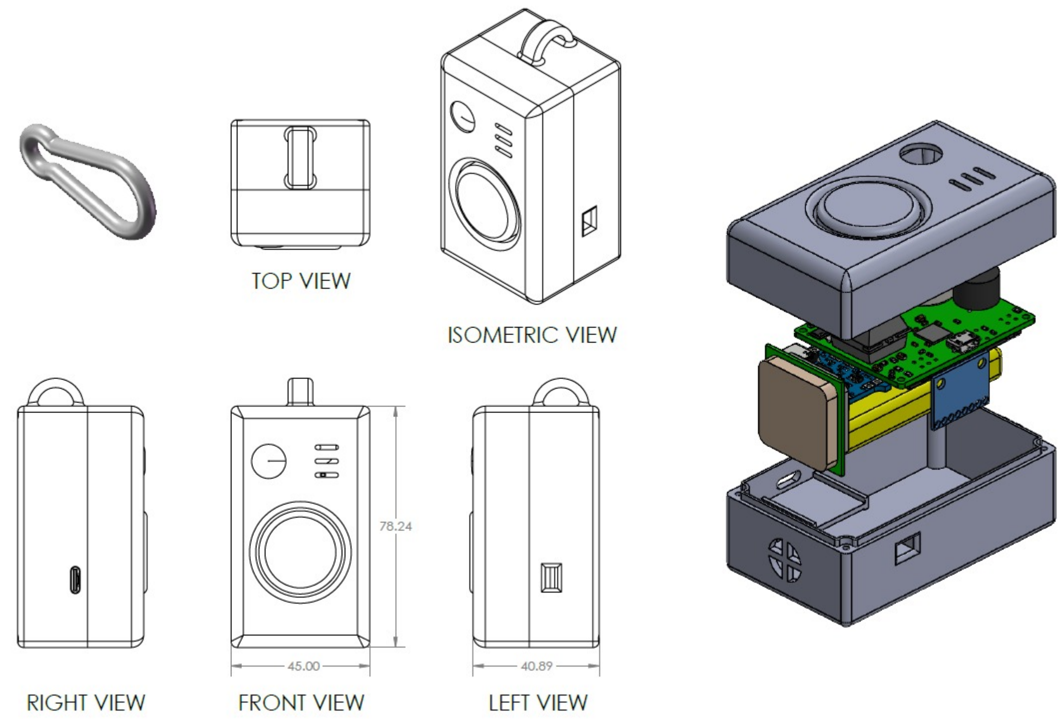

Figure 3: Final Sketch of the Product

Figure 4: Part (1)

Figure 5: Part (2)

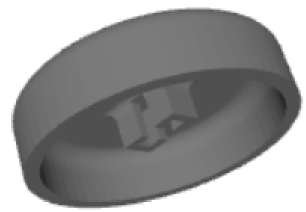

Figure 6: Button Cap

5 PCB Design

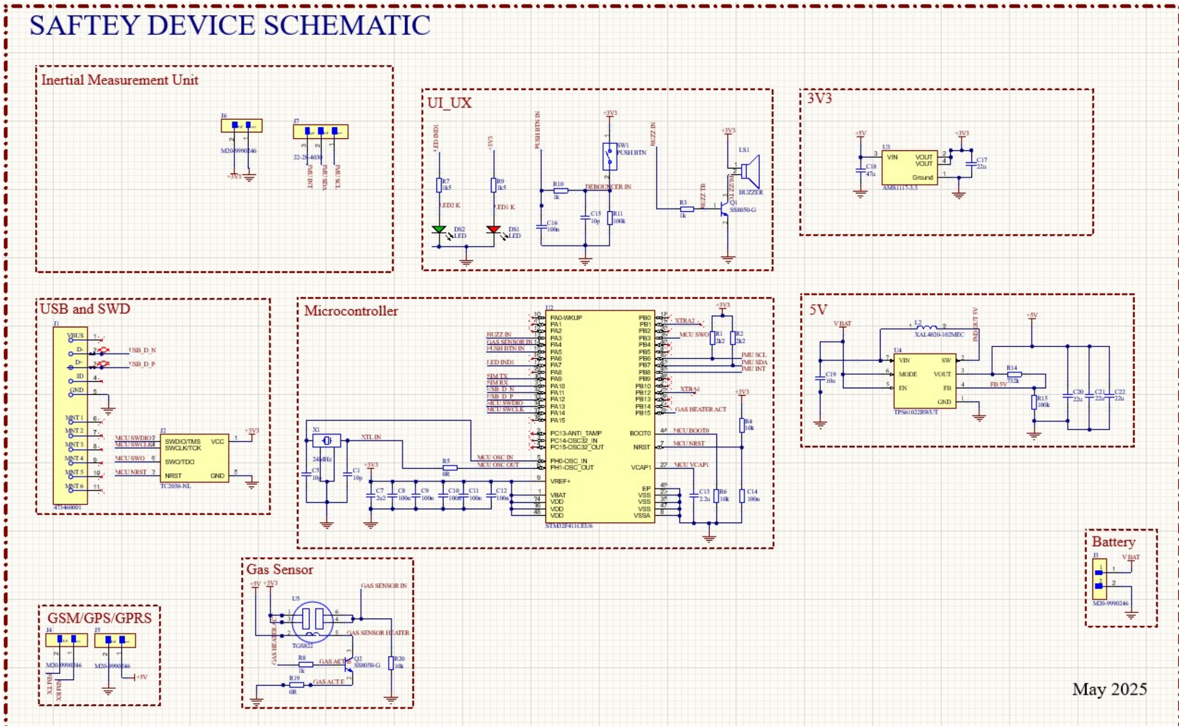

Figure 7: Schematic Diagram

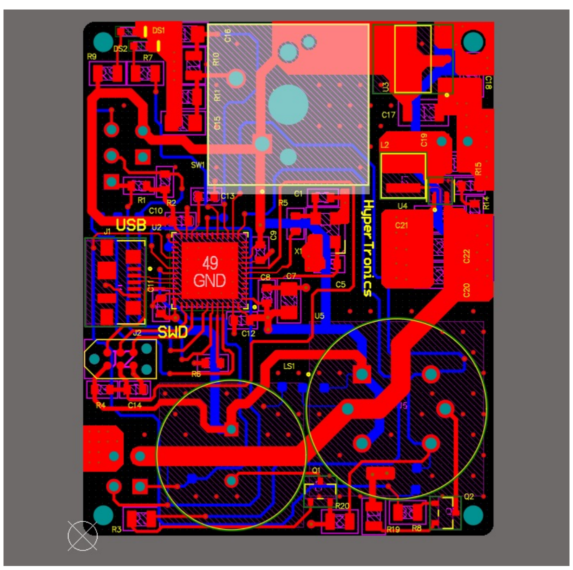

Figure 8: PCB layout

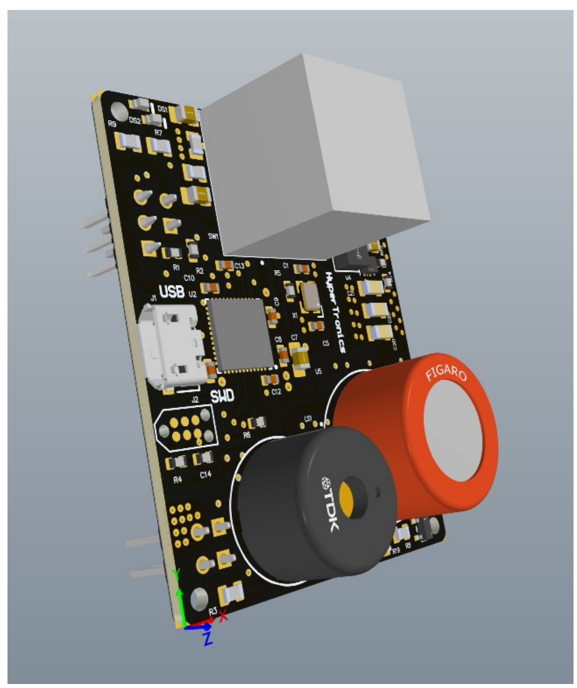

Figure 9: PCB (3D)

6 Product Specifications

- **Device Type:** Wearable Workplace Safety Device
- **Key Functions:** Fall detection, Gas detection, GPS-based location tracking, SMS alerting
- **Sensors Used:** MPU-6050 (accelerometer), MQ-5 (gas sensor)
- **Communication:** GPS/GPRS Module
- **Power Supply:** 3.7V 1600mAh LiPo battery with TP4056 charging module
- **Power Consumption:** Approximately 247 mW average
- **Battery Life:** Up to 24 hours on a full charge
- **Charging Time:** Approximately 4h
- **Dimensions:** 45 x 79 x 41 mm
- **Enclosure Material:** 3D printed PETG plastic
- **Indicators:** Buzzer, LED
- **Manual Control:** Tactile switch to cancel alerts manually
- **Target User Group:** Mine workers and laborers in high-risk industrial environments

7 Final Product

8 Cost per Product

Component	Unit Price (Rs.)	Quantity	Price (Rs.)
MQ-5 Gas Sensor	400.00	1	400.00
MPU-6050 Triple Axis Analog Accelerometer	600.00	1	600.00
3.7V 1600mAh LiPo Battery	1320.00	1	1320.00
TP4056 Charging Module	60.00	1	60.00
Surface-Mount Components			
Capacitors			
100nF	1.35	7	9.45
22uF	38.79	4	155.16
10pF	0.78	2	1.56
2.2uF	5.14	2	10.28
10u	3.22	1	3.22
Resistors			
1k	0.57	3	1.71
1.5k	0.63	2	1.26
2.2k	0.36	2	0.72
10k	0.45	2	0.90
0R	0.45	2	0.90
100k	0.66	1	0.66
732k	0.36	1	0.36
LEDs	5.80	2	11.60
Power Inductors	303.23	1	303.23
24MHz Crystal Oscillator	20.67	1	20.67
STM32F411 Microcontroller	849.78	1	849.78
TPS61022 Boost Converter	144.78	1	144.78
AMS1117 3.3V Voltage Regulator	55.05	1	55.05
NPN transistor	4.90	1	4.90
Micro-USB connector	155.15	1	155.15
PCB manufacturing cost	1036.00	1	1036.00
Enclosure	2562.00	1	2562.00
Total Cost			**7709.34**

8.1 Final Selling Price

The total cost of producing one unit, including all components is Rs. 7,709.34. We applied a 15% overhead on the production cost for assembly, testing, packaging, labor and administrative tasks:

7,709.34 × 0.15 = Rs. 1,156.40

Subtotal = Rs. 7,709.34 + Rs. 1,156.40 = Rs. 8,865.74

We added a 30% profit margin to support potential reinvestment in development and support:

8,865.74 × 0.30 = Rs. 2659.72

The selling price is approximately Rs. 11,525.46. After rounding-off, final selling price is,

Rs. 11,525.00 per unit

9 Marketing, Sales and Beyond

We have planned a practical phased marketing strategy to reach the market effectively.

- We plan to introduce the product through pilot programs in selected small and medium-sized mining sites.
- We will build networks with mining officers and construction site managers during our initial surveys and introduce the product through direct, personal connections.
- We will first focus on the Sri Lankan mining and construction sectors, targeting companies that lack access to real-time safety technologies but are increasingly aware of worker safety needs.
- We plan to build a simple product website with demo videos, pricing, and contact information. It helps us to reach safety officers and decision makers online.
- We aim to collaborate with construction companies and industry associations to promote the product as part of broader occupational safety programs.

10 Future Improvements

Due to budget constraints, the integration of an oxygen sensor was not included in our current prototype. We plan to add this sensor to monitor oxygen levels in the mining environment in our future versions. If the oxygen concentration falls below a safe threshold value, the device will automatically give an alert. This modification will further improve the device's capability to detect hazardous atmospheric conditions and increase worker safety.

11 Task Allocation

Name	**Task**
Bandara W.D.A.C.	Enclosure Design
Upekshani T.S.	Enclosure Design
Wijesekara W.A.G.S.	PCB Layout and Design
Wijesinghe U.G.S.K.D.	Programming STM32