Palestine Polytechnic University

College of Information Technology and Computer Engineering

Computer Engineering Department

Computer Systems Engineering

Graduation Project

Smart Safety Helmet for Workers

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Certification and Anti-Plagiarism Declaration

This is to declare that the graduation project produced under the supervision of Eng. Raed Shamas , having the title “Smart Safety Helmet for Workers”, was prepared by the students listed below in partial fulfillment of the requirements for the degree of Bachelor in Engineering of Computer Engineering, and that no part of this work has been reproduced illegally or can be considered plagiarism.

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Any use of Artificial Intelligence (AI) tools in the preparation of this project has been clearly declared and documented in the related appendix at the end of the report, in accordance with Palestine Polytechnic University guidelines.

Date: August 2025

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ABSTRACT

Industrial workers are frequently exposed to hazardous conditions such as falls, smoke, and harmful gases, which can lead to severe injuries or fatalities if not detected promptly. This project presents the design and implementation of a Smart Safety Helmet System aimed at enhancing worker safety through real-time monitoring and automatic response mechanisms.

The proposed system is built around two ESP32 microcontrollers communicating via the ESP-NOW protocol. The helmet unit integrates an MQ2 gas sensor for smoke and gas detection and an MPU6050 sensor for motion, fall detection, and temperature monitoring. Real-time data is displayed on an OLED screen, while detected hazards trigger automatic responses such as activating a ventilation fan or issuing an audible alert using a buzzer.

Experimental results demonstrate that the system accurately detects falls and hazardous gas conditions with low latency and reliable wireless communication. The proposed helmet proved to be portable, power-efficient, and suitable for industrial environments. Future enhancements may include cloud connectivity, additional environmental sensors, and improved power optimization techniques.

الملخص

يهدف هذا المشروع إلى تصميم وتنفيذ خوذة أمان ذكية لتعزيز سلامة العاملين في البيئات الصناعية. تعتمد الخوذة على متحكم ESP32 وتدمج حساس MQ2 للكشف عن الدخان والغازات القابلة للاشتعال، وحساس MPU6050 لاكتشاف الحركة والسقوط وقياس درجة الحرارة.

تعرض الخوذة البيانات بشكل فوري على شاشة OLED، كما يتم استخدام بروتوكول ESP-NOW للتواصل اللاسلكي مع متحكم آخر يقوم بتشغيل نظام تهوية تلقائي عند اكتشاف الغازات الخطرة. في حال سقوط العامل، يصدر النظام إنذارًا صوتيًا باستخدام الجرس لتنبيه الأشخاص القريبين.

أظهرت نتائج الاختبار أن النظام يتميز بسرعة الاستجابة ودقة الكشف، مما يجعله مناسبًا للاستخدام في المواقع الصناعية. ويمكن تطوير النظام مستقبلًا بإضافة مستشعرات بيئية أخرى وربطه بتطبيقات سحابية..

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to our supervisor, **Raed Shammas** , whose expertise, guidance, and continuous encouragement have been invaluable throughout every stage of this project. Their constructive feedback and technical advice played a crucial role in shaping the direction and quality of our work.

We also wish to extend our thanks to the **Department of Computer Engineering** at **Palestine Polytechnic University** for providing the necessary resources, tools, and facilities that enabled us to design, develop, and test the Smart Safety Helmet System effectively.

We are sincerely thankful to our families for their patience, understanding, and emotional support during this journey. Their encouragement gave us the motivation to stay focused and determined, even in moments of difficulty.

Finally, we acknowledge all the researchers, engineers, and developers whose previous work and open-source contributions provided the foundation upon which this project was built. Without the combined effort of everyone mentioned, this project would not have been possible.

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LIST OF ABBREVIATIONS

Abbreviation	Description
ESP32	Espressif 32-bit Microcontroller
IoT	Internet of Things
MPU6050	Motion Processing Unit Sensor
MQ2	Gas and Smoke Sensor
OLED	Organic Light Emitting Diode
Wi-Fi	Wireless Fidelity

Chapter 1: Introduction

1.1 Preface

In recent years, the demand for smart safety systems in industrial and construction environments has significantly increased. This project presents a Smart Safety Helmet System that aims to enhance worker safety by integrating multiple sensing and communication technologies into a single wearable device. The system is built around two ESP32 microcontrollers that cooperate over the ESP-NOW protocol: a helmet node (ESP32-S) that collects and processes sensor data (MQ2, MPU6050), and a remote actuation node (ESP32-R) that receives events and controls external devices. which collects real-time data from various sensors including gas (MQ2), and motion /temperature (MPU6050).

The ESP32 processes this data and performs decision-making actions such as detecting falls and hazardous gases. In case of a fall detection, the system activates an audible alarm using a buzzer to alert nearby personnel. For gas or smoke detection the helmet wirelessly communicates with an external ESP32-based ventilation system via ESP-NOW (peer- to-peer) activating a fan to improve air quality.

Additionally, the system includes a small OLED display that continuously shows live sensor data, including temperature, gas levels, movement values, and G-Force. The entire system is designed to be power-efficient, compact, and suitable for deployment in environments where worker safety is critical .

1.2 Problem Statement

In industrial environments such as construction sites or factories, workers are constantly exposed to hazardous conditions including falls, exposure to harmful gases, and extreme temperatures. Traditional safety measures are often reactive, relying on human intervention or delayed alerts, which may lead to severe injuries or fatalities.

There is currently no affordable, real-time, and fully automated system that monitors workers' conditions continuously and responds immediately to critical situations.

For example, if a worker falls unconscious or is surrounded by smoke or gas , the absence of instant alerts or automatic ventilation can result in life-threatening consequences. Existing solutions lack the capability to detect falls, trigger ventilation, and notify supervisors—all in an integrated and intelligent way.

This project aims to solve this gap by developing a Smart Safety Helmet System that:

- Monitors the worker's environment and physical state in real-time.
- Detects accidents like falls using an MPU6050 sensor.
- Identifies gas or smoke presence using an MQ2 sensor.
- Activates a ventilation system automatically when gas is detected.
- Activates an audible alarm using a buzzer to alert nearby personnel
- Displays real-time sensor data (temperature, motion, gas , g-force) on an OLED screen.

Thus, the problem addressed by this project is the lack of an automated, intelligent, and integrated safety system capable of protecting workers immediately in case of danger—without waiting for manual response.

1.3 Project Aims and Objectives

1.3.1 General Objective:

To design and implement a Smart Safety Helmet System that enhances worker safety by providing real-time monitoring, automatic hazard detection, and immediate response actions in industrial environments.

1.3.2 Specific Objectives:

1. To develop an embedded system using two ESP32 microcontrollers that cooperate over ESP-NOW a helmet ESP32 (ESP32-S) for sensing/processing and a remote ESP32 (ESP32-R) for actuation.
2. from multiple sensors inside the helmet.
3. To integrate an MPU6050 sensor for detecting worker movement and identifying fall events accurately.
4. To connect an MQ2 gas sensor for detecting the presence of smoke or harmful gases in the worker's environment.

5. To automatically activate a ventilation fan (via ESP-NOW communication between two ESP32 modules) when smoke or gas is detected, using a separate ESP32 system.
6. To utilize an OLED screen to continuously display real-time sensor data such as gas presence, temperature, G-Force, and motion status.
7. To provide a fall detection alert that notifies nearby personnel using a buzzer.
8. To ensure the system operates on battery power efficiently, using a 5V battery (power bank) with proper voltage regulation.
9. To simulate and validate the full system design using EasyEDA for hardware design and relevant Arduino code for software functionality.

1.4 **Project Requirements**

1.4.1 Functional Requirements:

10. Data Collection from Sensors:
    The system must collect data from the MQ2 gas sensor, and MPU6050 (motion / fall detection & temperature).
11. OLED Display:
    The ESP32 must display real-time readings of temperature , gas status, g-force , and motion status on the OLED screen continuously.
12. Fall Detection & Alerting:
    When a fall is detected by the MPU6050, the ESP32 must immediately trigger an audible alert using the buzzer to notify nearby personnel, ensuring a quick response to potential accidents.
13. Gas Detection & Ventilation Activation:
    the ESP32 in the helmet must send an ESP-NOW message to another ESP32 that controls a fan (ventilation system) to turn it on.
14. System Power Management:
    The system employs an advanced triple-source power management strategy: a dedicated 5V power bank is integrated into the helmet to ensure wireless mobility for the worker, while the base station utilizes a dual-rail architecture—a 5V supply for the ESP32 logic and a separate 12V line to drive the high-power exhaust fan via a relay.

15. Reliable Wireless Communication:

    ESP-NOW must be used reliably between the helmet ESP32 and the remote fan-controller ESP32.

1.4.2 Non-Functional Requirements:

16. Real-Time Operation:

    The system should respond to sensor data and trigger actions (displaying, alerting, ESP-NOW transmission) within milliseconds.

17. Portability:

    All components inside the helmet must be compact and lightweight to ensure worker comfort.

18. Durability:

    The system should be durable and reliable in industrial working conditions such as heat, dust, and vibrations.

19. Low Power Consumption:

    Battery life should last for several hours under continuous operation.

20. User-Friendly Display:

    The OLED display should be clearly readable in indoor and outdoor environments.

21. Maintainability:

    Components should be easy to replace or maintain in case of damage or malfunction.

1.5 System Description

The proposed system is a smart safety helmet designed to enhance worker protection in hazardous industrial environments. It functions by continuously monitoring the worker’s surroundings and physical state using embedded sensors. The helmet integrates two main sensors:

- A **gas/smoke sensor** (MQ2) to detect harmful gases or smoke.
- A **motion and fall / temperature sensor** (MPU6050) to detect if the worker has fallen.

All data collected by these sensors are processed by a helmet microcontroller (ESP3-S) embedded inside the helmet. The system displays the sensor readings in real-time on a small screen, making it easy for the worker to stay informed.

If a fall is detected, the system immediately activates an audible alarm using a buzzer to alert nearby personnel , ensuring rapid response to potential injuries. If dangerous gas levels are detected, "… the helmet communicates with a remote ventilation unit via ESP-NOW peer-to-peer wireless communication to activate a fan to activate a fan and improve air quality in the workspace. This fan system is managed by another ESP32 microcontroller located outside the helmet.

The entire system is powered by rechargeable batteries, making it portable and suitable for continuous use during work hours. The design prioritizes safety, comfort, and reliability, aiming to provide workers with real-time awareness and automated emergency responses without requiring any manual interaction.

1.6 Project Limitations/Constraints

While the smart helmet system offers several safety features, there are certain limitations and constraints that need to be acknowledged:

- **Limited Power Supply**: The system relies on rechargeable batteries, which may require frequent charging depending on sensor usage and communication activity.
- **Environmental Interference**: Gas and motion sensors may produce inaccurate readings in extreme environmental conditions such as high humidity, strong winds, or electromagnetic interference.
- **Dual ESP32 Architecture**: The system uses two ESP32 modules (sensing and actuation). This improves separation of concerns but slightly increases BOM and requires maintaining ESP-NOW peer configuration, limiting multitasking or highly complex processing capabilities.
- **ESP-NOW Range**: Typically longer than classic Bluetooth in open space, but actual range depends on obstacles, antennas, and transmit power."

- **Basic User Interface**: The OLED screen provides limited visual feedback due to its small size and low resolution, restricting how much information can be shown at once.
- **Not Waterproof**: The system is not designed to be fully waterproof, so it may malfunction in rainy or wet conditions.

1.7 Project Schedule

Phase	Key Tasks	Duration
Research & Analysis	Literature review, problem identification, requirement analysis	2 weeks
System Design	Architecture planning, component selection, circuit design	3 weeks
Development	Sensor integration, microcontroller programming	4 weeks
Testing & Optimization	Functional testing, debugging, performance improvements	3 weeks

Table 1 : Project Schedule

1.8 Report Outline

This report is structured into Six main chapters, each addressing a specific aspect of the smart safety helmet system:

Chapter One: Introduction

Introduces the project background, problem statement, objectives, system description, project requirements, limitations, schedule, and report structure.

Chapter Two: Theoretical Background and Literature Review

Presents the theoretical concepts related to embedded systems, IoT, sensors, and wireless communication. It also reviews related work and highlights the limitations of existing systems.

Chapter Three: System Design

Describes the overall system architecture, hardware and software components, design alternatives, block diagrams, conceptual diagrams, algorithms, flowcharts, sequence diagrams, use cases, and schematic diagrams.

Chapter Four: Implementation And Testing

Details the hardware and software implementation processes, implementation challenges, and system validation through testing under different scenarios.

Chapter Five: Result And Discussion

Analyzes system performance, sensor accuracy, communication reliability, and discusses the obtained results in comparison with related systems.

Chapter Six: Conclusion and Future Work

Summarizes the project achievements and presents recommendations for future improvements and extensions.

Chapter 2: Theoretical Background

2.1 Preface

This chapter presents the theoretical background necessary to understand the technologies and concepts used in the Smart Safety Helmet system. The system implements local IoT principles by enabling smart communication between ESP32 units to monitor the worker's ambient temperature, gas levels, and movement. In case of a fall, the system triggers an audible alert using a buzzer, and it automatically activates a ventilation fan when smoke or harmful gases are detected. The chapter also provides an overview of the key hardware components, including the ESP32 microcontroller, sensors such as the gas sensor (MQ2) and motion sensor (MPU6050), as well as the ESP-NOW communication module. Furthermore, it explains the importance of using OLED displays for real-time monitoring and the role of embedded systems in implementing smart wearable solutions.

2.2 Theoretical Background Concepts

The Smart Safety Helmet project incorporates several theoretical concepts from embedded systems [1] [4] , wireless communication [2] , and the Internet of Things (IoT) [8] . Key concepts include:

- **Embedded Systems**: The project is based on two ESP32 microcontrollers working together over ESP-NOW [1] [2] , which are low-power embedded systems capable of processing sensor data, managing decision logic, and handling communication protocols .
- **Sensor Integration**: The system uses multiple sensors such as MQ2 (gas detection) [3] , and MPU6050 (motion and fall detection) [4] . These sensors operate based on analog/digital principles and require calibration, threshold settings, and real-time data acquisition [3] [4].
- **Wireless Communication**: The system relies on ESP-NOW peer-to-peer wireless communication between two ESP32 units [2] , without the need for a Wi-Fi router or pairing process . Understanding how serial communication (UART) work [1] is essential for integrating these modules.

- **Real-time Monitoring**: The OLED display is used to provide immediate feedback to the user [5] . This involves refreshing data constantly without blocking system functions, which is achieved using non-blocking programming techniques [6].
- **Power Management:** The system integrates battery management [1] to maintain stable performance in a wearable environment, ensuring reliable operation for extended periods.

Together, these concepts form the theoretical basis of the smart helmet system and allow it to function reliably in industrial safety scenarios.

2.3 Literature Review

Several recent projects have addressed the development of smart helmets and IoT-based worker safety systems [7] [8] . The following table summarizes some of the most relevant projects in terms of purpose, technologies used, and limitations:

Project Title	Purpose	Technologies Used	Limitations
Smart Helmet for Hazardous Work Environments (2022)	Detect gas and temperature in mining sites	Arduino Uno, MQ2, GSM module	No fall detection, no OLED display
IoT-based Helmet with Accident Alert (2021)	Send alerts during road accidents	ESP8266, GPS, GSM	No gas detection or real-time data display
Industrial Safety Helmet using IoT (2020)	Monitor worker's environment	NodeMCU, DHT11, Sound sensor	Limited sensors, poor Bluetooth communication
Smart Helmet with Air Quality Monitoring (2023)	Measure toxic gases	Arduino Mega, MQ135, LCD	No fall detection or mobile alert system
Safety Helmet with ESP-NOW (Proposed System) (2021)	ESP-NOW (Proposed System) -based alerts in case of danger	ESP32, ESP-NOW, Vibration sensor.	Lacks GSM integration and OLED feedback

Table 2 : Literature Review

2.4 Summary

This chapter provides a comprehensive theoretical foundation for the proposed Smart Safety Helmet System. It began with an overview of the key concepts and technologies used in the system, including ESP32 microcontrollers [1] , gas sensor [3] , ESP-NOW communication between two ESP32 boards
[2] , and OLED displays [5] . The literature review highlighted similar projects [7] [8] and identified their limitations in terms of functionality and integration. Our system addresses these gaps by continuously monitoring the worker’s ambient temperature, gas levels, and movement, triggering an audible alert via a buzzer in case of a fall, and automatically activating a ventilation fan when smoke or harmful gases are detected. This theoretical background guides the implementation and evaluation of the system in the upcoming chapters.

Chapter 3: System Design

3.1 Prefaces

This chapter describes the design and operation of the Smart Safety Helmet for Workers, explaining how its hardware and software components are integrated to form a reliable safety system. It discusses the selection of the ESP32 microcontroller, sensors, display, and wireless communication modules, and justifies their choice over alternative solutions.

The chapter also explains how system components interact to collect sensor data, process it in real time, and make safety-related decisions. Block and conceptual diagrams are used to illustrate the overall system architecture and data flow.

Hazard detection is achieved using predefined sensor thresholds and multi-stage decision algorithms, including a reliable fall detection methodology based on acceleration analysis, orientation change, and immobility confirmation. Once a hazardous condition is confirmed, the system responds automatically through audible alerts or ventilation control using ESP-NOW wireless communication.

Flowcharts, sequence diagrams, use case diagrams, and detailed schematic diagrams are presented to support system implementation and testing. Overall, this chapter provides a clear and practical design framework that prepares the system for the implementation and evaluation phases.

3.2 System Components and Design Alternatives (Hardware and Software)

The Smart Safety Helmet for Workers is composed of a set of carefully selected hardware and software components that operate together to provide real-time monitoring and automatic response to hazardous working conditions. The system is designed using a dual-unit architecture consisting of a helmet-mounted sensing unit (Sender Unit) and a remote actuation unit (Receiver Unit).

This section describes each major hardware and software component, explains its functional role within the system, and discusses the alternative solutions that were evaluated before finalizing the design. Component selection was based on performance, reliability, power efficiency, communication latency, and suitability for wearable industrial safety applications.

3.2.1 Hardware Components

1- Microcontroller Unit (ESP32)

The ESP32 is selected as the main processing and control unit of the system. One ESP32 is integrated inside the helmet (Sender Unit) to handle sensor data acquisition, real-time processing, and hazard detection, while a second ESP32 (Receiver Unit) is responsible for alert activation and ventilation control.

The ESP32 processes data from the MPU6050 and MQ2 sensors, applies predefined threshold values and decision algorithms, and communicates detected hazard events wirelessly using the ESP-NOW protocol. Its built-in Wi-Fi module enables fast, low-latency peer-to-peer communication without requiring an internet connection.

Alternatives considered: Arduino Uno, STM32

Reason for choosing ESP32: The ESP32 provides superior wireless capabilities, higher processing power, low power consumption, and better cost-performance compared to the alternatives, making it ideal for wearable and real-time safety systems.

2- Motion and Temperature Sensor (MPU6050)

The The MPU6050 is a 6-axis motion tracking sensor that integrates a 3-axis accelerometer and a 3-axis gyroscope, and it represents a core component of the Smart Safety Helmet system. Its primary function is to monitor worker movement and accurately detect fall events in real time.

Fall detection is implemented using a multi-stage methodology based on acceleration magnitude, orientation change, and immobility confirmation. The acceleration magnitude is calculated using the following equation:

G = $\sqrt{Ax^2 + Ay^2 + AZ^2}$

A potential fall is detected when the acceleration exceeds 2.5g within 300 ms, followed by a significant orientation change where the pitch or roll angle exceeds 60 degrees, and finally confirmed if no significant movement is detected for at least 3 seconds. This approach ensures accurate fall detection while minimizing false alarms.

In addition to its primary role in motion and fall detection, the MPU6050 includes an internal temperature sensor that measures the ambient temperature around the worker. The temperature values are displayed on the OLED screen for real-time awareness and system stability monitoring. Normal operating temperature ranges between 20°C and 45°C, while temperatures exceeding 50°C trigger a warning display without initiating automatic actions.

Alternatives considered: ADXL345, LSM6DS3

Reason for choosing MPU6050: It provides reliable motion sensing, integrated temperature measurement, good accuracy, low power consumption, and strong library support for embedded systems.

3- Gas Sensor (MQ2)

The MQ2 sensor is used to detect flammable gases and smoke in industrial environments. It can identify gases such as LPG, methane (CH_4), propane, hydrogen, and smoke.

Gas concentration levels are classified using predefined threshold values:

- Safe: < 1200 (Normal air quality)
- Dangerous: > 2000 (High concentration – Alarm Active)

When gas concentration exceeds 2000 , the system immediately sends an ESP-NOW signal to the receiver unit, which activates the ventilation fan automatically to improve air quality.

Alternatives considered: MQ135, MQ7

Reason for choosing MQ2: The MQ2 sensor offers fast response time, high sensitivity to a wide range of combustible gases, and suitability for industrial safety applications.

4- OLED Display

The OLED display provides a clear and low-power visual interface for showing real-time system information, including gas status, temperature readings, motion state, and fall alerts.

Alternatives considered: LCD (16×2), TFT displays

Reason for choosing OLED: OLED displays offer better readability, faster refresh rates, lower power consumption, and a compact size suitable for helmet integration.

5- Power Supply (5V Power Bank)

The helmet unit is powered using a 5V rechargeable power bank, ensuring portability and extended operating time during work shifts.

Alternatives considered: Custom Li-ion battery packs

Reason for choosing power bank: It provides stable voltage output, built-in protection circuitry, easy recharging, and safer operation for wearable systems.

6- Buzzer

The buzzer is used as an audible alert device to notify nearby personnel when a worker fall is confirmed. It is directly controlled by the receiver ESP32 to ensure immediate alert activation.

Reason for inclusion: Audible alarms provide fast local awareness without relying on external networks or mobile devices.

7- Relay Module

The relay module is connected to the receiver ESP32 and is used to control high-power devices such as the ventilation fan. Upon receiving a gas hazard signal via ESP-NOW, the relay activates the fan automatically.

Alternatives considered: MOSFET driver circuits

Reason for choosing relay module: Relays provide electrical isolation, robust switching capability, and simple interfacing with the ESP32.

8- Wireless Communication (ESP-NOW)

ESP-NOW is used as the wireless communication protocol between the sender and receiver ESP32 units. It enables direct peer-to-peer data exchange using MAC addresses, without the need for Wi-Fi routers or internet connectivity.

Alternatives considered: Bluetooth, LoRa

Reason for choosing ESP-NOW: It offers ultra-low latency, low power consumption, reliable communication, and fast response time, which are critical for real-time safety systems.

9- Weight of Helmet-Mounted Components

No.	Component	Weight (g)
1	ESP32	8
2	MPU6050	2
3	MQ2 Gas Sensor	5
4	OLED Display	10
5	5V Power Bank	120
6	Wires & Mounting Parts	30
7	TOTAL	175

Table 3 : Weight of Coponents

3.2.2 Software Components

Programming Language

The system will be programmed in C/C++ using the Arduino framework or PlatformIO environment.

Libraries

- ESP32 Wi-Fi libraries (used for ESP-NOW communication).
- Adafruit MPU6050.
- U8g2 or SSD1306 for OLED.
- standard relay control libraries.

Development Environment

Arduino IDE or VS Code with Platform IO plugin.

Component	Options Considered	Final Choice	Reason for Selection
Microcontroller	Arduino Uno, STM32, ESP32	ESP32	built-in Wi-Fi/Bluetooth, power efficient, low cost
Motion Sensor	ADXL345, LSM6DS3, MPU6050	MPU6050	6-axis motion detection, reliable, supported
Gas Sensor	MQ135, MQ7, MQ2	MQ2	fast response, wide gas range detection
Display	LCD 16x2, TFT, OLED	OLED	low power, clear, small footprint
Battery	NiMH, Li-ion	5V Power Bank	built-in protection circuitry , rechargeable
Fan Control	MOSFET driver, Relay	Relay	robust, simple to interface
Connection Protocols	ESP-NOW, LoRa, Bluetooth	ESP-NOW	Simple, cheap, and works without pairing

Table 4 : Component of System

3.3 Conceptual system description

3.3.1 General Block Diagram

Illustrates the overall system architecture and the interaction between the Helmet Unit and the Receiver Unit.

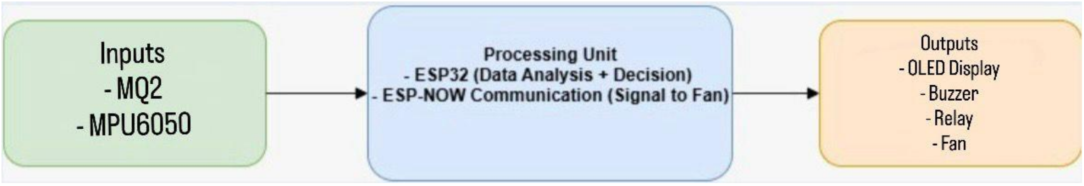

Figure 1 : General Block Diagram

3.3.2 Conceptual Diagram

Depicts the data flow from the sensors up to the decision-making process.

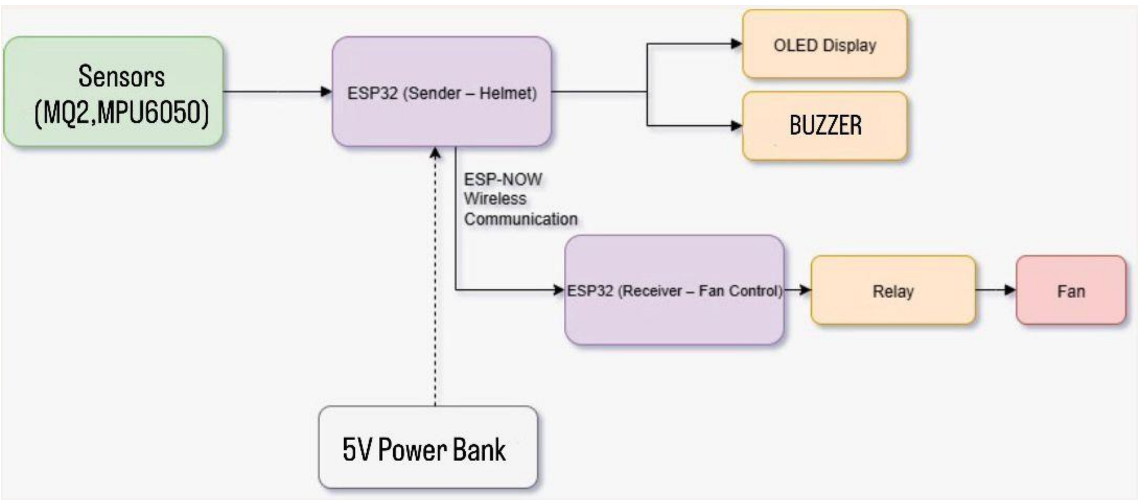

Figure 2 : Conceptual Diagram

3.4 Algorithms and methodologies

3.4.1 Flow Charts

Represents the decision-making logic upon detecting gas or a fall.

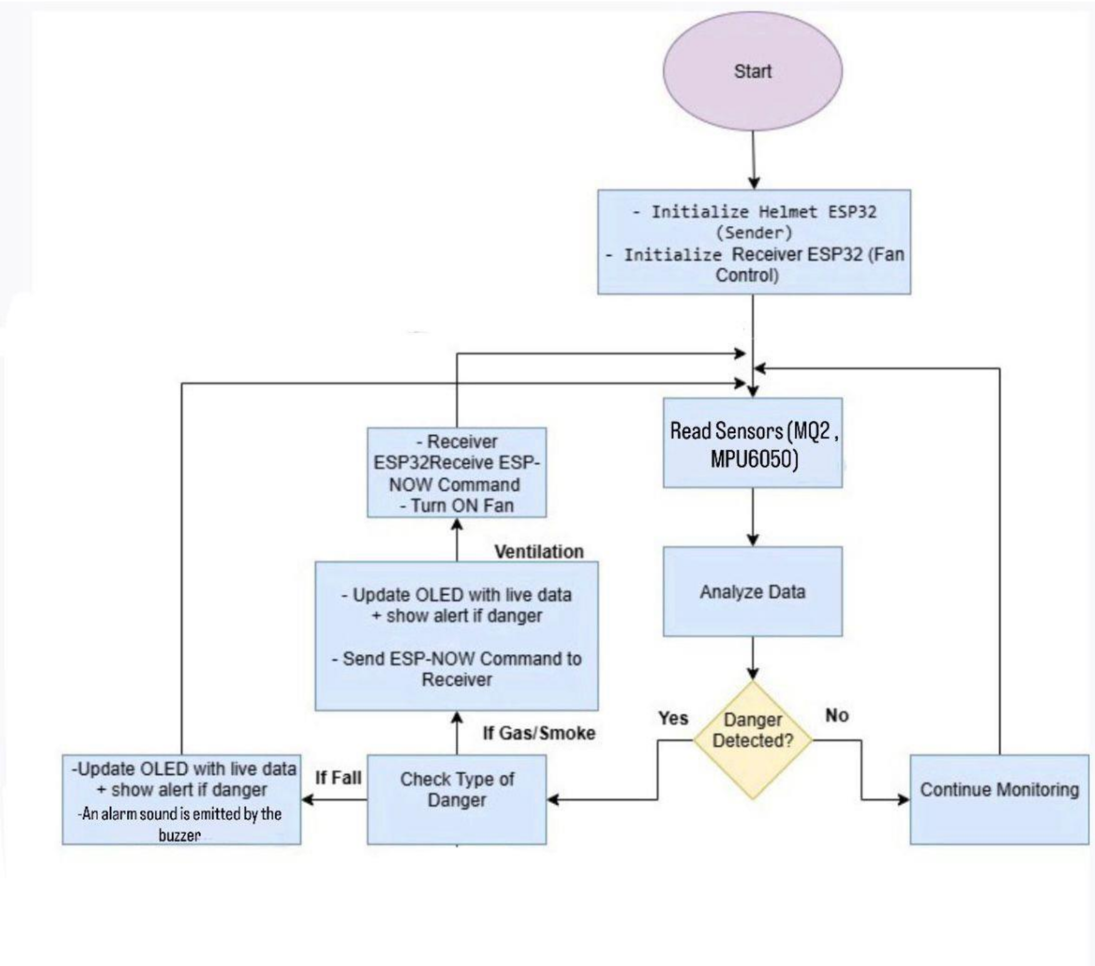

Figure 3 : Flow Charts

3.4.2 Sequence Diagrams

Shows the interaction sequence between the ESP32-S (Sender) and ESP32-R (Receiver).

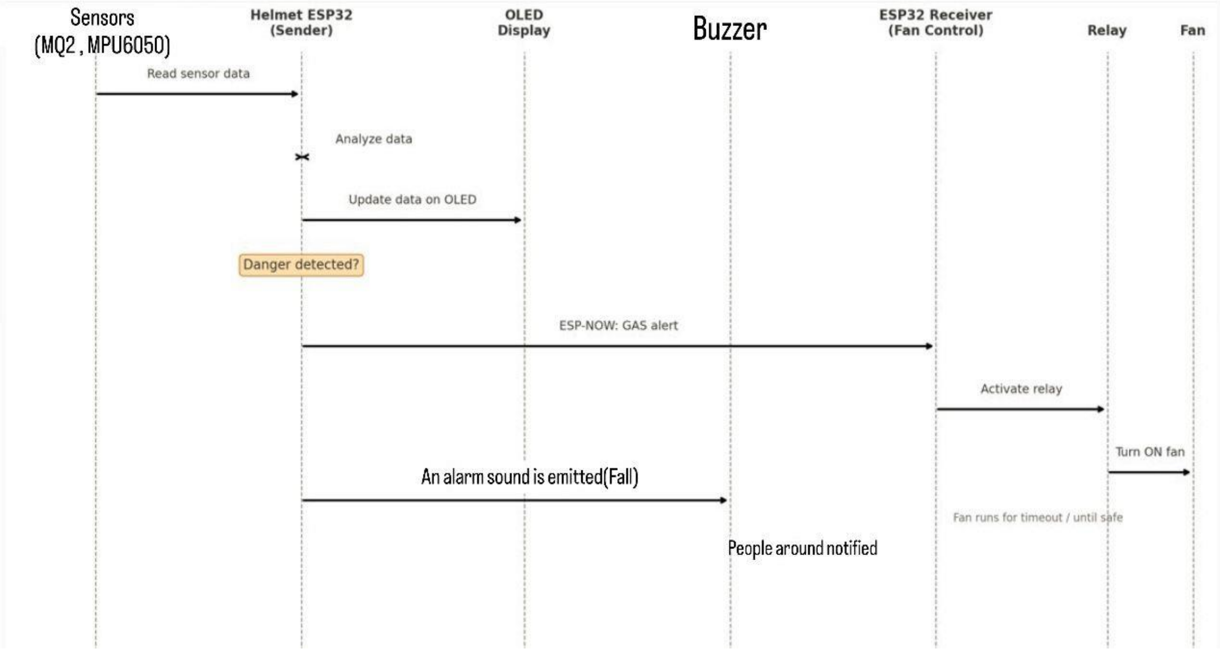

Figure 4 : Sequence Diagrams

3.4.3 Use Cases

Highlights the main scenarios of system interaction with the worker.

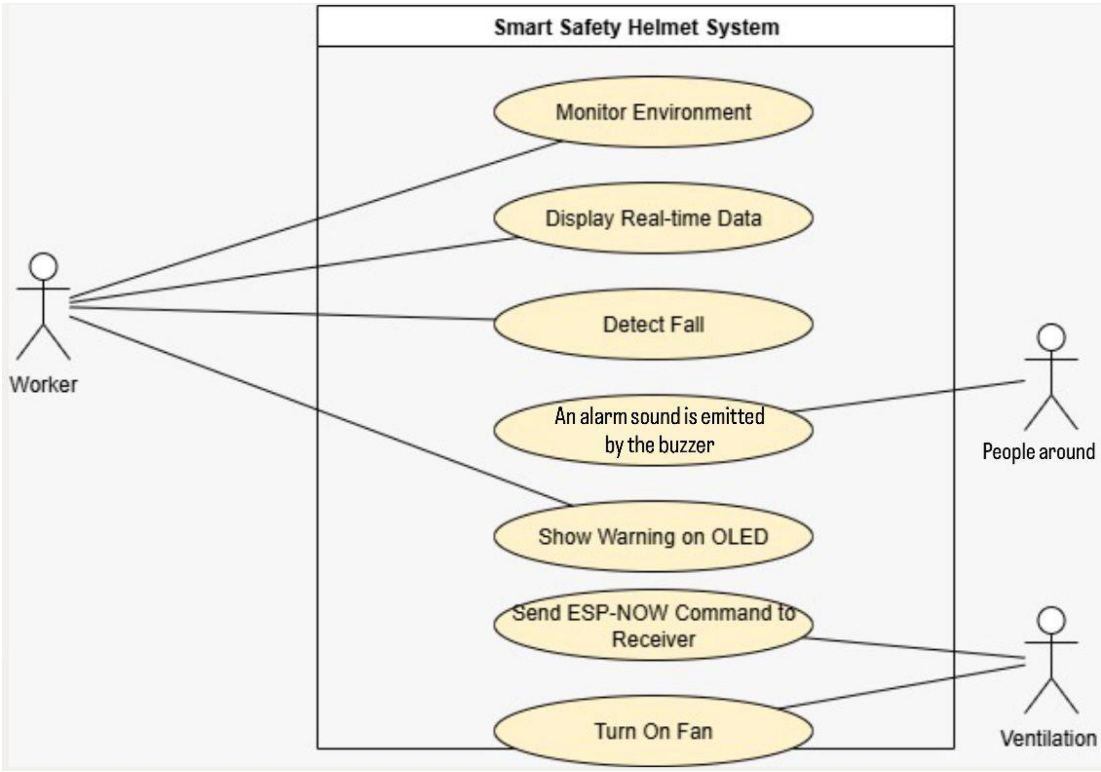

Figure 5 : Use Cases

3.5 Schematic Diagrams

Illustrates the complete electrical connections of all components.

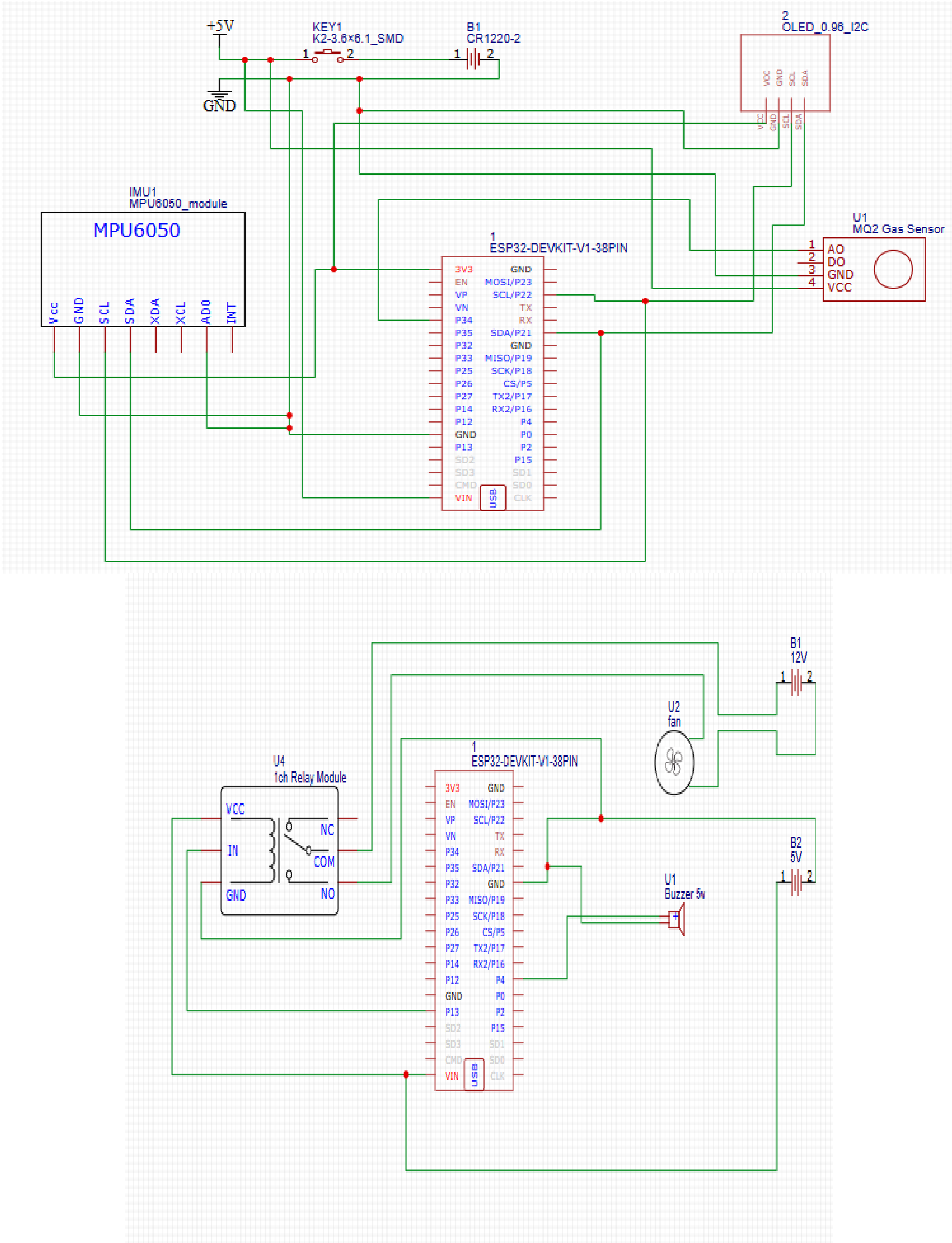

Figure 6 : Schematic Diagrams

3.6 Summary

This chapter presented the complete design and hardware implementation of the Smart Safety Helmet System. The system is built around two ESP32 microcontrollers communicating via the ESP-NOW protocol: a helmet unit (ESP32-S) that collects and processes data from the MQ2 gas sensor and MPU6050 motion/temperature sensor, and a receiver unit (ESP32-R) responsible for controlling external devices such as ventilation fans and buzzer .

The ESP32-S processes real-time sensor data to detect potential hazards. When harmful gases or smoke are detected, the helmet unit sends a wireless signal to the receiver, which activates an external fan to improve worker safety. In the case of a fall, an audible alarm via a buzzer is triggered to alert nearby personnel.

Live sensor readings including gas concentration, temperature, and motion are continuously displayed on an OLED screen for monitoring in real time. The system is powered directly from a main power source.

The full circuit schematic was designed using EasyEDA to ensure proper integration of all components, while system diagrams and data flow were illustrated using draw.io for clear visualization. Overall, the Smart Safety Helmet System successfully achieves its design objectives by detecting environmental hazards and falls, alerting nearby personnel when necessary, and activating preventive actions such as fan control and buzzer , making the system reliable, intelligent, and suitable for industrial safety applications.

Chapter 4 : IMPLEMENTATION AND TESTING

4.1 Implementation Overview

This chapter presents the practical implementation and testing of the Smart Safety Helmet System. The implementation phase focused on integrating the hardware components, developing the embedded software, and validating the communication between the two ESP32 units using ESP-NOW. The system was implemented according to the design specifications presented in Chapter Three, ensuring that all functional requirements were satisfied.

The implementation process was divided into two main parts: hardware implementation and software implementation. After completing the integration, the system was tested under different operating conditions to evaluate its performance, reliability, and responsiveness.

4.2 Hardware Implementation

The hardware implementation includes assembling all electronic components and embedding them into the helmet structure. The main ESP32 (ESP32-S) is mounted inside the helmet and connected to the MQ2 gas sensor, MPU6050 motion and temperature sensor, and OLED display.

Figure 7: Smart Safety Helmet prototype

The MQ2 sensor is positioned to allow effective detection of smoke and hazardous gases in the surrounding environment. The MPU6050 is fixed securely inside the helmet to accurately detect motion, orientation changes, and potential falls. The OLED display is placed in a visible location for the worker to monitor real-time system status.

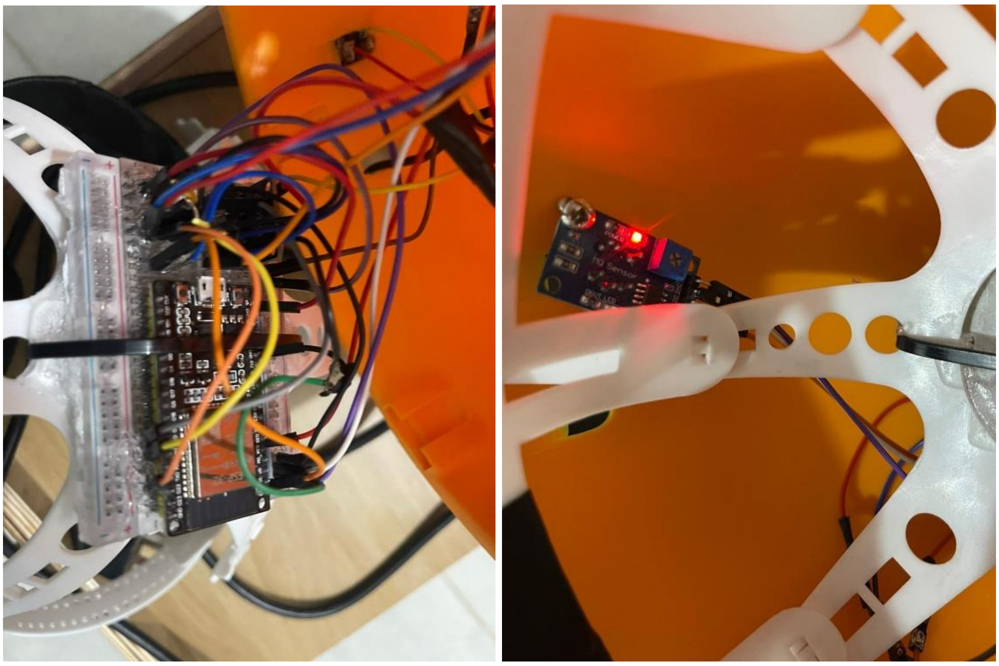

Figure 8 : Helmet internal Components

A second ESP32 (ESP32-R) serves as a remote control unit connected to a relay module that operates a ventilation fan. Located outside the helmet, it communicates wirelessly with the helmet unit using ESP-NOW. A buzzer near the fan provides an audible alert in case of a fall, allowing nearby workers or supervisors to respond quickly. Both ESP32 units are powered by a stable 5V supply, ensuring portability and continuous operation.

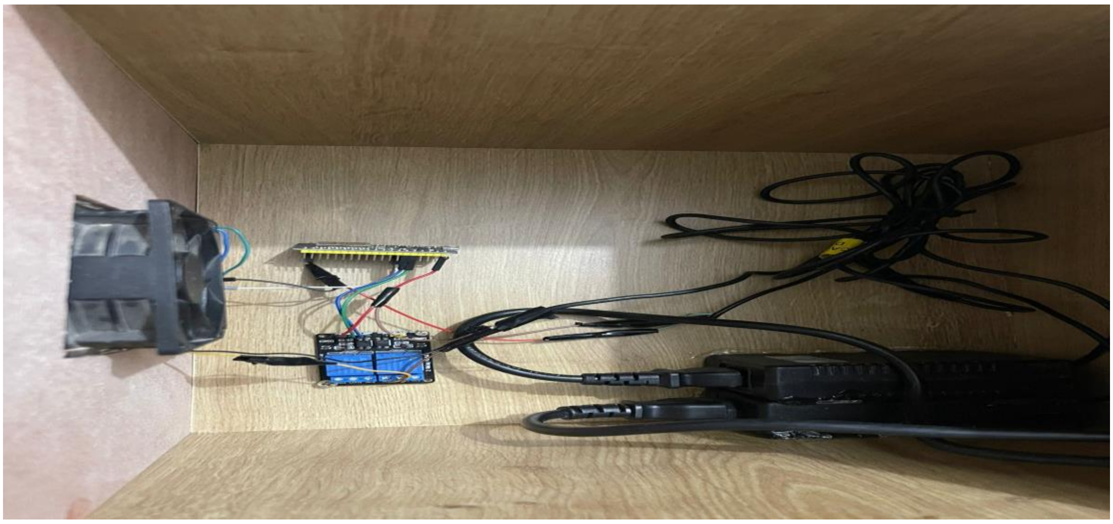

Figure 9 : Receiver Unit

4.3 Software Implementation

The software implementation was developed using the Arduino IDE. Two separate programs were written: one for the helmet ESP32 (sender) and another for the remote ESP32 (receiver).

The helmet ESP32 continuously reads sensor data from the MQ2 and MPU6050. Motion data is processed using threshold-based logic to detect falls based on sudden acceleration, orientation change, and immobility. The ambient temperature around the worker is also measured using the MPU6050 internal sensor and displayed on the OLED screen.

```
#include <esp_now.h>
#include <WiFi.h>
#include <Wire.h>
#include <MPU6050.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include "soc/soc.h"
#include "soc/rtc_cntl_reg.h"

#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define OLED_RESET -1
#define OLED_ADDRESS 0x3C
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT,
&Wire, OLED_RESET);


uint8_t receiverAddress[] = {0xF4, 0x65, 0x0B, 0x48, 0x71,
0x4C};

const int SMOKE_SENSOR_PIN = 34;
const int SMOKE_ALARM_THRESHOLD = 2000;


#pragma pack(1)
typedef struct struct_message {
  bool fallDetected;
  float temperature;
  int smokeValue;
} struct_message;
#pragma pack()

struct_message myData;
esp_now_peer_info_t peerInfo;
MPU6050 mpu;
int16_t ax, ay, az;


const float IMPACT_THRESHOLD = 2.5;
const float SIDE_AXIS_THRESHOLD = 0.8;
const float Z_AXIS_TILT_THRESHOLD = 0.5;
const long IMMOBILITY_TIME_MS = 5000;
long impactTime = 0;
const int MPU_READ_DELAY = 20;

void setup() {
 WRITE_PERI_REG(RTC_CNTL_BROWN_OUT_REG, 0);
 Serial.begin(115200);
 Wire.begin(21, 22);
```

```
 if(!display.begin(SSD1306_SWITCHCAPVCC,
OLED_ADDRESS)) {
   Serial.println(F("â SSD1306 allocation failed."));
   for(;;);
 }
 display.clearDisplay();
 display.setTextSize(1);
 display.setTextColor(SSD1306_WHITE);
 display.setCursor(0,0);
 display.println("System Loading...");
 display.display();

 mpu.initialize();
 if (!mpu.testConnection()) {
   Serial.println("â ï¸ MPU6050 connection failed!
Continuing...");
   display.println("MPU: Not Connected");
   display.display();
   delay(2000);
 } else {
   Serial.println("â
 MPU6050 connection successful.");
   display.println("MPU: Connected OK");
   display.display();
 }

 WiFi.mode(WIFI_STA);
 if (esp_now_init() == ESP_OK) {
   memcpy(peerInfo.peer_addr, receiverAddress, 6);
   peerInfo.channel = 0;
   peerInfo.encrypt = false;
   if (esp_now_add_peer(&peerInfo) != ESP_OK) {
     Serial.println("Failed to add peer");
   }
 }

 display.println("Network: Ready");
 display.display();
 delay(1000);
}
```

```
void loop() {
  mpu.getAcceleration(&ax, &ay, &az);
  float accelX = ax / 16384.0;
  float accelY = ay / 16384.0;
  float accelZ = az / 16384.0;
  float totalAccel = sqrt(pow(accelX, 2) + pow(accelY, 2) +
pow(accelZ, 2));

  int16_t rawTemp = mpu.getTemperature();
  myData.temperature = (float)rawTemp / 340.0 + 36.53;
  myData.smokeValue = analogRead(SMOKE_SENSOR_PIN);

  bool fall_status_to_send = false;
  if (totalAccel > IMPACT_THRESHOLD) {
    if (impactTime == 0) impactTime = millis();
  }

  if (impactTime != 0) {
   bool isLyingDown = (abs(accelZ) <
Z_AXIS_TILT_THRESHOLD) &&
                 (abs(accelX) > SIDE_AXIS_THRESHOLD ||
abs(accelY) > SIDE_AXIS_THRESHOLD);
   if (isLyingDown) {
    if (millis() - impactTime >= IMMOBILITY_TIME_MS)
{ fall_status_to_send = true; }
   } else {
    if (millis() - impactTime > 3000) impactTime = 0;
   }
  }

  if (fall_status_to_send) {
    myData.fallDetected = true;
    esp_now_send(receiverAddress, (uint8_t *) &myData,
sizeof(myData));
    impactTime = 0;

    display.clearDisplay();
    display.setTextSize(3);
    display.setCursor(0, 0); display.println("FALL");
    display.setCursor(0, 32); display.println("ALARM!");
    display.display();
    delay(5000);
  }

  static unsigned long lastSend = 0;
  if (millis() - lastSend > 3000) {
    myData.fallDetected = false;
    esp_now_send(receiverAddress, (uint8_t *) &myData,
sizeof(myData));
    lastSend = millis();
  }

  display.clearDisplay();
  if (myData.smokeValue > SMOKE_ALARM_THRESHOLD) {
    display.setTextSize(2);
    display.setCursor(0, 0); display.println("SMOKE!");
    display.setCursor(0, 25); display.println("DANGER");
    display.setTextSize(1);
    display.setCursor(0, 50); display.print("Value: ");
display.print(myData.smokeValue);
  } else {
    display.setTextSize(2);
    display.setCursor(0, 0); display.println("SAFE");
    display.setTextSize(1);
    display.setCursor(0, 25); display.print("Temp: ");
display.print(myData.temperature, 1); display.print(" C");
    display.setCursor(0, 40); display.print("G-Force: ");
display.print(totalAccel, 2);
    display.setCursor(0, 50); display.print("Smoke: ");
display.print(myData.smokeValue);
  }

  display.display();
  delay(MPU_READ_DELAY);
}
```

Figure 10 : Sender Unit Code

When a hazardous gas level is detected, the helmet ESP32 sends a wireless alert message via ESP-NOW to the remote ESP32, which activates the ventilation fan. In the event of a fall, the system immediately triggers an audible alarm using a buzzer to alert nearby personnel.

```
#include <esp_now.h>
#include <WiFi.h>


const int BUZZER_PIN = 4;
const int FAN_PIN = 13;
const int RESET_BUTTON_PIN = 27;

const int BUZZER_FREQ = 1000;
const int SMOKE_THRESHOLD = 2000;


bool isBuzzerActive = false;

#pragma pack(1)
typedef struct struct_message {
  bool fallDetected;
  float temperature;
  int smokeValue;
} struct_message;
#pragma pack()

void OnDataRecv(const esp_now_recv_info * info, const uint8_t
*data, int len) {

  struct_message myIncomingData;
  memcpy(&myIncomingData, data, sizeof(myIncomingData));

  bool isGasHigh = (myIncomingData.smokeValue >
SMOKE_THRESHOLD);


  if (myIncomingData.fallDetected && !isBuzzerActive) {
    isBuzzerActive = true;
    tone(BUZZER_PIN, BUZZER_FREQ);
    Serial.println("!!! FALL DETECTED! BUZZER LOCKED
ON. !!!");
  }

  Serial.printf("Received: Fall=%s | Gas Alarm=%s | Temp=%.1f
C | Smoke Val: %d\n",
          myIncomingData.fallDetected ? "TRUE (Alarm)" :
"FALSE",
          isGasHigh ? "TRUE (Fan ON)" : "FALSE",
          myIncomingData.temperature,
          myIncomingData.smokeValue);

  if (isGasHigh) {
    digitalWrite(FAN_PIN, LOW);
  } else {
    digitalWrite(FAN_PIN, HIGH);
  }
}

void setup() {
  Serial.begin(115200);

  pinMode(BUZZER_PIN, OUTPUT);
  pinMode(FAN_PIN, OUTPUT);
  pinMode(RESET_BUTTON_PIN, INPUT_PULLUP);
  digitalWrite(FAN_PIN, HIGH);
  noTone(BUZZER_PIN);

  tone(BUZZER_PIN, BUZZER_FREQ); delay(300);
  noTone(BUZZER_PIN);
  Serial.println("Receiver Ready.");

  WiFi.mode(WIFI_STA);
  if (esp_now_init() == ESP_OK) {
    esp_now_register_recv_cb(OnDataRecv);
    Serial.printf("Receiver MAC: %s\n",
WiFi.macAddress().c_str());
  } else {
    Serial.println("â Error initializing ESP-NOW");
  }
}

void loop() {
  if (digitalRead(RESET_BUTTON_PIN) == LOW &&
isBuzzerActive) {
    isBuzzerActive = false;
    noTone(BUZZER_PIN);
    Serial.println("BUZZER RESET MANUALLY.");
    delay(500);
  }

  delay(10);
}
```

Figure 11 : Receiver Unit Code

4.4 Validation and Testing

The system was tested under controlled conditions to verify its functionality and reliability. Several test scenarios were conducted, including gas detection, fall detection, wireless communication reliability, and display accuracy.

During testing, the MQ2 sensor successfully detected smoke and gas presence within the predefined threshold range. The fall detection algorithm accurately identified simulated falls while minimizing false triggers during normal movements. ESP-NOW communication demonstrated low latency and reliable data transfer between the two ESP32 units.

All system components operated as expected, confirming that the implementation meets the project objectives and functional requirements.

4.5 Summary

This chapter detailed the implementation and testing of the Smart Safety Helmet System. Both hardware and software components were successfully integrated and validated. The testing results confirmed that the system performs reliably in detecting hazardous conditions, communicating alerts, and responding automatically to potential risks.

Chapter 5 : Results and Discussion

5.1 Results Overview

This chapter presents and analyzes the results obtained from testing the Smart Safety Helmet System. The evaluation focused on system accuracy, response time, communication reliability, and overall performance in real-world scenarios.

5.2 Sensor Performance Analysis

The MQ2 gas sensor demonstrated effective detection of smoke and flammable gases, triggering alerts within a short response time. The MPU6050 accurately detected motion patterns and fall events using acceleration and orientation data. Ambient temperature readings were stable and consistently displayed on the OLED screen.

5.3 Communication and System Response

ESP-NOW communication between the two ESP32 units provided fast and reliable data transmission without requiring an external network. The ventilation fan was activated immediately upon receiving a gas alert, and the buzzer responded instantly when a fall was detected.

5.4 Discussion of Results

The results indicate that the system successfully achieves its design goals. Compared to similar systems discussed in the literature, this project offers improved integration by combining gas detection, fall detection, real-time display, and wireless actuation in a single wearable solution.

Some limitations were observed, such as sensitivity variations in the MQ2 sensor and dependency on battery power. However, these limitations do not significantly affect system performance and can be addressed in future improvements.

5.5 Summary

The experimental results confirm that the Smart Safety Helmet System is reliable, responsive, and suitable for industrial safety applications. The system provides effective real-time monitoring and automated responses to hazardous situations.

Chapter 6 : Conclusion and Future Work

6.1 Conclusion

This project successfully designed and implemented a Smart Safety Helmet System that enhances worker safety in industrial environments. By integrating gas detection, motion and fall detection, wireless communication, and automated ventilation control, the system provides real-time protection and rapid response to dangerous conditions.

The use of ESP-NOW communication ensures low-latency and reliable data exchange between system components. The compact design, real-time data visualization, and automatic alert mechanisms make the system practical, efficient, and cost-effective.

6.2 Future Work

Future enhancements to the system may include:

- Integration of additional environmental sensors such as CO_2 and humidity sensors.
- Development of a mobile or cloud-based monitoring platform.
- Optimization of power consumption and battery life.
- Implementation of machine learning techniques to improve fall detection accuracy and reduce false alarms.
- Miniaturization of hardware components to improve comfort and usability.

General Conclusion

The Smart Safety Helmet System successfully integrates multiple sensing and wireless communication technologies to enhance worker safety in industrial environments. By combining gas detection using the MQ2 sensor, motion and fall detection using the MPU6050, and wireless control of a ventilation system, the helmet provides real-time protection against hazardous conditions.

The use of ESP-NOW communication between two ESP32 units ensures a reliable and low-latency connection without relying on external networks or internet connectivity. Automatic responses, such as activating a ventilation fan during gas detection and triggering an audible alarm upon fall detection, enable immediate local awareness and preventive action.

The system's compact design, real-time data visualization on an OLED display, and efficient decision-making mechanisms make it a practical and cost-effective solution for improving occupational safety. Overall, this project demonstrates the feasibility and effectiveness of IoT-based wearable safety systems in proactively protecting workers in high-risk environments.

References

1. Espressif Systems. (2024). *ESP32 Technical Reference Manual*. Retrieved from: https://www.espressif.com

2. Espressif Systems. (2024). *ESP-NOW User Guide*. Retrieved from: https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api-reference/network/esp_now.html

3. Hanwei Electronics. (2023). MQ-2 Semiconductor Sensor for Combustible Gas. Retrieved from: https://www.pololu.com/file/0J309/MQ2.pdf

4. InvenSense. (2022). *MPU-6050 Product Specification*. Retrieved from: https://invensense.tdk.com

5. Adafruit Industries. (2024). *Adafruit SSD1306 OLED Display Documentation*. Retrieved from: https://learn.adafruit.com/monochrome-oled-breakouts

6. Arduino. (2024). *Arduino IDE Documentation*. Retrieved from: https://docs.arduino.cc

7. Kumar, R., & Sharma, S. (2021). Smart Helmet for Industrial Workers Using IoT. *International Journal of Engineering Research & Technology (IJERT),* 10(6), 1-5.

8. Patel, D., & Singh, A. (2020). IoT-Based Safety Helmet for Hazardous Industrial Environment. *International Journal of Innovative Research in Science, Engineering and Technology*, 9(4), 2345–2351.

نموذج إقرار وتوثيق استخدام أدوات الذكاء الاصطناعي في مشروع التخرج

اسم الطالب / أسماء الطلبة: كرم الدرابيع / ليانا أبو أسعد	عنوان المشروع: Smart Helmet For Worker
الرقم / الأرقام الجامعية:211998 / 211137	اسم المشرف الأكاديمي: د.رائد شماس
الكلية / الدائرة: كلية تكنولوجيا المعلومات وهندسة الحاسوب	السنة/الفصل الدراسي: 2025

الغرض من الاستخدام	اسم الأداة	أماكن الاستخدام في التقرير (فصول / صفحات)	الأمر الأساسي المستخدم (**Prompt**)	هل تم تعديل الناتج؟	نسبة الاستخدام التقديرية	ملاحظات
توليد نصوص	ChatGPT	الفصل 1 (المقدمة، الأهداف) والفصل 2 (الخلفية النظرية)	"مقدمة عن نظام خوذة أمان ذكية للعمال تحتوي على mq2و dht22و mpu6050"	نعم	10%	
	Gemini					
	Claude					
	Microsoft Copilot					
	other: _____					
تدقيق لغوي	Grammarly					
	Quillbot					
	Word Editor AI					
	other: _____					
تلخيص محتوى	ChatGPT	الفصل 2	"لخص أهم الفروقات بين المشاريع المشابهة"	نعم	10%	
	SMMRY					
	Notion AI					
	Scholarcy					
	other: _____					
تحليل بيانات	Excel Copilot					
	Python AI Assistants					

	Tableau AI					
	other: _____					
رسم مخططات / أشكال	DALL·E					
	Canva AI					
	Visio AI					
	Lucidchart AI					
	other: _____					
كتابة أكواد برمجية	GitHub Copilot					
	Replit AI					
	Codeium					
	other: _____					
توثيق مراجع	EndNote					
	Mendeley					
	Zotero					
	ChatGPT	مراجع	طريقة توثيق المراجع APA		10%	
	other: _____					
أخرى (حدد :) _____						

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