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Development of Smart Helmet System with GSM And IoT for Hazardous Gas Detection

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Abstract

The advent of smart helmets has revolutionized safety measures across various industries, particularly in oil and gas, mining, and motorcycling. These innovative devices integrate advanced technologies to enhance user safety, monitor health conditions, and provide real-time data communication This paper aims to design a smart helmet that enhances worker safety in hazardous industrial environments by using sensors and wireless communication technologies to monitor and analyze data related to toxic gases, noise levels, and high temperatures, and sends immediate warning notifications to workers in the event of a safety hazards. The industry's ongoing digital transformation, often referred to as Oil and Gas 4.0, is increasingly leveraging technologies like the Internet of Things (IoT), artificial intelligence (AI), and automation to address these challenges, with a primary focus on predictive maintenance, operational optimization, and, most critically, worker safety. The smart helmet uses an MQ2 gas sensor to detect hazardous gases, a GPS module for real-time geolocation, and an ESP32 WiFi module for sending live data to a smartphone or cloud dashboard, enabling real-time monitoring and emergency response. The helmet sends emergency SMS alerts via GSM900 and live data to a smartphone or cloud dashboard using IoT protocols such as MQTT or HTTP.

Keywords: Smart Safety Helmet, IoT, ESP32, GPS Integration, GSM Technology, microcontroller.

الملخص: أحدث ظهور الخوذات الذكية ثورة في إجراءات السلامة في مختلف الصناعات، لا سيما في قطاعات النفط والغاز والتعدين وقيادة الدراجات النارية. تدمج هذه الأجهزة المبتكرة تقنيات متقدمة لتعزيز سلامة المستخدم، ومراقبة الحالة الصحية، وتوفير اتصال بيانات فوري. تهدف هذه الورقة البحثية إلى تصميم خوذة ذكية تعزز سلامة العمال في البيئات الصناعية الخطرة باستخدام أجهزة استشعار وتقنيات اتصال لاسلكية لمراقبة وتحليل البيانات المتعلقة بالغازات السامة ومستويات الضوضاء ودرجات الحرارة المرتفعة، وإرسال تنبيهات فورية للعمال في حالة وجود مخاطر تتعلق بالسلامة. يعتمد التحول الرقمي المستمر في هذه الصناعة، والذي يُشار إليه غالبًا باسم "النفط والغاز 4.0"، بشكل متزايد على تقنيات مثل إنترنت الأشياء والذكاء الاصطناعي والأتمتة لمواجهة هذه التحديات، مع التركيز بشكل أساسي على الصيانة التنبؤية وتحسين العمليات، والأهم من ذلك، سلامة العمال. تستخدم الخوذة الذكية مستشعر غاز **MQ2** للكشف عن الغازات الخطرة، ووحدة **GPS** لتحديد الموقع الجغرافي في الوقت الفعلي، ووحدة **ESP32 WiFi** لإرسال البيانات مباشرة إلى هاتف ذكي أو لوحة تحكم سحابية، مما يتيح المراقبة الفورية والاستجابة لحالات الطوارئ. تقوم الخوذة بإرسال تنبيهات **SMS** للطوارئ عبر **GSM900** وبيانات مباشرة إلى هاتف ذكي أو لوحة تحكم سحابية باستخدام بروتوكولات إنترنت الأشياء مثل **MQTT** أو **HTTP**.

الكلمات المفتاحية: قبعة الأمان الذكية، انترنت الأشياء، المتحكم، شريحة إي أس بي، نظام تحديد المواقع المدمج، تقنية ارسال واستقبال الرسائل ادجي اس ام، المتحكم الدقيق.

I. INTRODUCTION

Smart helmets are wearable devices equipped with sensors and communication technologies designed to improve safety and health monitoring. They are particularly beneficial in high-risk environments such as construction sites and for motorcyclists, where the risk of accidents is significantly high. The integration of Internet of Things (IoT) technology allows these helmets to communicate vital information to users and emergency services, thereby enhancing response times during accidents. The rise in motorcycle accidents, industrial hazards, and the need for real-time health and environmental monitoring have driven the development of smart helmets. These devices are increasingly used in motorcycling, construction, mining, and emergency services, aiming to reduce injuries and fatalities by providing proactive safety measures and rapid emergency response [1,2,3]. Smart helmets typically integrate multiple sensors—such as accelerometers, gyroscopes, gas detectors, temperature and humidity sensors, and heart rate monitors—alongside microcontrollers and wireless communication modules (e.g., GSM, GPS, IoT connectivity) [4,5,6,7].

Key functionalities include:

- **Accident Detection and Emergency Alerts:** Sensors detect impacts or abnormal movements, triggering automatic alerts with location data to emergency contacts or services [8,9,10].

Health and Environmental Monitoring: Real-time tracking of vital signs and environmental hazards (e.g., toxic gases, high temperatures) enhances user safety, especially in industrial and mining settings [11,12].

- **Alcohol and Drowsiness Detection:** Integrated sensors can prevent vehicle operation under unsafe conditions, such as intoxication or fatigue [13].
- **Augmented Reality and Navigation:** Some prototypes feature AR displays for hands-free access to navigation, hazard alerts, and communication [14].
- **Remote Monitoring:** IoT-enabled helmets allow supervisors or family members to monitor user status and location in real time [15].

The integrity of aging infrastructure and intricate industrial assets necessitates routine inspection protocols to uphold safety standards and operational reliability [16]. Conventional inspection methodologies are frequently characterized by their labor-intensive nature, significant time commitment, and inherent risks to personnel safety [17,18]. Consequently, there is an increasing imperative for the development and adoption of more efficient and secure inspection techniques.

Recent advancements have propelled wearable technology, specifically smart safety helmets equipped with integrated sensors, into prominence as a viable solution for enhancing inspector capabilities and mitigating associated occupational hazards.

Functioning as sophisticated personal protective equipment, these helmets provide dual benefits: safeguarding workers while simultaneously embedding advanced sensory apparatus, such as cameras, to facilitate real-time environmental monitoring and analysis [19,20,21]. Industrial contexts, including construction sites, oil and gas installations, and power generation facilities, present inherently high-risk environments where acute situational awareness is paramount [22,23]. Annually, these sectors report thousands of occupational injuries and fatalities, frequently occurring during critical inspection and maintenance operations. By enabling hands-free visual monitoring and providing immediate access to pertinent information, smart helmets endeavor to augment safety protocols and minimize the incidence of human error [24].

II. PROBLEM STATEMENT

Industrial environments, such as oil fields, present significant occupational hazards, primarily the elevated risk of hydrogen sulfide (H_2S) gas exposure for personnel. H_2S is a highly toxic, colorless, and odorless gas that, at lethal concentrations, can induce unconsciousness or fatality within minutes of inhalation. A fundamental challenge lies in the reliance of conventional safety systems on manual protocols or passive devices, which frequently lack real-time alerting capabilities and precise location tracking. This deficiency is particularly critical in remote areas where prompt intervention is arduous. Although specialized H_2S sensors are available, their prohibitive cost and restricted accessibility pose a substantial impediment to student-led projects and prototype development. This project endeavors to mitigate this challenge by introducing the MQ2 sensor as an economical and viable alternative for detecting flammable gases frequently co-emitted with \$H_2S\$. The proposed system integrates real-time alerting, geolocation, and Internet of Things-based communication, thereby augmenting worker safety and facilitating swift emergency responses in hazardous environments.

III. DESIGN OBJECTIVE

The objective of the research is to design a smart helmet that enhances worker safety in hazardous industrial environments by providing real-time alerts and precise location tracking. The research aims to leverage integrated gas detection, WiFi-based IoT connectivity, and GSM communication to ensure rapid detection of dangerous conditions and immediate alerting to reduce exposure to toxic substances and prevent accidents.

IV. METHODOLOGY

This research endeavors to advance the development of smart helmet systems through the integration of sophisticated sensors, communication modules, and display interfaces into conventional protective headgear. An empirical analysis concerning the evolution of smart helmets offers a detailed examination of their constituent elements and technological innovations, which is instrumental in shaping critical system design decisions. The study particularly investigates the applications and inherent benefits of smart helmets across diverse sectors such as motorcycling,

cycling, construction, and emergency services, highlighting their practical implementation for augmenting safety, connectivity, and operational performance.

In this work, a combination of hardware and software components, including an Arduino microcontroller, an ESP32 WiFi module, a GPS module, and an MQ2 gas sensor were used. An IoT protocols such as MQTT or HTTP for real-time data exchange were used as well. In addition, the Internet of Things is conceptualized as an architecture of interoperable sensors and modules that collaboratively operate through a communication infrastructure. Its primary function is to facilitate real-time environmental surveillance of hazardous conditions and to generate immediate alerts for designated users or integrated external systems.

The study uses a combination of hardware and software components, including the ESP32 NodeMCU, MQ2 gas sensor, GSM SIM900 module, GPS NEO-6M, and ESP32-CAM, to develop the smart helmet system.

V. HARDWARE AND SOFTWARE REQUIREMENTS

The primary components are crucial for ensuring optimal system functionality, as illustrated in the block diagram Figure 1 for the safety helmet to protect workers in hazardous industrial or field environments. To address these requirements, the proposed system will incorporate specific hardware and software components. It emphasizes both local alerts and remote connectivity via GSM and WiFi-based IoT communication. The system consists of the following primary modules:

A) Central Unit (Main Control Module)

This is the brain of the smart helmet. It is based on an Arduino microcontroller that processes input from multiple sensors. It integrates three key technologies:

- A GPS module for real-time geolocation.
- A GSM900 module for sending SMS alerts to emergency contacts with gas type and location data.

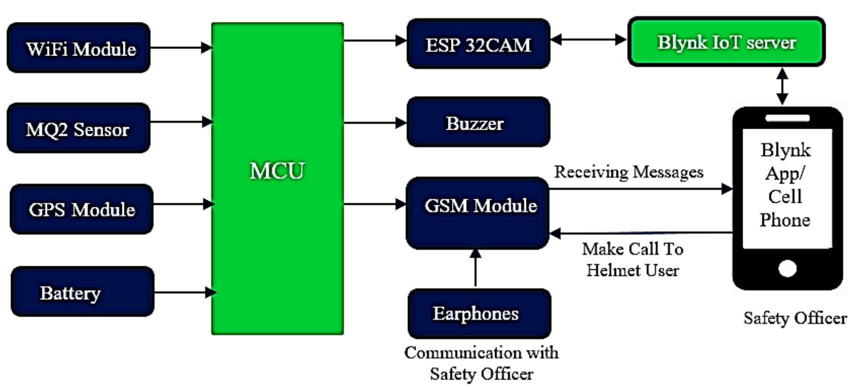

Figure 1. Block diagram

- An ESP32 WiFi module for sending live data (sensor values, GPS location, camera feed) to a smartphone or cloud dashboard using IoT
- protocols such as MQTT or HTTP. This unit is responsible for sensor data processing, decision-making, and communication through both cellular and internet channels.

B) Receiver Unit (User and Monitoring Interfaces)

This includes external devices such as smartphones, web-based dashboards, or monitoring stations. It receives alerts either through:

- GSM SMS for critical emergencies.
- WiFi IoT connection for live data, notifications, and historical logs accessible via a mobile app or cloud server, ensuring flexibility and redundancy in communication.

C) Gas Sensing Unit – MQ2 Sensor

The MQ2 gas sensor is employed for the continuous surveillance of environmental conditions to detect hazardous and/or combustible gases. Upon the detection of concentrations exceeding predefined safety thresholds, the collected sensor data is promptly transmitted to a central processing unit for real-time analysis and the subsequent initiation of appropriate actions.

D) Power Supply Unit

This module supplies stable power to the entire system, including the Arduino, GPS, GSM, ESP32, and the camera. It typically consists of a rechargeable battery or external power source with adequate capacity to support continuous field operation.

*E) Visual Monitoring Unit – ESP32-CAM Camera*In addition to image capturing and live video streaming, the ESP32-CAM module also provides WiFi connectivity, allowing it to serve dual purposes:

- Capture and store footage during incidents (e.g., gas leaks).
- Stream data wirelessly to monitoring platforms or mobile apps over WiFi as part of the IoT subsystem. This visual insight significantly enhances emergency assessment and response capabilities.

In addition, IoT technology were deployed in this paper to to address the challenges associated with annual facilities in the oil and gas sector. In contrast, the IIoT-Based Smart Helmet provides a comprehensive IoT solution that enhances workplace safety and mitigates incidents. For this purpose, an ESP32 NodeMCU have used as a powerful development board that combines a microcontroller with integrated Wi-Fi and Bluetooth capabilities, making it ideal for modern IoT applications. Developed by Espressif Systems, the ESP32 features a dual- core 32-bit processor, higher clock speed, and significantly more memory compared to traditional Arduino boards such as the Uno or Nano. It also offers a larger number of digital I/O pins, multiple ADC channels, and support for PWM, SPI, I2C, and UART interfaces.

To develop, program, and deploy the smart helmet's functionality—including GPS, GSM, and WiFi communication-the following software tools and libraries must be used:

- **Arduino IDE:** The official development platform for writing, compiling, and uploading code to the Arduino and ESP32 boards.
- **Adafruit_GPS Library:** Enables the parsing and communication with NMEA compatible GPS receivers for real-time location tracking.
- **Adafruit_GSM Library:** Facilitates communication with the GSM module (e.g., SIM900) for sending SMS alerts in case of emergency
- **Software Serial Library:** Allows serial communication via digital pins, enabling simultaneous communication with multiple modules (e.g., GPS, GSM) on boards with limited UART ports.

VI. SYSTEM IMPLEMENTATION AND VALIDATION

The developed system comprises of all electronic components mentioned above. Figure 2 shows the diagram connection and integration of these various components to an Arduino-based IoT system.

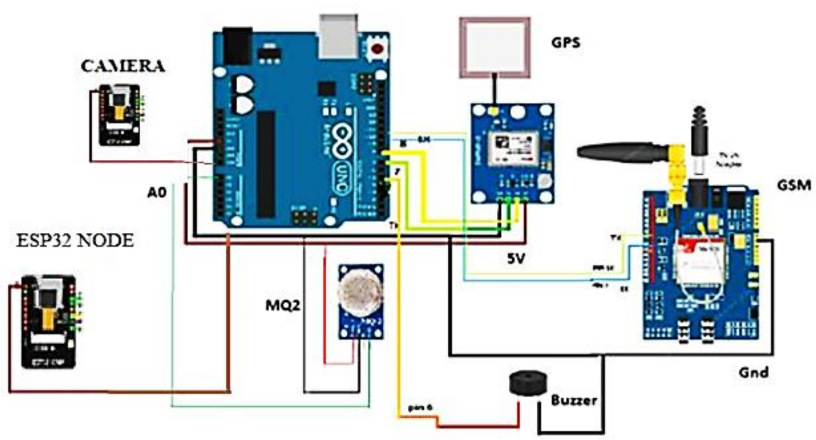

Figure 2. connection diagram of the developed smart helmet system

The system is powered by a compact rechargeable battery, with components integrated into the helmet to maintain user comfort and mobility. This holistic integration yields a comprehensive wearable safety solution for coal miners, amalgamating gas detection, local and remote alerts, and environmental monitoring within a single intelligent helmet. The developed helmet-mounted system is illustrated in Figure 3.

The designed system is portable and powered by 5 V supply, allowing the Arduino microcontroller to acquire data continuously.

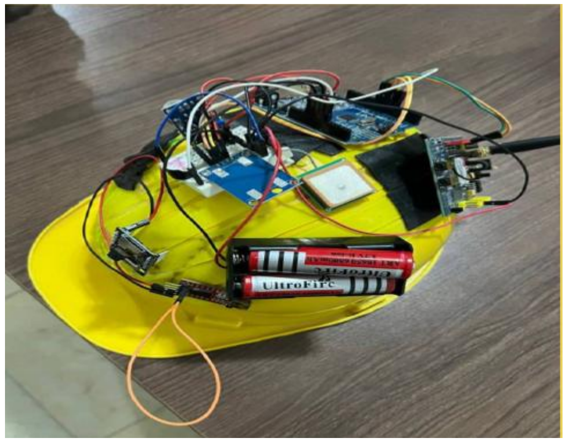

Figure 3. Developed helmet-mounted gas monitoring

Sensor data are transmitted to a mobile device at 1 s intervals, with simultaneous alerts issued. Consequently, rescue operations can be initiated promptly, thereby safeguarding workers' lives and averting further exposure to hazardous gases.

To facilitate remote monitoring and alerting, the system leverages the Blynk IoT platform. The ESP32 microcontroller connects to Wi-Fi and relays real-time sensor data to the Blynk mobile application, enabling supervisors or safety officers to remotely monitor gas concentrations and receive notifications upon detection of hazardous conditions.

Test results showed that the MQ2 gas sensor responded effectively to changes in flammable gas concentrations. Under regular testing conditions, gas readings ranged between 350 – 450 ppm, confirming sensor sensitivity and system responsiveness. As soon as the ESP32 NodeMCU was powered and connected, it began transmitting gas readings from the MQ2 sensor to the Blynk mobile app. The data was displayed through:

- A circular gauge indicating the current gas level in ppm.
- A real-time chart (Super Chart) plotting sensor values over time

As part of enhancing emergency response efficiency, an **email alert feature** was integrated into the smart helmet system using the **Blynk IoT Cloud** platform. This system allows automatic email notifications to be sent to predefined addresses when gas concentration levels exceed safe thresholds. The ESP32 continuously transmits sensor data to the Blynk cloud in real time. When dangerous levels of gases such as methane, propane, or hydrogen are detected, an **automation trigger** within the Blynk application is activated. This trigger sends a structured email containing specific details such as the type of gas, its concentration, and the date and time of detection, allowing safety personnel to take immediate action—even in cases where GSM coverage is unavailable or the user is off-site. As illustrated in Figure 4, an example of an automatic alert email generated by Blynk is shown, displaying the warning details and timestamp. This email alert system operates in parallel with GSM text messages and mobile push notifications, enhancing the **reliability and redundancy of the system**, while also providing an additional layer of **incident documentation and safety assurance**. The stored alerts can be used later for event analysis and policy improvement.

When the gas reading exceeded a pre-set threshold (e.g., 800 ppm), the GSM SIM900 module sent an automatic SMS alert. The message contained the warning "GAS DETECTED" followed by the geographic location obtained from the NEO-6M GPS module. As shown in Figure 5.

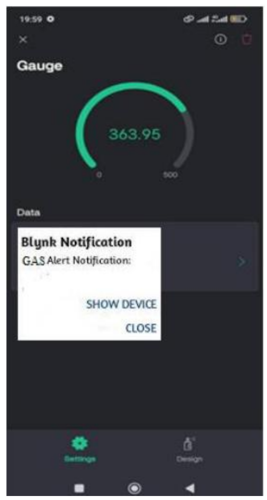

Figure 4. ESP32 using Blynk notifications IoT Cloud | Email Alert System.

Figure 5. Example of a real-time SMS alert from the GSM module, including gas detection and GPS coordinates.

VII. DISCUSSION

The findings demonstrated overall satisfaction with smart helmets, particularly in relation to gas detection, fall detection, and real-time health monitoring, signifying a favorable reception of these advanced safety technologies. The developed system yielded the following summarized results:

- MQ2 readings were transmitted via Virtual Pin V1 to Blynk.
- Time of each reading was logged using NTP and displayed via Virtual Pin V2.
- The buzzer was triggered only during actual gas threshold exceedance.
- No warning was displayed on Blynk unless specifically programmed.

The system succeeded in reliably collecting and transmitting environmental data via the ESP32 NodeMCU, with gas readings displayed clearly in the mobile app. The SMS alert mechanism proved effective for critical conditions, while the Blynk interface served as a continuous passive monitor.

VIII. CONCLUSION

The implementation of a smart helmet using IoT-based embedded systems represents a significant advancement in occupational safety, particularly in hazardous industrial environments. By integrating the MQ2 gas sensor, GSM SIM900 module, GPS NEO-6M, ESP32-CAM, and ESP32 NodeMCU, the system offers a multi-functional and autonomous solution capable of detecting gas leaks, tracking worker location, and sending real-time alerts both via SMS and the internet. The dual communication approach—using GSM for emergency alerts and Wi-Fi for real-time IoT data transmission—ensures communication redundancy and flexibility. The addition of visual monitoring via ESP32-CAM adds a critical layer of environmental awareness, allowing supervisors or rescue teams to assess situations remotely with visual feedback. The use of the ESP32 NodeMCU enhances processing efficiency and allows seamless integration with the Blynk IoT platform, facilitating real-time mobile app interaction and cloud data logging. Despite the successful implementation, the project faced challenges, including high power consumption, unstable GSM coverage in remote areas, sensor calibration sensitivity, and limited performance of locally available lithium-ion batteries. However, the system proved to be functional, scalable, and cost-effective for future expansion or deployment.

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