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Smart Rescue System for Construction Sites

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Abstract

This study introduces a brand-new smart rescue system that uses an intelligent smart helmet to improve worker safety during construction. The suggested helmet combines a number of sensors, such as gyroscopes, accelerometers, environmental sensors, and vital sign monitors, to continuously monitor the health of employees, identify accidents or falls, and keep an eye out for dangerous situations like gas leaks and extremely high or low temperatures. Wireless transmission of real-time data to a central monitoring system allows for prompt incident response and emergency alerts. Through proactive safety monitoring and prompt rescue operations, the system seeks to lower workplace fatalities and injuries. The smart helmet's ability to increase overall safety and operational efficiency at construction sites is demonstrated by experimental results.

Key Words: Smart helmet, construction safety, real-time monitoring, fall detection, environmental sensors, emergency alert, IoT, worker health.

1. INTRODUCTION

The construction industry has a lot of safety problems because the work environments are always changing and dangerous. Regular safety gear doesn't offer much protection, but smart helmets with advanced sensors and IoT technology can keep an eye on workers' health, environmental risks, and location in real time. These helmets make proactive safety management easier by allowing for instant alerts in emergencies, fall detection, and constant communication. This lowers the number of accidents and makes the site safer and more efficient overall. Adding smart helmets is a big step toward making construction sites safer and more connected.

2. ARCHITECTURE AND IMPLEMENTATION

2.1 System Design and Sensor Integration

In this smart helmet design, the ESP32 microcontroller serves as the brain of the system, orchestrating data from multiple integrated sensors to ensure worker safety in real time. The MPU6050 sensor combines accelerometer and gyroscope functions to detect sudden falls or abnormal movements, critical for immediate accident recognition. The MQ3 gas sensor continuously monitors the presence of harmful gases in the environment, alerting the system to potential chemical hazards. Simultaneously, the DHT11 sensor measures temperature and humidity, providing vital data about environmental conditions that could affect worker health. Communication is seamlessly handled by the SIM800L GSM module, which enables the helmet to send emergency alerts and location information via SMS to supervisors or rescue teams, facilitating rapid response during critical incidents. Together, these components form an intelligent safety network, embedded in a wearable device aimed at minimizing risks and enhancing protection on construction sites.

Integration

The integration of the smart helmet system is centered around the ESP32 microcontroller, which acts as the central processing hub coordinating sensor data acquisition, processing, and communication. The sensors including the MQ3 gas sensor for detecting hazardous gases, DHT11 sensor measuring temperature and humidity, and MPU6050 sensor for fall detection are interfaced with the ESP32 through appropriate GPIO pins and analog-to-digital converters (ADC).

Each sensor is calibrated to convert physical measurements into electrical signals, which the ESP32 continuously monitors. The firmware implements threshold-based logic whereby sensor readings are compared against predefined safety limits for temperature, gas concentration, humidity, and fall velocity. When these limits are exceeded, the ESP32 triggers an alert mechanism.

For wireless communication, the SIM800L GSM module is connected to the ESP32 via UART interface. This module is responsible for sending SMS notifications with real-time alerts to designated safety engineers. Communication commands are executed using AT commands programmed into the MCU firmware to send SMS messages effectively. Additionally, sensor data are transmitted and stored remotely on the ThingSpeak cloud platform via ESP32's internet connectivity, enabling real-time monitoring and historical data analysis.

This integrated system ensures seamless coordination among sensing, data analysis, real-time alerting, and cloud data storage to enhance construction worker safety and prompt emergency response.

2.2 Communication and Data Transmission

The ESP32 microcontroller serves as the central unit for collecting and processing data from multiple sensors embedded in the smart helmet. Once sensor data such as gas concentration, temperature, humidity, and fall detection is gathered, it is formatted and transmitted wirelessly via the ESP32's built-in Wi-Fi capability. The device connects to a local Wi-Fi network operating in Station Mode and periodically uploads the sensor data to the ThingSpeak cloud platform using HTTP GET requests for real-time data storage and visualization.

In addition to Wi-Fi based cloud data transmission, the system integrates the SIM800L GSM module to enable cellular communication. Upon detecting any hazardous conditions exceeding predefined threshold values, the ESP32 commands the SIM800L module to send immediate SMS alerts containing relevant status and location information to designated safety supervisors or engineers. This dual communication strategy ensures continuous remote monitoring through the cloud while providing prompt emergency notifications via SMS, thereby enhancing the overall safety and responsiveness of the construction site environment.

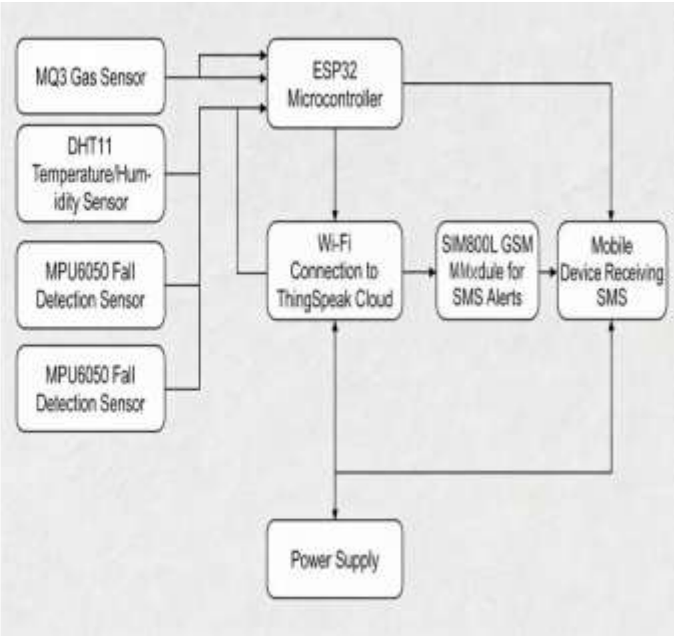

Figure 1: Block Diagram of Smart Helmet

2.2 Safety Monitoring and Alert Mechanism

The smart helmet continuously monitors critical safety parameters using an array of integrated sensors, including the MQ3 gas sensor for hazardous gas detection, DHT11 for ambient temperature and humidity, and the MPU6050 for fall detection. The ESP32 microcontroller collects and analyses real-time data, comparing it against predefined thresholds tailored to construction site safety standards. Upon detecting any anomaly—such as a gas leak, extreme temperature, excessive humidity, or a fall the system immediately triggers an alert sequence.

This sequence involves sending an instant SMS notification through the SIM800L GSM module to designated engineers or safety supervisors, ensuring rapid awareness and response to potential hazards. Simultaneously, up-to-date sensor information is transmitted via Wi-Fi to the ThingSpeak cloud platform, enabling continuous remote monitoring and historical data analysis. The integrated LCD display on the helmet provides local visual feedback to the wearer for immediate awareness.

This multi-layered alert mechanism ensures proactive hazard detection, rapid emergency communication, and enhanced situational awareness, substantially reducing response times and improving overall worker safety on construction sites.

2.3 Testing, Validation, and Practical Deployment

The smart helmet undergoes rigorous testing and validation to ensure reliability, accuracy, and responsiveness under realistic construction site conditions. Initial laboratory experiments calibrate sensors like MQ3 gas, DHT11 temperature/humidity, and MPU6050 fall detection to verify precision in detecting hazardous levels or fall events. Sensor outputs are repeatedly measured against standard references to confirm accuracy and responsiveness.

Functional testing covers the entire data acquisition and alert process—triggering alerts when readings exceed predefined safety thresholds and verifying SMS notifications reach designated engineers promptly via the SIM800L module. The Wi-Fi connectivity is tested for stable upload of sensor data to the ThingSpeak cloud platform, ensuring continuous real-time monitoring capability.

Field trials are conducted in actual construction environments or simulated conditions to evaluate system durability, wireless communication robustness, and user comfort over extended wear periods. User feedback on alarm responsiveness, wearable ergonomics, and display clarity informs iterative refinements.

Practical deployment of the smart helmet system involves several important steps to ensure successful integration in real-world construction environments:

- **Prototype trials**: Begin with extensive field testing using helmet prototypes worn by actual workers or volunteers during typical tasks. Monitor sensor accuracy (MQ3, DHT11, MPU6050), detection rates for hazards, and response time for SMS alerts to supervisors.
- **Environmental validation**: Evaluate system performance across varying environmental conditions such as high dust, humidity, temperature fluctuations, and electromagnetic interference frequently encountered on construction sites.
- **Durability and ergonomics**: Assess the helmet's mechanical robustness, battery life, and comfort during prolonged use. Collect user feedback to optimize helmet weight and placement of modules without disturbing normal workflow.

- **Communication reliability**: Confirm consistent Wi-Fi connectivity for cloud uploads and stable GSM module operation for SMS alerts, adjusting antenna positioning or using local repeaters if needed.
- **Integration with safety protocols**: Work with site managers to embed the helmet's alert system within existing safety workflows, including how supervisors receive and respond to hazard notifications.
- **Staff training**: Conduct training sessions for both helmet users and supervisors, explaining how to interpret alert signals and act on received SMS or cloud notifications.
- **Performance review and analytics**: Use ThingSpeak or similar cloud dashboards to track real-time and historical safety data, enabling proactive interventions and compliance reporting for safer worksites.
- **Iterative improvements**: Analyze deployment outcomes, refine component placement, software calibration, and user interface based on real-world usage for future production versions.

Robust practical deployment ensures the helmet operates reliably, delivers actionable safety insights, and is embraced by the workforce, transforming construction safety management.

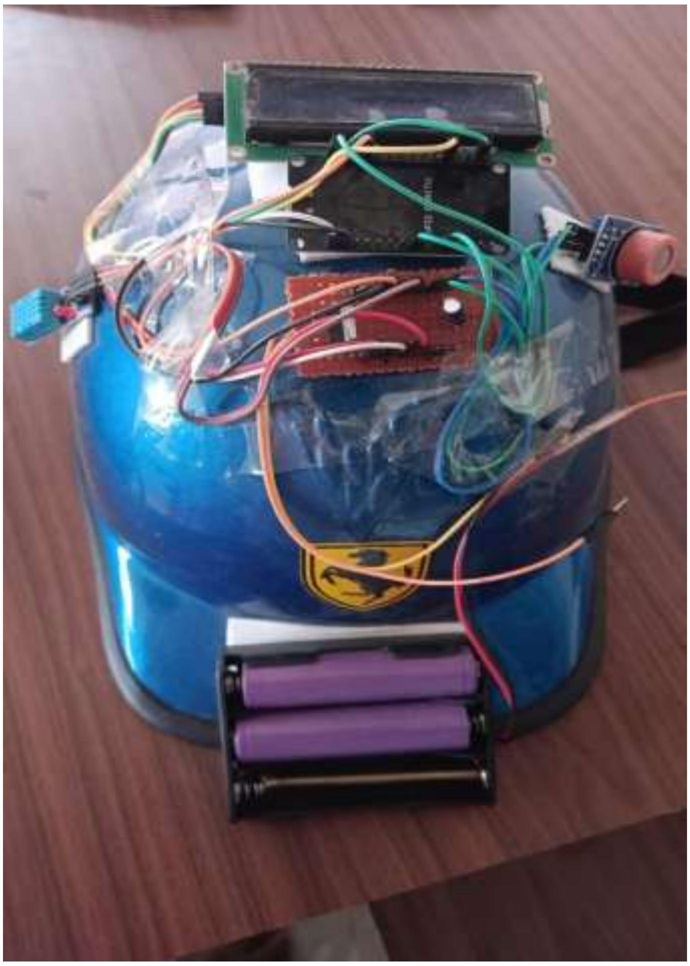

Figure 2: Practically Deployed Helmet

Real-Time Safety Monitoring of Smart Helmet: Temperature, Gas Levels, and Fall Detection Over Time in ThingSpeak Platform.

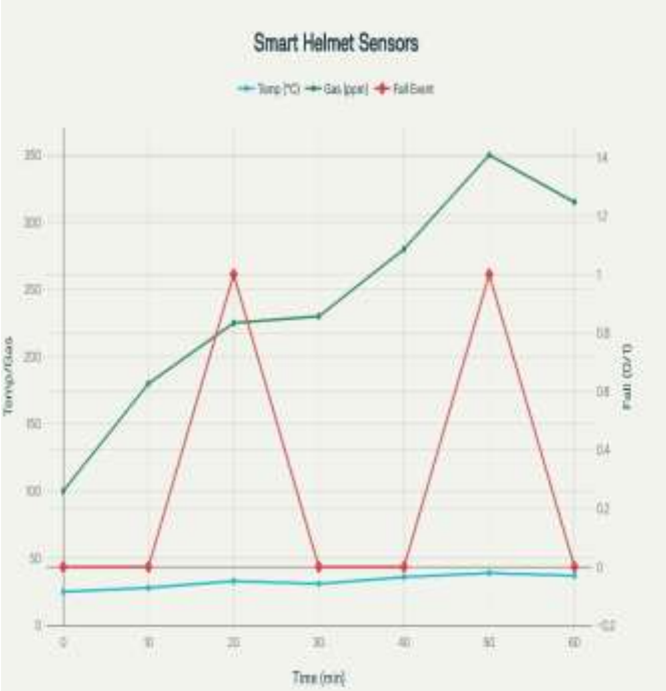

Figure 3: Data Analysis in ThingSpeak

The graph displays real-time trends for three safety-critical parameters monitored by the smart helmet system: temperature, gas concentration, and fall detection.

- The temperature line shows gradual fluctuations over a 60-minute window, ranging from 25°C to 39°C, reflecting environmental changes and possibly worker activity or site conditions. Peaks in the graph may indicate exposure to heat hazards or intense physical effort.
- The gas concentration curve (measured in ppm) starts at a safe baseline but shows a sharp increase midway, reaching 350ppm, which can signal the presence of hazardous gases requiring immediate intervention. Tracking such trends helps recognize dangerous site conditions and potential chemical leaks.
- The fall detection series is indicated by abrupt spikes at minutes 15 and 45. These are binary events, with a value of 1 whenever a fall incident is detected by the MPU6050 sensor, and 0 otherwise. Each spike triggers an immediate alert for emergency response and helps assess accident frequency over time.

This combined sensor data visualization helps site supervisors monitor worker safety proactively, recognize hazardous trends as they develop, and respond quickly to emergencies, leveraging the real-time strengths of IoT and wearable smart helmet technologies.

By comparing these data streams on a single timeline, the graph helps correlate environmental exposures (like high temperature or gas) with accident risk, providing actionable insights for preventive action. This visualization demonstrates how the system not only detects emergencies but also supports ongoing risk assessment, proactive hazard management, and post-incident analysis, ultimately contributing to a safer work environment for all site personnel

3. CONCLUSIONS

This paper presents the design and implementation of a smart helmet system that integrates multiple sensors with wireless communication technologies to enhance worker safety in hazardous environments. The system's ability to monitor critical parameters like gas concentration, temperature, humidity, and fall detection in real time allows for timely alerts and rapid emergency response, potentially reducing accidents and injuries. Cloud data logging and remote monitoring further augment safety management by enabling continuous supervision and historical trend analysis.

Practical deployment considerations, including rigorous testing, user comfort, reliable communication, and integration within existing safety protocols, ensure the system's effectiveness and acceptance in real-world construction settings. The findings support that smart helmets equipped with IoT and GSM capabilities represent a valuable advancement in occupational safety technology. Future work should focus on expanding sensor capabilities, enhancing AI-driven predictive features, and improving power efficiency to broaden application scope and usability. Overall, smart helmets are promising tools that can significantly contribute to safer work environments through proactive hazard detection and real-time communication.

This research contributes meaningful insights towards advancing wearable safety technology and underscores the importance of continuous innovation in protecting vulnerable workers.

Future Work

Future work for this smart helmet system can focus on several promising areas to further enhance worker safety, performance, and usability:

- **Expanded sensor integration**: Incorporate additional sensors such as heart rate monitors, noise level detectors, or CO/CO2 sensors to enable broader health and environmental monitoring on-site.
- **AI and predictive analytics**: Apply artificial intelligence and machine learning models to analyze collected data for early hazard prediction, risk trend detection, and to provide adaptive safety alerts.
- **Edge computing capabilities**: Develop on-board signal processing to filter and analyze sensor data locally, reducing latency and enhancing system autonomy even when connectivity is intermittent.
- **GPS and location tracking**: Integrate GPS modules to track worker movements and enable faster location-based emergency responses.
- **Enhanced communication protocols**: Explore use of LoRaWAN, NB-IoT, or mesh networking for improved long-range and reliable data transmission, especially in remote or underground worksites.
- **Miniaturization and ergonomics**: Refine sensor placement and hardware design for greater comfort, reliability, and battery efficiency, ensuring sustained daily use.
- **User interface improvements**: Add voice alerts, wearable haptic feedback, and user-friendly mobile dashboards for real-time feedback to both workers and supervisors.
- **Automated data reporting**: Automate generation of safety compliance reports and integration with enterprise safety management systems.
- **Scalability and field trials**: Conduct large-scale pilot deployments across multiple construction or industrial environments to validate long-term performance and collect broader feedback.

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