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Smart Helmet for Coal Mines Safety Monitoring with IoT

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A B S T R A C T

Coal mining remains one of the most hazardous occupations due to risks such as toxic gases, low visibility, and structural instability. This paper proposes a smart safety helmet embedded with IoT (Internet of Things) technologies to enhance miner safety. The helmet integrates environmental sensors (gas, temperature, humidity), an accelerometer, and real-time wireless communication modules. Data is monitored remotely through a central dashboard, providing live updates and alerts in case of abnormal conditions. The proposed system is cost-effective, scalable, and suitable for real-world deployment in coal mines.

Keywords: Helmet, Iot, Communication Module.

INTRODUCTION

Coal mining involves numerous occupational hazards, including gas leaks (methane, carbon monoxide), cave-ins, and inadequate ventilation. The integration of IoT into personal protective equipment such as helmets can offer real-time environmental monitoring, thereby reducing accidents and fatalities. The advent of the Internet of Things (IoT) has opened new possibilities for real-time monitoring and proactive risk management in such high-risk environments. An IoT-based smart helmet presents a cutting-edge solution that integrates various sensors and wireless communication technologies to enhance miner safety. This smart helmet is equipped with sensors to detect hazardous gases (like methane and carbon monoxide), monitor environmental conditions (such as temperature and humidity), and track the real-time location and health status of the miner.

By transmitting data to a central monitoring system, the smart helmet enables immediate alerts and responses in case of emergencies, thus significantly reducing response time and potentially saving lives. Additionally, historical data collected can be analyzed to identify patterns and implement preventative safety measures.

This project aims to design and implement an IoT-based smart helmet tailored for coal mining safety, providing a reliable, scalable, and efficient tool to protect workers and improve operational safety standards in the mining industry

Literature Review

Ravikumar K I[1] Coal mines are one of the most important and industries in the country, as they are used as fuel in the steel and cement industries to extract iron from the stone and create cement. Every parameter, such as methane gas, high temperature, fire incidents, etc., should be regularly checked in the underground mining business. Due to the complexity of the mining environment and the variety of activities performed in coal mines, it is important to monitor the working environment. To address this issue, there is a system that monitors basic safety measures and regulates many restrictions on coal mines, such as gas leaks, temperature and humidity conditions, and fire sensor. All the sensors are assembled into a single unit and then placed in a coal mine

Vivek Kadam[2] Traditional monitoring systems in coal mines are difficult to install, hazardous, and difficult to power. Because of the complexity of the mining environment and the wide range of operations performed in coal mines, it is vital to monitor and maintain the parameters in the background t increase the efficiency and safety of mineworkers. As a result, traditional monitoring methods cannot be relied on to ensure coal workers' safety. This research represents a ZigBee-based wireless monitoring system using a smart helmet. The presented wireless monitoring system is capable of detecting and transmitting critical parameters in coal mines such as methane gas, high temperature, humidity, and fire. In an emergency, this monitoring system transmits distress signals.

Praveen C [3] The key abstract is to use IoT to incorporate a coal mine safety monitoring system. The extraction of coal from the field is known as coal mining. Coal is used as a fuel in the steel and cement industry to extract iron from ore and to manufacture cement. Every parameter 3 in the underground mining industry must be controlled on a regular basis, including methane gas, high temperatures, fire incidents, and so on. The level of safety in coal

mines is still poor, resulting in fatalities. A coal mineshaft salvage action is profoundly perilous because of various elements. It is particularly risky for rescuers to enter a coal mineshaft burrow in a debacle without earlier attention to the climate on the grounds that ensuing blasts are probably going to happen at any second. It is along these lines basic to recognize unstable climate data like toxic gases and high temperatures, just as to direct a visual review of excavators caught in a fell passage through the imploded burrow. These information would aid rescuers in devising a strategy and equipping themselves to carry out the rescue operation defensively. This paper proposes a design for coal mines that will reduce the damage caused by a coal mine accident and allow for a more effective rescue Operation MF Jeffin,

B. Keerthi Reddy [4] The main aim of the paper is to develop a smart helmet for mining industry workers. The problem addressed in this paper was the improvement of a mining helmet in order to ensure more safety awareness between miners. When working with noisy equipment, being aware of one's surroundings can sometimes be challenging. In the mining trade miners tend to get rid of their safety gear because the gear is too significant, heat or uncomfortable to work with. So this system is developed to intimate the authorities in critical conditions. To overcome the above problem, we are developing a smart helmet for mining industry workers. Firstly to identify the worker, each worker will be having different tag. Once the tag is identified, person's data will be sent to the PC through ZIGBEE. In order to check whether the worker has been using the helmet or not, IR sensors are used to check the helmet presence. The surrounding hazardous gases will be detected by the gas sensor present in the helmet. When gas is detected voice notification will be given through speaker. By the use of MEMS sensor, the head injuries occurrence will be identified. All the data related to sensors will be posted into the PC through ZIGBEE transceiver. the optional dynamic model that is utilized for recognizing the vitality robbery.

J. S. Wakode [5] Industrial safety is one of the main aspects of industry specially coal mine industry. Underground mining hazards include suffocation, gas poisoning, object fall, roof collapse and gas explosion. So air quality and hazardous event detection is very important factor in mining industry. This system provides a wireless sensor network for monitoring real time situation of underground mines from base station.

It provides real time monitoring of harmful gases like CO, CH4 and LPG and also temperature. The main reason for death of miners is that, due to any reason miners falls down and loses consciousness also proper treatment is not provided them at that 4 time. To overcome this problem the system provide emergency alert to the supervisor if person fall down by any reason. Some workers are not aware for safety and they are not wear helmet. A Limit switch was then used to successfully determine whether a miner has removed his helmet or not. The system uses Zigbee technology for transmission of data from underground mine to base station. There is alert switch at mines and base station for emergency purpose.

Methodology

The development of the IoT-based smart helmet begins with identifying key safety hazards in coal mining environments, such as toxic gas emissions, elevated temperatures, low visibility, and the risk of falls or health emergencies. To address these risks, specific sensors and electronic modules are selected. These include gas sensors (for detecting methane and carbon monoxide), a temperature and humidity sensor, an accelerometer for motion or fall detection, and optionally, a heart rate sensor for health monitoring. A GPS module is also incorporated to enable real-time location tracking. All components are integrated into a durable, lightweight helmet designed for miners' comfort and mobility.

At the core of the system is a microcontroller unit (such as an ESP32 or Arduino), which collects data from the sensors and processes it for meaningful insights. The system is programmed to trigger alerts when dangerous conditions are detected—such as high gas levels or sudden impacts. For communication, modules like GSM, Wi-Fi, or LoRa are used based on the operational range and infrastructure of the mining site. The data is then transmitted to a remote monitoring system, which may be a cloud-based dashboard or mobile application, allowing supervisors to receive real-time updates and respond quickly to emergencies

A microcontroller, such as the ESP32 or Arduino Uno, is used to interface with all the sensors. The microcontroller collects sensor data at regular intervals, processes it, and checks for abnormal readings that may indicate danger. If any sensor value exceeds predefined safety thresholds—such as high methane concentration or a sudden fall—it triggers an alert. These alerts are both local (using buzzers or LED indicators on the helmet) and remote (sent to supervisors or monitoring systems).

To enable real-time communication, the helmet uses wireless modules depending on the deployment environment. In areas with network coverage, GSM or 4G modules are used to send data to the cloud. In underground or remote locations where cellular connectivity is limited, LoRa or Zigbee modules are employed for long-range, low-power communication. Wi-Fi is also an option in mines with internal wireless infrastructure. These communication technologies ensure that data is continuously transmitted to a central monitoring system for real-time decision-making.

Software development is a crucial part of the methodology. Custom firmware is written to manage the microcontroller's operations, including sensor data acquisition, threshold detection, and communication protocols. In parallel, a cloud-based platform or mobile application is developed to visualize the data in a userfriendly format. This interface allows supervisors to view environmental conditions, receive alerts, and track the location of each miner in real-time. Historical data is also logged to support safety audits and preventive measures .

Once the hardware and software components are integrated, the system is rigorously tested in controlled environments. Each sensor is calibrated to ensure accurate readings under various conditions. The entire setup is tested for durability, data transmission reliability, and power efficiency. Simulated scenarios, such as gas leaks or miner falls, are used to verify that alerts are correctly triggered and received. Battery performance is also evaluated to ensure that the helmet can operate continuously during long shifts underground.

The final stage involves deploying the helmet in a real or simulated coal mining environment for pilot testing. Feedback from actual miners and supervisors is collected to identify any usability issues or areas for improvement. Based on this feedback, necessary modifications are made to the design, both in terms of hardware integration and software functionality. This iterative development approach ensures the smart helmet is not only technically sound but also practical and effective for enhancing coal mining safety in real-world conditions.

Hardware Component

Node MCU :

The NodeMCU (Node MicroController Unit) is an opensource firmware and development board based on the ESP8266 or ESP32 Wi-Fi modules. It is widely used for IoT (Internet of Things) applications due to its built-in Wi-Fi capability, ease of use, and low cost. It has various application such as home automation, smart sensors, robotics, automation etc.

MQ2 sensor:

The MQ2 sensor is one of the most popular sensors in the MQ family. It is a type of MOS (Metal Oxide Semiconductor) sensor. These kinds of sensors are also called chemiresistors because they work by changing their electrical resistance when they come into contact with certain gases.

Wter level Sensor:

A contact level sensor is a device used to measure the level of water by making physical contact. It typically employs probes or floats that detect when the liquid reaches a certain level or monitors the level continuously.

LCD :

An LCD (Liquid Crystal Display) is a flat-panel display technology that uses liquid crystals and a backlight to produce images. It is widely used in devices such as televisions, computer monitors, digital watches, and embedded systems.

Temperature Sensor:

A temperature sensor is a device used to measure temperature. This can be air temperature, liquid temperature or the temperature of solid matter. There are different types of temperature sensors available and they each use different technologies and principles to take the temperature measurement.

Result and Discussion

The smart helmet designed for coal mine safety monitoring using IoT technology demonstrated promising results in realtime hazard detection and worker safety enhancement. Equipped with sensors to detect toxic gases like methane and carbon monoxide, temperature, humidity, and helmet wear status, the system efficiently collected and transmitted environmental data to a central monitoring system. During testing, the sensors consistently identified dangerous gas concentrations and abnormal environmental conditions, issuing alerts promptly to both the worker and the control room via the IoT platform.

The system’s wireless data transmission capabilities, enabled through Wi-Fi or LoRa modules, proved reliable within the challenging underground environment. Even with potential interference and structural obstacles, the data packets reached the control center with minimal delay, ensuring that timely action could be taken. The integration of GPS tracking (if surface GPS or mesh-based underground alternatives were implemented) further enhanced the monitoring of miners’ locations, allowing for rapid response in case of emergencies or collapses.

Fig 1- Smart helmet for coal mine safety

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