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Intelligent IoT-Based Helmet for Coal Miner's Safety with Lock System

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Abstract **- Mining remains one of the world's most hazardous industries, where workers frequently encounter unpredictable and unsafe underground conditions. Traditional protective gear, such as helmets, primarily offers passive safety and lacks the ability to monitor physiological or environmental conditions in real time. Recent developments in the Internet of Things (IoT) have enabled the creation of intelligent safety equipment that can actively monitor and report potential threats. This review highlights the design and application of an IoT-integrated Smart Helmet System intended to strengthen occupational safety standards in coal mining environments. A central feature of this system is the incorporation of a helmet lock verification circuit, designed using an active-high digital logic configuration. This mechanism ensures that the safety module becomes operational only when the helmet is properly secured, thereby reinforcing compliance with safety requirements. In addition, a built-in timer records the total duration of helmet use, facilitating accurate logging of working hours and personnel attendance. The proposed system employs multiple sensors to continuously measure parameters such as oxygen concentration, toxic gas levels, and the miner's body temperature. The collected data are processed through a NodeMCU ESP8266 microcontroller and transmitted wirelessly to a cloud-based platform— specifically, the Blynk application— for centralized supervision. Real time access to this information enables control room operators and medical staff to assess worker safety conditions continuously. Whenever the system detects hazardous variations, such as reduced oxygen or elevated toxic gas concentrations, it activates immediate warning signals using a buzzer and LED indicators. These alerts provide both local and remote notifications, allowing rapid response and minimizing the delay in emergency interventions. Such prompt communication enhances situational awareness and can significantly reduce the risk of severe incidents. The Smart Helmet operates on a rechargeable lithium-ion battery, supporting uninterrupted performance throughout an entire work shift. By combining sensor technology, IoT-based data transmission, and cloud monitoring into a single wearable device, this system offers a reliable and cost-effective approach for improving safety and efficiency in underground mining operations. The integration of intelligent sensing and communication mechanisms demonstrates the growing potential of IoT solutions in transforming industrial safety frameworks.**

Keywords**—- IoT, Smart Helmet, Coal Mining, Gas Detection, Biometric Monitoring, Worker Safety, Sensor Networks, Real-Time Alerts, Wireless Communication component.**

I.INTRODUCTION

Mining has long been recognized as one of the most physically demanding and hazardous occupations. Miners frequently operate deep beneath the earth's surface, where they are continuously exposed to unstable geological structures, toxic gases, high temperatures, limited ventilation, and unpredictable environmental conditions. In such confined and challenging surroundings, every movement carries risk. Conventional safety helmets used in mining offer essential mechanical protection but lack the capability to detect environmental threats or monitor a worker's physiological condition. As mining operations modernize, there is a pressing need for intelligent safety systems that go beyond passive protection. To address these challenges, this research proposes an advanced safety solution titled "IoT- Based Smart Helmet with Lock System for Coal Miner Safety." Unlike a traditional helmet that functioning merely as a physical barrier, the proposed system acts as a comprehensive, sensor- driven monitoring device. It integrates various IoT technologies to provide real-time tracking of the miner's health parameters and environmental conditions, enabling a shift from reactive safety to proactive risk prevention. A key innovation of the system is its intelligent helmet locking mechanism, designed to ensure compliance with safety protocols. The helmet remains non-

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functional unless securely fastened. Once the lock is engaged, an internal timer is activated to record the total duration the helmet is worn. This timing data can be used to monitor working hours, exposure time inside the mine, and can directly assist in attendance records and wage calculation, ensuring transparency and accountability. Environmental safety is strengthened through the integration of an MQ-series gas sensor, capable of detecting hazardous gases commonly found in coal mines, such as methane and carbon monoxide. When gas concentrations exceed predefined safety limits, the system triggers an alert sequence: a red LED illuminates and a buzzer activates, with the buzzer's intensity increasing relative to the severity of the threat. Under normal operating conditions, a green LED remains lit, providing miners with a clear visual indication of a safe environment. To safeguard worker health, the helmet incorporates multiple biomedical sensing technologies. The MAX30100 optical sensor continuously measures heart rate and peripheral oxygen saturation (SpO_2). These parameters are critical for detecting early symptoms of fatigue, low oxygen availability, or respiratory distress—conditions that can rapidly escalate in underground environments. Additionally, a DHT11 temperature sensor is placed inside the helmet to measure the worker's body temperature rather than ambient temperature. This feature helps detect signs of heat stress, dehydration, fever, or other physiological abnormalities that may compromise a miner's endurance or cognitive performance. All sensor outputs—including gas concentration, heart rate, oxygen saturation, and body temperature—are processed by the NodeMCU ESP8266 microcontroller, which provides built-in Wi-Fi connectivity for seamless data transmission. The collected data is transmitted in real time to a cloud- based Blynk application, where supervisors, safety officers, and medical personnel can remotely monitor each miner's status. This enables rapid decision-making during emergencies, supporting timely medical intervention and evacuation procedures. The entire system is powered by a rechargeable lithium-ion battery, selected for its lightweight structure, high energy density, and capacity to sustain long operational hours. This ensures reliable performance throughout a miner's work shift without frequent recharging. Overall, the proposed smart helmet system serves as an intelligent protector—continuously sensing, analyzing, and communicating crucial safety information. By integrating environmental monitoring, physiological assessment, safety compliance, and real-time connectivity, it transitions mining safety protocols from passive protection to dynamic, data-driven, and responsive safety management. This system demonstrates how IoT can bridge the gap between underground hazards and above- ground allows early identification of hazardous gas supervision, potentially reducing fatal accidents and enhancing the overall safety infrastructure within the mining industry.

II. . LITERATURE SURVEY

Several studies have explored IoT-enabled smart helmets for improving underground mining safety. Early research introduced safety-integrated helmets equipped with gas sensors and wireless communication modules. These systems demonstrated clear potential in reducing accidents; however, many lacked real-world validation, limiting their practical deployment. Other works focused on combining IoT and wearable technologies using platforms such as Zigbee and Wi Fi. While these studies showed effective hazard detection, issues such as signal interference and sensor instability were frequently reported. advancements in Additional sensor research technologies, examined including accelerometers, gyroscopes, and gas detectors. These sensors provided real-time hazard awareness but were rarely tested across diverse underground conditions. Case-based studies evaluated smart helmets in controlled hazardous environments, showing reliable gas detection and alerting performance. Nonetheless, scalability concerns and limited large-scale trials were noted. Some designs integrated biometric monitoring and alert modules, proving useful in accident prevention, though ergonomic aspects and user comfort remained underexplored. Energy-efficient smart helmet systems have also been proposed, using low-power sensors and optimized communication protocols to support long mining shifts. Comprehensive systems incorporating gas sensors (MQ-series), temperature sensors (DHT11), LDR modules, and mobile app dashboards further demonstrated the feasibility of real-time safety monitoring. Despite promising outcomes, recurring challenges—including battery maintenance, communication instability, minimal field testing, and lack of ergonomic refinement—highlight the need for further research and practical implementation in actual mining environments.

2.1 Sensing Module

The sensor module forms the foundational layer of the proposed smart helmet system and is responsible for continuously monitoring both environmental conditions and the miner's physiological well-being. This module integrates multiple sensors that collectively enable comprehensive situational awareness, making it a critical component for ensuring operational safety in underground coal mines. A primary element of this module is the MQ-series gas sensor, widely used for industrial safety due to its high sensitivity to combustible and toxic gases. In coal mining environments, gases such as methane (CH_4) and carbon monoxide (CO) are major contributors to explosions, suffocation incidents, and ventilation failures. The MQ sensor continuously measures gas concentration levels in the ambient air and provides real- time analog signals corresponding to the detected gas density. When the concentration exceeds predefined safety thresholds, the sensor output activates warning mechanisms. This instantaneous detection capability build up,significantly reducing the likelihood of catastrophic events. In addition to environmental monitoring, the sensor module also incorporates biometric sensing to track the miner's physiological status. The MAX30100 pulse oximetry sensor uses infrared and red LEDs to measure heart rate and peripheral oxygen saturation (SpO_2). These parameters are crucial indicators of a miner's respiratory health and oxygen intake levels, which can be adversely affected in poorly ventilated underground settings. Sudden variations in SpO_2 or heart rate may signal conditions such as hypoxia, extreme fatigue, or respiratory distress, enabling timely intervention. Furthermore, the DHT11 temperature sensor is included to monitor the miner's body temperature rather than the environmental temperature. Underground mines are known for high humidity and heat exposure, which can thermal stress, dehydration, or fever. By capturing the worker's internal temperature, the sensor helps identify early symptoms of heat-related illnesses, ensuring physical safety during extended working hours. The real-time data generated by these sensors provides a continuous stream of environmental and

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physiological information that reflects both external threats (toxic gases, poor air quality) and internal health risks (reduced oxygen levels, elevated body temperature). By combining multiple sensing modalities, the module ensures that the helmet operates as an intelligent monitoring system rather than a purely mechanical protective device. Without this integrated sensor suite, the smart helmet would be unable to detect hazards or collect critical health data, making automated safety assessment and emergency alerting impossible.

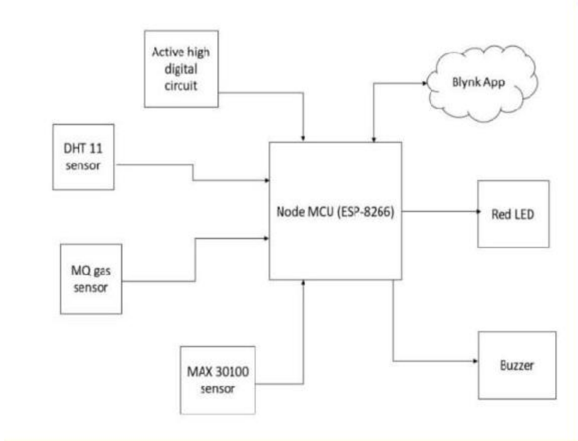
2.2 Microcontroller (Node MCU - ESP8266)

The Node MCU ESP8266 functions as the central processing and communication unit of the proposed smart helmet system. It integrates both computational capability and wireless connectivity, making it essential for acquiring, analyzing, and transmitting sensor data. All sensing modules—including gas sensors, biometric sensors, and temperature sensors—are interfaced directly with the ESP8266, allowing it to continuously gather real-time information from the miner's surroundings and vital parameters. The microcontroller executes the logical operations required to interpret sensor readings and classify environmental conditions as either safe or potentially hazardous. This includes comparing measured values with predefined safety thresholds and initiating corresponding actions. For instance, when abnormal gas concentration or irregular health parameters are detected, the NodeMCU activates local alert mechanisms such as LEDs and buzzers. It also interacts with the helmet-lock detection system, ensuring that monitoring begins only when the helmet is properly secured. One of the key strengths of the ESP8266 is its integrated Wi-Fi module, which enables seamless communication with cloud-based platforms, notably the blynk server. Through this wireless link, the helmet transmits sensor data to remote dashboards where supervisors, safety personnel, and medical responders can monitor miners in real time. This remote visibility enhances situational awareness and shortens response time during emergencies. Beyond data transmission, the NodeMCU supports efficient power management and lightweight computation, making it suitable for battery-operated wearable systems used in harsh underground environments. Without this microcontroller, the smart helmet would lack the ability to process sensor outputs, make autonomous safety decisions, or facilitate wireless data exchange—functions that are fundamental for an IoT-based safety device.

III. METHODOLOGY

3.1 Proposed Block Diagram

The proposed smart helmet system is designed using the Node MCU ESP8266 as the central controller, functioning as the intelligence hub of the entire architecture. All sensing modules, safety circuits, and communication components interface with the microcontroller, enabling continuous monitoring, local decision-making, and wireless data transmission. Figure-based explanations may be added as per IEEE format.



The operation of the helmet begins with a helmet-lock verification mechanism based on an active-high digital circuit. This circuit ensures that the system becomes operational only when the helmet strap is securely fastened. The safety lock mechanism prevents workers from bypassing mandatory safety protocols. Once the lock is engaged, the microcontroller initiates an internal timer that records the duration for which the helmet is worn. This timing information is valuable not only for ensuring safety compliance but also for shift tracking, attendance monitoring, and supporting payroll calculation based on actual working hours inside the mine. Environmental safety is monitored through an MQ-series gas sensor, responsible for detecting flammable and toxic gases such as methane and carbon monoxide—common threats in underground mining. The sensor provides continuous analog readings to the NodeMCU, which compares the values with predefined threshold limits. If gas concentration rises beyond safe levels, the system immediately triggers a red LED indicator and activates a buzzer alarm, with the buzzer intensity increasing proportionally to the severity of the gas hazard. This ensures that miners receive instant, clear warnings even in noisy underground environments. To ensure the health and well-being of miners, the system incorporates a MAX30100 optical biometric sensor, which continuously measures heart rate and blood oxygen saturation (SpO_2). These parameters help identify early signs of fatigue, hypoxia, or stress—conditions that can escalate rapidly in underground settings with limited oxygen availability. The real-time health monitoring capability ensures that any abnormal physiological changes are detected promptly. The DHT11 temperature sensor is positioned inside the helmet to capture the miner's internal body temperature rather than ambient temperature. Sudden or sustained increases in body temperature may indicate heat exhaustion, dehydration, infection, or other health risks. As underground mines often involve high humidity and physical exertion, temperature monitoring plays a critical role in preventing medical emergencies. All sensor data—including gas concentration, heart rate, oxygen saturation, and body temperature—is collected and processed by the Node MCU ESP8266. The microcontroller then transmits the processed data wirelessly to the Blynk cloud platform, leveraging its built-in Wi-Fi capabilities. Through the Blynk mobile application, supervisors, safety officers, and medical personnel can monitor miners' status in real time. The cloud server handles data storage, updates, and forwarding, ensuring that critical information is displayed instantly on the mobile dashboard.

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The entire helmet operates on a rechargeable lithium-ion battery, selected for its high energy density, lightweight nature, and suitability for long-duration usage. The system is designed to optimize power consumption, enabling stable performance throughout extended mining shifts without frequent recharging. The methodology integrates environmental sensing, physiological monitoring, cloud communication, and local alert mechanisms into a unified system. This ensures that both internal (health-related) and external (environmental) threats are detected in real time. The combination of hardware reliability, software intelligence, and IoT connectivity provides miners with continuous safety supervision and supports rapid intervention during emergencies. Thus, the proposed smart helmet transforms traditional passive safety gear into an active, intelligent protective system tailored for high-risk underground environments. The operational flow of the proposed smart helmet begins with system initialization, followed by a mandatory helmet-lock verification that ensures the device activates only when worn securely. Once enabled, the system performs environmental monitoring through gas sensors to detect toxic or flammable gases, and simultaneously measures the worker's body temperature to identify signs of heat stress or illness. The helmet then conducts continuous physiological monitoring using heart rate and SpO_2 sensors to detect irregularities such as fatigue or oxygen deficiency. All collected data is processed by the controller and transmitted wirelessly to the Blynk cloud platform, where it becomes accessible to supervisors in real time through a dashboard interface. This structured sequence ensures a comprehensive and continuous safety assessment of both the miner and the surrounding environment. In summary, this streamlined operational sequence transforms a conventional helmet into an intelligent, IoT-enabled safety system capable of continuously evaluating both environmental hazards and worker health conditions. By integrating sensor data acquisition, automated safety checks, and real-time cloud based monitoring, the helmet ensures that critical information reaches supervisors without delay, enabling timely interventions during emergencies. This closed-loop process not only enhances underground situational awareness but also provides miners with an additional layer of active protection, ultimately strengthening overall safety management in coal mining operations.

IV. ADVANTAGES & DISADVANTAGES

4.1 Advantages:

1) Toxic gas concentration, heart rate, oxygen saturation (SpO_2), and body temperature. This uninterrupted flow of data ensures that both the miner and monitoring personnel are aware of any abnormal changes as soon as they occur. Real-time monitoring is essential in underground mines where conditions can deteriorate rapidly without visible warning signs.

2) Early Warning System When the helmet detects any dangerous condition, such as elevated gas levels or abnormal health readings, it instantly activates a red LED and an audible buzzer. These alerts help miners recognize threats immediately, even in noisy or low visibility environments. Simultaneously, the alert information is sent to the control room, allowing supervisors to respond quickly and coordinate emergency actions.

3) Prevents Bypass of Safety Protocols The helmet includes a lock-detection mechanism that ensures the system activates only when the helmet is securely worn. This prevents workers from avoiding safety procedures or removing their helmets during operation.

4) Remote Access for Supervisors and Medical Teams Through the Blynk cloud platform, the helmet transmits live data to a remote dashboard accessible via smartphones or computers. This remote accessibility enables supervisors and medical personnel to monitor multiple miners simultaneously, regardless of their location. It also ensures that critical information is available instantly during emergencies, improving decision making and coordination.

5) Health-Based Emergency Response The continuous monitoring of vitals such as heart rate, SpO_2, and body temperature helps medical staff anticipate health-related emergencies. Early detection of issues like oxygen deprivation, fatigue, or heat stress allows doctors to prepare essential treatment before the miner reaches the surface, significantly reducing the overall response time and improving survival outcomes.

6) Improves Safety Compliance The smart helmet supports automatic monitoring and logging of safety-related events, helping organizations ensure that miners follow established safety regulations. This reduces the dependence on manual inspections and improves accountability. Automated compliance reinforces a safer working culture and decreases the likelihood of preventable accidents.

7) Cloud Storage and Analytics Sensor data is stored on the cloud, enabling long-term analysis of environmental conditions and worker health trends. This historical data is valuable for generating safety reports, identifying recurring hazards, optimizing mine operations, and supporting regulatory documentation. It also helps in predictive analysis to prevent future accidents.

8) Worker Shift Tracking The system includes a timer that begins once the helmet is locked. This provides an accurate record of the time a miner spends inside the mine. Such information is useful for managing worker schedules, calculating payroll based on actual working hours, and ensuring that no miner exceeds the recommended exposure limits in hazardous environments.

4.2 Disadvantages:

1) Cost of Implementation Implementing the smart helmet system on a large scale can be expensive due to the cost of multiple sensors, microcontrollers, batteries, and wireless communication modules. Mines with limited budgets may find it challenging to deploy such advanced technology across their entire workforce. Additionally, maintenance and periodic calibration of sensors add to operational expenses.

2) Battery Dependency The smart helmet relies on a rechargeable lithium-ion battery to power all sensors, communication modules, and alert systems. Continuous real-time monitoring consumes energy, which may result in shorter battery life during long shifts. This requires frequent charging or battery replacement, which can interrupt workflow and increase maintenance requirements.

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V. APPLICATIONS

1. Identifies the presence of toxic or flammable gases (e.g., methane, CO) using MQ sensors to prevent explosions and poisoning.

2. Tracks heart rate and blood oxygen levels using the MAX30100 sensor to detect stress, fatigue, or hypoxia.

3. Monitors the miner's body temperature with the DHT11 sensor to detect heat stress or illness.

4. Ensures the helmet is properly worn using an active high digital circuit; the system only activates when securely locked.

5. Helps doctors prepare in advance if a miner's health parameters drop below safety levels.

6. Minimizes the chances of accidents and enables faster response, ensuring miner safety in hazardous environments.

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