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IOT Integrated Smart Helmet for Enhanced Miner Safety

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Abstract : Mining comes under the most dangerous industries, with workers being exposed to risks at every moment in the form of hazardous gases, high heat, and accidents. This paper proposes a smart helmet which try to improve miners' safety through IoT based sensors with real-time monitoring. The device revolves around a NodeMCU-ESP8266 microcontroller, which accepts, processes data taken from sensor , such as the MQ2 which detect poisonous gases, the DHT11 for temperature and humidity, an da GPS module to check the miner's location. Sensor readings in real-time are displayed on a monitoring station, while a buzzer is utilized for audible alarms under dangerous situations and a buzzer is used for audible alarm during hazardous situations. In addition, an emergency pushbutton allows miners to report emergency messages or indicate device failure. By merging traditional method with IoT based monitoring, this solution takes mining safety to the good level helping to prevent accidents and respond quickly when emergencies happen.

IndexTerms **- Smart Helmet, IoT, GPS Tracking, Miner Safety, Environmental Monitoring, Real-Time Alerts.**

I. INTRODUCTION

Mining is one of the most dangerous job in world ,in which workers faced to many hazards includes toxic gases, high temperatures, and chance of collapse. While few developments have integrated an modern technologies into mining , most safety systems still depend on heavy manual check and responses, which usually fail to prevent accidents or react quickly during emergencies. This becomes more obvious in underground mining where visibility is poor and communication is limited thus making safety very challenging.

The IoT and wearable technologies offer an unparalleled opportunity to transport miner safety to this revolution with smart devices. Technologies make it easier to monitor the location in real time and send automatic alerts and track locations, helping to keep workers safe and respond quickly in serious situation. A smart helmet with sensors and communication modules is perfect because it continuously reads gas level, temperature, and humidity as well as locational tracking of the worker.

Project introduces a smart helmet system featuring an MQ-2 gas sensor, a DHT11 temperature and humidity sensor, a GPS module and all connected to NodeMCU ESP8266 microcontroller. Real time facts is shown on monitor screen, and a buzzer generates immediate alerts in serious situations. Additionally, a manual pushbutton allows miners to report malfunctions or critical incidents. By integrating IoT with traditional safety gear, this system delivers prompt warnings and bridges the gap between existing safety measures and cutting-edge technology, providing a reliable and scalable solution for enhancing miner safety which can save government budget by buying this small price helmets instead of ordering and costliest machines and giving priceless lives after the incidence.

II. LITERATURE SURVEY

A lot of research has been conducted on how wearable technology and IoT can be used to increase the safety of workers in risky industries such as mining. Singh et al. (2020) talked about how IoT can utilize real-time environmental sensing to illustrate how sensor networks can be merged and utilized to sense dangerous gases and high temperatures. Their research emphasized the cost effectiveness of MQ-series gas sensors in air quality monitoring and also the difficulty of calibrating such sensors for a particular type of gas. In mining uses, Kumar et al. (2018) outlined the use of MQ-135 and MQ-2 sensors for detection of methane (CH_4) and carbon monoxide (CO), which are common in underground settings. While sensors shown adequately performance in laboratory settings studies focused on frequent adjust and heavy duty casings to ensure maintaining reliability under humid and dusty conditions.

Bhardwaj and Gupta (2021) discussed multi-modal warning systems in danger zones. The authors determined that the combination of visual and sound alerts was more good in loud environments such as mines, where alarms that utilize only sound alone might go undetected. The addition of aspects such as LED indicators or vibration feedback was recommended to improve the overall alerting system.

Patel et al. (2019) designed an IoT-based industrial helmet that was integrated with GPS and gas sensing capabilities. Their system lacked a fault reporting feature that would ensure safe failures. This has been addressed in the present project by incorporating a manual pushbutton for fault reporting and emergency alert.

Ester et al. (1996) proposed density-based spatial clustering algorithms for the control the noise and outliers in environmental information. These all algorithms can improve accuracy of sensors by removing temporary outliers.

Other technological advancements in IoT-based safety devices were observed by Rana et al. (2022), who researched wearable technologies to monitor health. They highlighted the integration of physiological sensors like heart rate sensors and oxygen saturation sensors to produce an efficient safety solution. This is consistent with the future use of the current project.

III. OBJECTIVE

The goal of this project is that to make this helmet with IOT based tech to checking its real time condition. It check the various condition like temperature, humidity, concentration of gas using sensor to observe everytime. It also consist of GPS module which gives us location of miner so that anything happens station gives quick reply. As it can send quick information to station. In the device we also add alarming system by adding the buzzer which can signal by alert buzzer upon receiving danger reading. The helmet has one pushbutton also which can use by miner to give information of danger situation in mining to radio monitoring situation if other system fails to do it

By including such functionality in a less but efficient and good way, the helmet is an active method to lower the risk and enhancing safety within mining area and to miners.

IV. METHODOLOGY

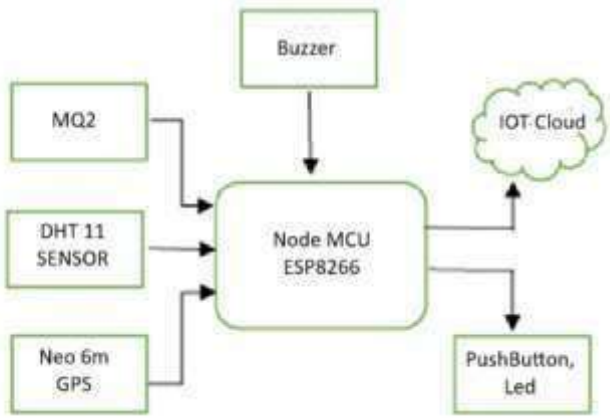
The device which is helmet was made using several function using design process applying IoT technologies, sensors. It also have communication modules to provide a safety feature. In the regular surveys the surrounding environment by sensing the levels of gases, temperature, humidity, and the position of the miner. Based on real-time data given to station and warnings, the helmet strongly enhance safety under risky mining moment.

A. System Design and Components

The system mainly use the NodeMCU ESP8266 microcontroller, which processes sensor data efficiently and do the good communication between and using various components. MQ2 gas sensor is used to get methane and propane gases, in mining environments. It monitor gas concentrations level and notify us if the levels increases then the safety limits, which indicate danger like gas leaks. The DHT11 sensor is used to detect temperature and humidity, also a key factor for operations in mines. false conditions can occur due to high temperatures or high level, resulting into increase of the risk for incident to happen. These sensors gather critical environment information to save the miners.

The system also works efficiently with a NEO-6M GPS module for real-time location mapping, in emergencies to get their location which turns out to be an essential feature. This functionality enables supervisors to quickly identify the precise location of a miner who may require help. Environment data, including gas concentration levels, temperature, humidity, and location are displayed on screen providing miners with a detail insight of their surroundings.

An integral part of the safety mechanism is Buzzer, when kept ON it continuously monitors the surroundings and immediately sets out an alarm as soon as the safety limits of monitored thresholds are breached. Additionally, a manual pushbutton is also provided for miners, to report any malfunctions or emergencies directly.



B. Data Flow and Communication

The system continuously gathers the information from the sensors which is further received by microcontroller and then processed. Information from the gas sensor, temperature and humidity sensor, and GPS module is delivered to the NodeMCU via pins. The microcontroller checks this data for safety limits If any parameter cross these thresholds, immediately NodeMCU triggers the buzzer, to alert the miners of possible dangers. At the same time, sensor measurements, such as GPS coordinates, provides real-time environmental information for awareness of the miners.

Calculating AQI:- The Air Quality Index (AQI) is calculated based on the MQ2 gas sensor, which senses chemical like CO, LPG, and smoke. The sensor gives an analog voltage output, which is translated into ppm (parts per million) based on the formula:

$$PPM = A \times (R_S/R_0)^B$$

where:

RS= Sensor resistance in gas

R0= Sensor resistance in clean air

A,B=Gas-specific coefficients (from the MQ2 datasheet) The AQI is derived using linear interpolation:

$$AQI = \frac{(I_H - I_L)}{(C_H - C_L)} \times (C - C_L) + I_L$$

where:

C= PPM

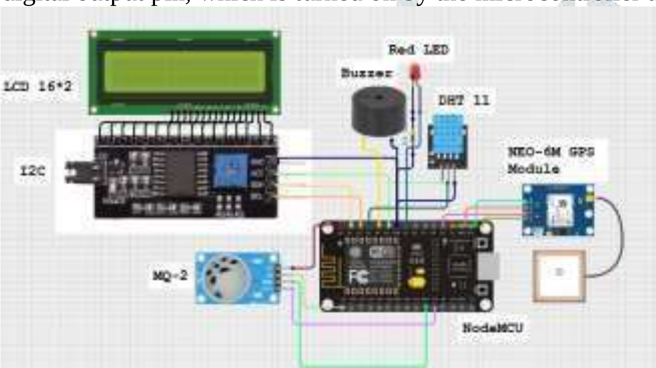
CL,CH= Lower and upper ppm limits for an AQI category

IL,IH= Corresponding AQI values

The pushbutton acts as a manual control mechanism. When we pressed, it sends a signal to the microcontroller, which trigger an alert to a central monitoring system or supervisor. This feature allows miners to report any issues such as equipment problems or any emergency situations. By merging automatic alerts with manual reporting, the system remains consistently good even if a sensor malfunctions.

C. Power Management and Circuit Design

The system is powered at 3.3V, which is suitable with the NodeMCU and other parts, sourcing power in a stable manner for continuous use in the field. The circuit is built with simplicity and configurability in mind and ensuring connectivity between each device and the microcontroller. The MQ-2 gas sensor is connected to an analog pin, with the DHT11 sensor using a digital pin for data transfer. The I2C LCD is communicated with using the SDA and SCL pins to display data efficiently. The GPS module is implemented with the UART pins, and the microcontroller processes location data in real-time. The buzzer is controlled through a digital output pin, which is turned on by the microcontroller as required to send out warnings.



Since the system is planned for repeated use in challenging environments, power efficiency is essential. The sensors and microcontroller are both use the least amount of power possible to provide extended use, especially in remote or underground regions with restricted access to charging facilities. Future upgrades may include a good integrating solar charging or other renewable power sources to provide even greater extension of the system's runtime and dependability.

D. Testing and Calibration

Before being used in a mining environment, the system undergoes carefully testing and configuration to ensure accurate sensor readings. The MQ-2 gas sensor is calibrated in various environments to guarantee its appropriate response to gases such as methane and propane, which are common in mining locations. Calibration is also done under controlled and actual environments to cover variables such as temperature and humidity, which could affect sensor precision. In the same manner, the DHT11 sensor is calibrated against known standards for temperature and humidity in order to ensure its reading will be within acceptable tolerances. The GPS module goes through location accuracy testing under open-air and simulated underground environments.

Whereas the GPS excels under open sky conditions, extra tests are conducted to measure possible loss of signal or delay problems where the GPS has weak coverage, for example, very deep underground tunnels. In an effort to taking action in such obstacles, future revisions of the system could integrate hybrid location technologies such as inertial measurement units (IMUs) or RF based positioning systems that may provide a accurate location tracking in zones of weak or no GPS signal.

E. Integration and System Validation

After testing and calibrating each sensors individually the system was put together into a prototype helmet. Them the completed prototype was put into a controlled mining environment to reproduce the real-world conditions. During this testing the responsiveness of the alert system, the accuracy of sensor readings, and the effectiveness of GPS tracking were thoroughly tested under different environmental scenarios. The GPS module successfully provided the system with the precise location updates in open areas, while the special availability of the Push Button helped the miners with manual report of the emergencies and the malfunctions.

The system was also tested for the brief period of time while taking into the consideration the long term use. This testing mainly paid the attention on sensor drift, potential component failures, and the ability to maintain stable communication between the sensors and the microcontroller. While the system showed strong reliability, areas for improvement were identified, particularly in sensor calibration, power management, and GPS performance in underground environments.

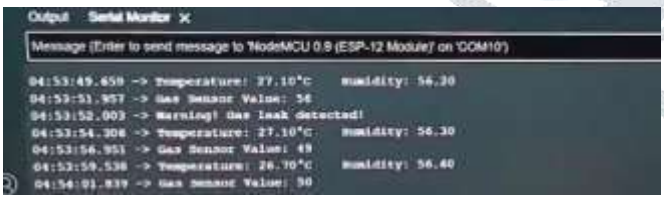
V. RESULTS AND DISCUSSION

The smart helmet system was evaluated in control environments to nature its performance, reliability, and response under simulated hazardous conditions. The performance shows that the system adequately fulfill its task of real-time monitoring, hazard detection, and alerting. Necessary features like sensor precision and accuracy, response times, alerting capabilities, and location mapping were precisely examined, and the results are discussed below.

Environmental Monitoring and Sensor Performance

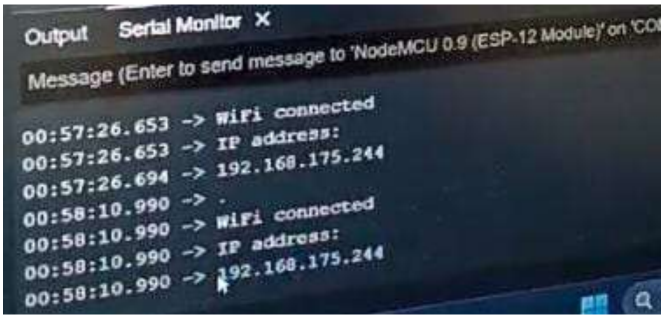
The MQ-2 gas sensor properly detected hazardous gases such as methane and propane, with frequent alarms given when gas concentrations were more than 300 ppm. Afterward, we calculated AQI accordingly. Sensor calibration delivered stable output, while meter variances in accuracy of various percentage points were noticed while there was high humidity, and frequent recalibration was needed to deliver stable performance over a long period. The DHT11 provided humidity and temperature readings with an error margin of less than ±2%. It properly detected environmental changes, like heat rises that can signal overheating, or an increase in the humidity level, which can potentially signal unsafe scenarios, and furnished the miner with real-time awareness of the environments.

:Environmental Monitoring Gauge



GPS Location Tracking

NEO-6M GPS module provided accurate real-time location tracking for open-sky conditions with the average accuracy being ±2 meters. In imitate underground mine conditions, the module was subject to issues such as signal loss and latency. The utilization of an external antenna greatly improved data transmission and reception of signals and assisted in offsetting these issues. This increase was critical for emergency rescue applications, where location accuracy of the miners is very important for rescue operations to be effective.



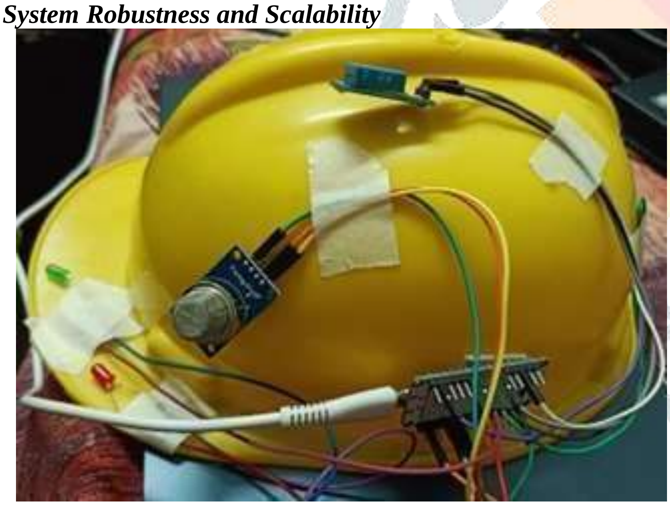
Alert Mechanisms

The buzzer alarm system continuously alerted when certain levels were reached, giving warnings. Under test situations in which the levels of gas were gradually built up, the buzzer responded within 2 seconds of going past the prescribed levels, showing the rapidity of the response of the system. In addition, the pushbutton feature was effective for manual notification, enabling miners to notify supervisors of urgent matters like sensor failure or emergencies. Such redundancy within the alert system makes the entire reliability of the smart helmet robust, covering potential points of failure**.**

Challenges Identified

Even though the system was successful in tests, there were a few issues that could influence its real-world. The MQ-2 gas sensor was sensitive to humidity, meaning it needed recalibration or replacement with more sophisticated sensors to gain more accurate measurements. The performance of the GPS module in subterranean environments was poor since signal attenuation was affecting location accuracy. These findings tell us for improvement, such as combining hybrid communication systems with advanced sensors to make sure better performance in hazardous environments.

System Robustness and Scalability



The entire system design of the intelligent helmet system was proved stable, and all components operated in harmony during prolonged testing. Its modular structure enables it to be easily scalable for the future by integrating more sensors for measuring more toxic gases and physiological coefficients, like heart rate and oxygen saturation. The ease of use of the system with IoT platforms also adds to its functionability, enabling real-time data transfer to central monitoring stations to enable more informed decisionmaking in case of crisis situations.

Practical Implications

The smart helmet represents improvement on traditional protective equipment as it involve real-time sensing and happened risk detection. Its small footprint, simple design, and optimal alerting capacity make it a very effective safety-improvement method for the mining industry. With the removal of core safety problems such as the identification of toxic gases, sensing of environments, and traceability, the system has great potential to bring about considerable lowering of accidents and deaths related to mining.

In summary, The findings supports the efficiency of the smart helmet system in enhancing miner safety. Despite a few minor limitations, system's design, performance provide a strong and adaption for IoT-based safety solutions in high-risk industries. The findings leave room open for extending the system in the future to overcome the limitations found and enhance the system further for field deployment.

VI. FUTURE WORK

The smart helmet system has shown vast potential in boosting miner safety, but there are several opportunities for future work to improve the solution to make it more comprehensive and well suited for real-world mining environments. One such option is the addition of other sensors, like carbon monoxide (CO) and hydrogen sulfide ($H2S$) sensors, to be able to sense a broader range of dangerous gases present in a mining setting. Including physiological monitoring functionality, such as heart rate and oxygen saturation monitors, would expand the safety solution to include monitoring not just the environment but the health status of the workers. Improving communications is another dimension of critical need. Including technologies such as LoRa WAN or Zigbee to wirelessly send information to central monitoring stations would allow real-time updates and make supervisors to track multiple miners in real time.

In addition, mitigating GPS limitations in underground environments through the use of hybrid systems, for example, by fusing GPS with inertial navigation or RFID-based location tracking, in this we will place RFID after some distance and place the tag on miner's helmet, could greatly improve location accuracy in difficult environments.

Future upgrades would be focused on power efficiency through the use of a low-power components and potentially with the addition of solar-powered modules to extend battery life when operated for long durations.

VII. CONCLUSION

This project was able to design a smart helmet system that utilizes IoT technologies to enhance safety in mining conditions. The helmet has sensors to sense dangerous gases, measure temperature and humidity, and locate, all driven by a NodeMCU microcontroller. With instant alerts from a buzzer upon detect of hazardous conditions. A manual reporting pushbutton also enables the miners to alert the supervisors to urgent situations or sensor faults. Test results confirm the functionality with right sensor readings and timely responses from alerting mechanisms to dangerous conditions. Some of the potential problems like high humidity sensor calibration and GPS signal weakness in underground conditions were also observed, which can be addressed in future revisions.

The intelligent helmet system is integrated, scalable solution to enhance miner safety with integrate to environmental sensing, location tracking and emergency reporting in one device. The inclusion of real-time threat detection and alert systems makes the helmet necessary instrument for accident mitigation as well as enhancing emergency response. The system is effective now, but there are plans in the future to enhance the GPS module for applications underground, including other sensors to identify a wider variety of gases, and maximizing communication for efficient real-time data transmission. In general, the smart helmet is a groundbreaking development in employing IoT technologies for improving safety in high-risk industries, and more innovations in mining safety and other dangerous working conditions are expected to follow.

VIII. ACKNOWLEDGEMENT

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