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Intelligent Coal Mines Safety and Real-Time Worker Health Monitoring System

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ABSTRACT

The AI Smart Mining Helmet is created to make mining workers safer by watching them in time. Sensors on the ESP32 gather information about health and the environment. GPS follows each worker's position. The ESP32 reads the sensor data. When it sees danger it rings a buzzer and shows a warning on an OLED screen. At the time the ESP32-CAM takes pictures. A YOLO-based AI model looks for safety gear such as helmets, vests and boots. All the sensor data, location data and AI safety checks appear on a Streamlit dashboard over Wi-Fi. This lets the manager see how safe each worker is, from one screen.

Keywords— Smart Mining Helmet, IoT, ESP32, YOLO, PPE Detection, Computer Vision, Gas Monitoring, Worker Safety, GPS, Streamlit.

I. INTRODUCTION

Coal mining is one of the dangerous jobs out there. Workers often deal with gases, high heat, fire risks and other unsafe conditions. In mines these dangers can be hard to spot. If a problem isn't noticed enough it can lead to serious accidents. Now safety mostly depends on manual checks and personal monitoring devices.. These don't always give continuous updates about the environment. That's why we need a system. One that can keep an eye on mine conditions and help protect workers better.

Some researchers have already started using tech to improve mining safety. For example Jadhav et al. (2025) Worked on a based smart helmet to help with coal mine safety. Kumar et al. (2025) Looked at using gas sensors, GPS and communication tools to track workers and monitor conditions. Sharma et al. (2024) Tested LoRa-based communication to watch changes and track where workers are. These studies show how IoT and smart helmets can make mining safer.

Inspired by this our project. The AI-Based Smart Coal Mine Safety and Worker Health Monitoring System. Puts together safety features into one system. We combine monitoring, health tracking, location tracking and artificial intelligence. The goal is to catch dangers early and give useful safety info so that action can be taken quickly.

The system uses an ESP32 microcontroller to gather data from sensors. An MQ gas sensor checks for gas levels. Another MQ sensor looks for smoke, which could mean a fire is starting. Temperature sensors measure air and object temperatures to spot changes. A MAX30102 sensor tracks

The worker's heart rate giving insight into their condition. A GPS module records location coordinates so we can know roughly where the worker is.

We also added AI-based personal protective equipment detection. An ESP32-CAM takes pictures. A YOLOv8 model analyzes them to check if workers are wearing safety helmets, reflective vests and safety boots. This helps make sure everyone is using the gear. The results can be affected by lighting, camera quality and how clear the worker is in the image.

To make the data easy to understand we built a Python-based Streamlit dashboard. It shows all info in one place: gas levels, temperature, heart rate, GPS location, buzzer status and PPE detection results. If any sensor reading goes above the limit the system turns on an audible buzzer to warn the worker. Having everything in one dashboard means no need to check each sensor separately.

The main goal of this project is to create a easy-to-use system that brings together different safety tools. By combining sensor data, health tracking, location info and AI-based PPE checks the system helps identify risks faster. It's meant to support mining safety practices not replace them. More testing and sensor calibration will be needed to see how well it works in mining conditions. Overall this project shows how IoT and AI can work together to create an environment, for coal mine workers.

II. RELATED WORK

Many studies have looked at using IoT-based helmets to make mining work safer. Aditya et al. [1] Developed a mining helmet that focuses on keeping miners safe and improving their work performance. Another study [2] used a based smart helmet to automatically monitor multiple health risks faced by miners underground. Reddy et al. [3]. Kanagavalli et al. [4] Studied systems that use IoT for safety monitoring detecting dangers and protecting workers in mining areas. Recent research by Kalpana et al. [5]. Bidkar et al. [6] Has continued this work exploring helmets that use connected technology to track health and safety.

For AI-based personal protective equipment detection, Redmon et al. [7] Created YOLO, a fast object detection method that works in time. Jocher et al. [8] Later released the Ultralytics YOLOv8, which made this approach easier to use and more powerful. These tools help identify safety gear like helmets and vests in images. The ESP32 datasheet and technical reference manual [9] [10] explain the hardware and communication setup needed for connecting sensors. The MAX30102 [11] and MLX90614 [12] datasheets describe the sensors used to measure heart rate and infrared temperature. OpenCV [13] helps with image processing while Streamlit [14] makes it possible to build monitoring dashboards.

III. PROPOSED SYSTEM

The proposed system is an AI-Based SmartMining Helmet designed to provide continuous and real-time monitoring of mining workers and their surrounding working environment. Mining workers are exposed to several hazards, including harmful gases, fire or smoke, temperature variations, health-related emergencies, and improper use of personal protective equipment (PPE). The proposed system addresses these challenges by integrating IoT-based sensing, worker health monitoring, GPS localization, wireless communication, local alerting, and AI-based PPE detection into a single wearable safety system. The complete system is divided into two major functional units: an ESP32-based sensor monitoring unit and an ESP32-CAM-based AI monitoring unit. The ESP32 works as the main controller and collects data from the connected environmental and physiological sensors. The ESP32-CAM captures the worker's live video and provides visual information for AI-based PPE monitoring. The collected information is then transmitted through Wi-Fi and integrated into a centralized Streamlit monitoring dashboard.

A. System Architecture

Theproposed AI Smart Mining Helmet is an integrated worker-safety monitoring system designed to improve safety in mining environments. The system uses the MAX30102 sensor to monitor heart rate, MQ-series gas sensors to detect changes in environmental gas and smoke-related readings, and the MLX90614 infrared sensor to measure temperature. A GPS module provides the worker's outdoor location coordinates. An ESP32 microcontroller collects sensor readings, compares them with predefined thresholds, and activates alerts through a buzzer and OLED display when required. An ESP32-CAM captures images of the worker for Personal Protective Equipment (PPE) monitoring. A YOLO-based object detection model running on a computer identifies PPE items such as helmets, safety vests, and boots. Sensor readings, location information, and AI detection results are presented through a Streamlit-based manager dashboard using Wi-Fi communication. This integrated approach supports real-time monitoring and helps supervisors identify potential safety risks.

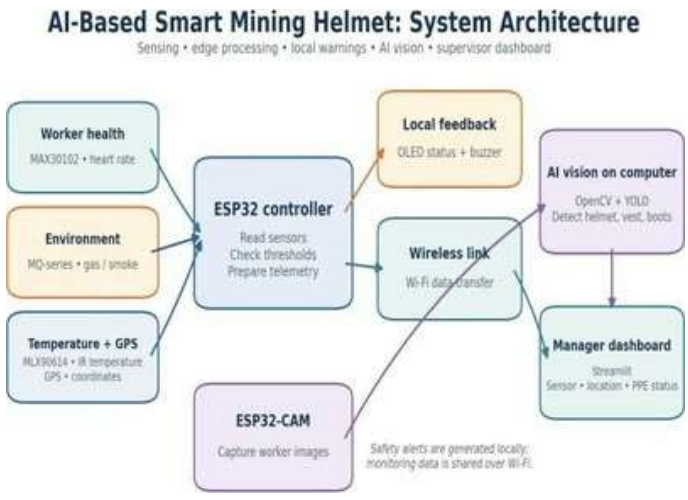


Fig. 1. Proposed system architecture.

B. Health Monitoring

The proposed system also monitors the physiological condition of the worker. A MAX30102 sensor is used to obtain heart-rate information, while a temperature sensor provides temperature measurements. The ESP32 periodically collects these measurements and processes them along with the environmental data. The heart-rate value provides information about the worker's physiological condition, while temperature monitoring helps identify unusual temperature conditions.The health information is displayed locally on the OLED and is also transmitted to the monitoring dashboard. This allows monitoring personnel to observe the worker's physiological condition together with environmental safety parameters. The current implementation primarily uses the MAX30102 for heart-rate monitoring. Although the MAX30102 is capable of supporting additional measurements such as SpO_2, the current implemented system should not claim SpO_2 monitoring unless it is actually implemented and tested.

C. Environmental Monitoring

Environmental monitoringis an important part of our smart mining helmet because miners can be exposed to harmful gases, smoke, and fire. The system uses an MQ-1 sensor for gas detection and an MQ-2 sensor for fire and smoke detection. The ESP32 continuously reads these sensor values and compares them with the predefined prototype threshold. If the readings are normal, the system continues monitoring. If a reading crosses the threshold, the buzzer gives an alert and the safety status is updated on the dashboard. The system also monitors temperature and buzzer status. The threshold values are selected for the prototype and are not official mining safety limits. For real-world use, proper calibration and certified sensors would be required.

D. GPS-Based Location Monitoring

Location tracking is incorporated to determine the geographical position of the mining worker. A GPS module provides the worker's latitude and longitude coordinates. The GPS coordinates are acquired by the ESP32 and transmitted along with the other sensor information through the Wi-Fi connection. The monitoring dashboard displays the worker's location so that monitoring personnel can determine where the worker is located.Location information becomes particularly useful when an abnormal environmental or health condition is detected because it provides an additional parameter for monitoring the worker's situation.

E. Local Alert Mechanism

The proposed helmet provides local warning mechanisms so that the worker can be immediately informed when an unsafe condition is detected. An OLED display provides visual information about sensor readings and system status. A buzzer provides an audible warning when the programmed safety conditions are violated. For example, when a gas or fire/smoke sensor reading exceeds its predefined prototype threshold, the ESP32 updates the safety status and activates the buzzer. This

provides an immediate indication to the worker without depending entirely on the remote monitoring dashboard.

F. AI-Based PPE Detection

One of the major features of the proposed system is the integration of computer vision for monitoring PPE compliance. An ESP32-CAM is mounted on the helmet to capture the worker's live video. The video stream is transmitted wirelessly to a computer using Wi-Fi. The received frames are processed using OpenCV, after which a trained YOLO-based object detection model analyzes the images. The trained model detects PPE-related classes such as
:Helmet, No-helmet, Vest, No-vest, Boots, No-boots The detected objects are represented using bounding boxes on the camera feed. This enables automated visual monitoring of whether the worker is using the required protective equipment. The AI component reduces the dependence on continuous manual visual inspection and provides an additional layer of safety monitoring.

G. Wireless Communication

Wireless communication connects the helmet with the monitoring system. The ESP32 uses Wi-Fi to transmit sensor information to the monitoring dashboard. The transmitted information includes: gas reading, Fire/smoke reading, Temperature, Heart rate, GPS latitude, GPS longitude, Temperature status, Buzzer status, Overall safety status.

IV.IMPLEMENTATION

The proposed AI Smart Mining Helmet was implemented by integrating environmental monitoring, worker health monitoring, location tracking, local alerting, wireless communication, and AI-based personal protective equipment (PPE) detection into a single wearable safety system. The main objective of the implementation is to continuously monitor important safety parameters of a mining worker and provide real-time information to the worker and monitoring personnel. The system consists of an ESP32-based sensor monitoring unit and an ESP32-CAM-based AI monitoring unit. The ESP32 acts as the main controller for collecting and processing sensor information, while the ESP32-CAM provides visual information for AI-based safety detection.

A. Hardware Implementation

The hardware setup includes an ESP32, a MAX30102 heart-rate sensor, an MQ-1 gas sensor, an MQ-2 fire/smoke sensor, a temperature sensor, a GPS module, an OLED display, a buzzer, and an ESP32-CAM. These sensors connect to the ESP32 based on their communication types. The MAX30102 and OLED use I2C, while the MQ sensors send analog readings to the ESP32. The GPS module gives the worker's location, and the buzzer sounds an alarm during unsafe conditions.

B. Sensor Integration and Processing

The MAX30102 monitors the worker's heart rate, while the MQ-1 tracks gas levels and the MQ-2 detects fire- and smoke-related conditions. A temperature sensor provides readings for safety monitoring. The ESP32 continuously collects and processes data from all sensors according to the programmed safety logic, then displays the readings on the OLED for local monitoring. If any value exceeds its predefined threshold, the system issues a warning and activates the buzzer.

C. Environmental Safety Monitoring

The environmental monitoring subsystem continuously checks readings from the gas and fire/smoke sensors. At regular intervals, the ESP32 collects analog values from the MQ sensors and compares them with the predefined threshold used in this prototype.If a gas or fire/smoke reading rises above that threshold, the system updates the relevant safety status and activates the warning mechanism. The monitored information includes:

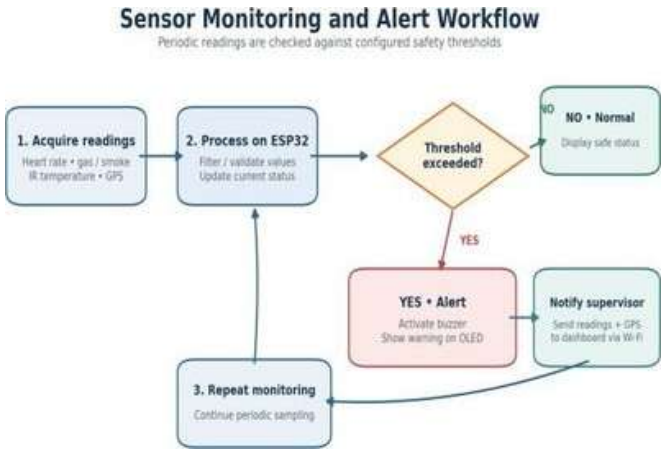


Fig.2.Sensormonitoringand alert workflow.

D. GPS and Wi-Fi Communication

The GPS module determines the worker's latitude and longitude, then sends the coordinates to the monitoring dashboard through the ESP32's Wi-Fi connection. The ESP32 also transmits data from the other sensors, including gas, fire and smoke, temperature, and heart rate.

E. AI-Based PPE Detection

An ESP32-CAM mounted on the helmet provides visual monitoring. It captures a live video feed and sends frames to a computer over Wi-Fi. OpenCV processes the incoming frames, while a trained YOLO model identifies PPE-related classes, including helmets, vests, and boots, as well as cases where each item is missing. The system highlights detected items and missing PPE with bounding boxes on the camera.

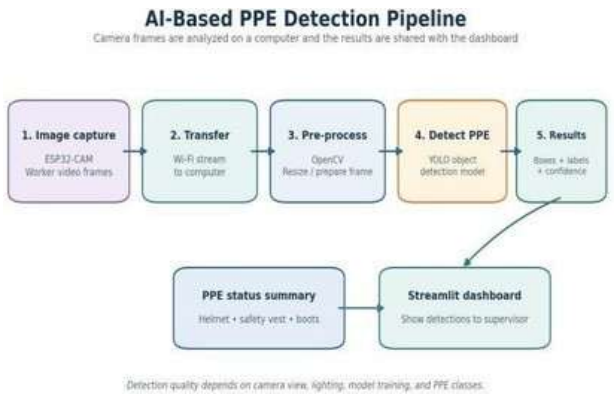


Fig. 3. AI-based PPE detection pipeline.

F. Monitoring Dashboard

A Streamlit dashboardbrings the helmet system's data together in one place. It displays environmental readings, heart rate, temperature, GPS location, buzzer status, and the worker's overall safety status. The camera feed and PPE detections are also shown on the dashboard, giving monitoring personnel a single interface to review the worker's condition and safety compliance.

V.CONCLUSION

This paper proposed an AI-based Smart Safety Helmet designed to improve worker safety in mining and hazardous environments. The system uses ESP32, sensors, GPS, buzzer, ESP32-CAM, and YOLO AI to monitor the worker and surrounding conditions. The helmet monitors heart rate, temperature, gas, and fire-related conditions and provides alerts when unsafe conditions are detected. The camera and AI model support visual safety monitoring, while the real-time dashboard allows supervisors to monitor the worker remotely. The prototype shows that IoT, AI, sensors, and GPS can be combined to create a practical safety system. In the future, the system can be improved through better AI accuracy, sensor calibration, wireless reliability, battery backup, and real-world testing.

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