Hybrid Smart Helmet with Industrial Safety Monitoring & Hazard Prediction (SIWS-HPS)

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The working environment in strial places like mines, chemical plants, construction sites and factories can be dangerous, with toxic gases, high temperatures, low visibility, falling materials or an emergency that can strike at any moment. Routine safety helmets can only protect against physical impacts and are unable to sense hazards or alert earlier to impending accidents. The proposed SIWS-HPS Hybrid Smart Helmet aims to improve the safety of the industrial workers by combining the advanced technologies, such as MQ-series gas sensor, DHT11 sensor for temperature and humidity measurement, and MPU6050 sensor for fall detection. In addition, there's a pulse sensor for heart rate, an LDR to automatically control the light and even a voice-recognition module, so that workers can summon an emergency even when offline. The ESP32 chip is the core of it all, it's used for communication, logging data on an SD card, adding the current time to all data and broadcasting alerts as they happen via Wi-Fi or GSM. This helmet is not a one size fits all. It is adaptable to various industrial environments, adds numerous safety features, foresees potential hazards before they even occur, and sends powerful alerts when things go wrong. This leads to quicker response times, improved protection, and a better understanding of the surrounding environment for those working on the site. It is a sound safety measure for mines, tunnels, factories and other industrial environments that are considered to be of a high risk.

Keywords—Smart Helmet, Industrial Worker Safety, IoT-Based Safety System, Hazard Detection, Gas Sensors (MQ Series), Fall Detection, Health Monitoring, ESP32, Real-Time Alerts, Wearable Safety Devices, Predictive Safety Systems.

I. INTRODUCTION

Industrial locations can be really hazardous. Consider mines, chemical plants, building sites, storage, factories. There are all kinds of dangers, like bad air, temps all over the place, wetness, crud in the air, difficulty seeing, big machines, and tough work. Staff are always at risk of sustaining serious injuries, developing health problems later or worse. It gets even worse when there is not adequate checking, problems are not detected quickly, and a standard safety device fails to alert people in time. With larger, more complex jobs, we must find smarter ways to keep workers safe and to reduce dangers. Normal hard hats will protect your head from being struck by something falling, but that's about it. They don't know if the air is bad, if they are able to keep an eye on your health, or if the accident is likely to occur. Helmets today cannot detect if there are harmful gases in the air, whether there is a temperature change or if there is too much moisture or if the lights are not safe.

In addition, they can't observe your heart rate or feel when you have fallen or been hit, so you may need assistance promptly. Due to this, the staff might sustain injuries which we could have prevented had we been better monitored and alerted. The use of the Internet, gadgets you can wear and fancy sensors have given us the opportunity to develop improved safety systems that can always monitor the area and people's bodies. Gas, temp, wetness, movement and heart rate sensors in smart helmets can detect danger early and alert you when it really counts. However, not all smart helmets are able to offer as much safety as they can, such as when the person is looking for gas or if a fall occurs. Not all of them have features such as fast emergency alerts that don't require a network, hazard guesses, and can work in many areas. There's no such device to wear that gets all the jobs done when it comes to keeping workers safe.

This paper presents an idea based on SIWS-HPS (Smart Industrial Worker Safety – Hybrid Predictive System) to solve these issues. It's a clever helmet that can do many things: it can scan the environment, monitor your health, detect falls, predict hazards, respond quickly to alerts, initiate an emergency call with your voice, and operate without any network coverage at all! It has gas sensors to detect bad air, a temp thing to monitor heat and moisture, another thing to monitor falls, a heart rate monitor, and a light sensor to provide lighting. When there is a need for help, workers can shout without a network to alert workers for help.

The ESP32 chip is the brain, it collects data, observes it, guesses what might happen, stores it and communicates warnings via wifi or a cell phone network. The SIWS-HPS makes work safer, detects potential hazards early, gets workers help early, and provides assurance that they understand what is going on in hazardous areas. It is supplied with a safety layer, danger indicators and effective alert systems, making it safe to use in mines, tunnels, chemical plants, storage areas and building sites.

This system is much more effective than traditional hard hats by consolidating a bundle of safety features into a single wearable smart device. It transforms safety from merely responding to issues into preventing them from occurring at all – contributing to smarter safety equipment for the job.

II. LITERATURE SURVEY

The first attempt at smart helmets was done by Kartik [1] who worked on an IoT based smart helmet that can detect hazardous situations in a mining environment. It explored the use of environmental sensors that could be used to detect gases such as methane and carbon monoxide, and how wearable technology can help to spot unsafe conditions early. The research was the first to talk about the idea of combining several sensors in a small wearable device to give real-time alerts to miners' safety. Sandaruwan and Hettige [2] did a comparative study of smart helmet systems for mining tracking and safety. They evaluated the various methods and identified the challenges in the real time monitoring, multi-sensor integration, and emergency alerting. They moved on to finding a helmet that could provide predictive alerts, remote monitoring and cross-industry flexibility – as a reference for developing a new smart helmet model.

Hamza et al. [3] came up with a concept of a smart helmet for unsafe event detection in mining industries by IoT. Their work was to automatically identify hazards using real-time data collection and to alert to them, which allowed them to respond rapidly to the emergency situations. They went on to demonstrate that the fusion of physiological and environmental sensors in one wearable device could, to a great extent, lead to the reduction of accidents in underground mining operations. To introduce a new paradigm of real-time monitoring in the mining context, Verma et al. [4] proposed a smart helmet to combine the IoT paradigm with wearable sensors. They were designed to continuously monitor the miner's position, measure environmental parameters and automatically notify the relevant staff through wireless systems. In the paper, the investigators suggest that sustainable innovation can combine with wearable safety devices to create a substantial decrease in occupational hazards.

To monitor the safety in coal mines Talpur et al. [5] developed a smart helmet to connect with a mobile application. In this research, the researchers have concentrated on environmental monitoring and also on mobile platform integration, enabling the supervisors to remotely monitor the hazards. The system thus provided effective situational awareness that was crucial in the timely starting of the response to the newly manifested, and most likely dangerous situations. Pradeepkumar et al. [6] developed a safety helmet for mining by utilizing LoRaWAN communication system which is capable of sending sensor data over long distance and at low powers. Their research highlighted a key point for remote environmental monitoring in underground mines – the controllers are able to identify the hazards of the environment and health problems of the workers without relying on the local network infrastructure, which improves safety when working remotely.

Durge et al. [7] developed a multifunctional intelligent helmet which will be able to increase the safety and comfort of a worker at the same time. These creative concepts included fall detection, heart rate measurement, gas detection, temperature and humidity monitoring in their design. Priyatharishini and Thillai Rani [8] have developed a smart safety helmet which is designed to protect mining workers. They mainly talked about an IoT, based real, time monitoring system that is coupled with emergency alerting and offline data logging. In their paper they discussed the issue of industrial safety and proposed that smart helmets could serve not only for safety but also for hazard prevention as well in the industrial field.

Devi et al. [9] came up with a machine learning, powered smart helmet concept which aims at air quality monitoring and hazardous event detection. The deployment of IoT with the predictive algorithms enabled the system to detect high spikes of hazard and provide early warnings. This study demonstrated the potential of artificial intelligence wearable safety devices to be implanted in the industrial safety management system for timely action. Reddy et al. [10] proposed an intelligent helmet to detect hazards in the mining environment using IoT technology. They were tasked with installing all the sensors inside the helmet that could detect the occurrence of gas leakage, temperature differences, and recognize when workers were in a risky situation. The platform offers the ability to access live monitoring, and also sends automatic alerts is an ideal example of the role of IoT in accident prevention and health protection of workers. In order to provide safety protection to coal miners.

Puviarasi et al. [11] developed a smart safety helmet system which integrates environmental and body sensors. A smart helmet with air quality monitoring, fall detection and heart rate monitoring could be developed via LoRaWAN to provide immediate notifications as per Shivaanivarsha et al. [12] for the air quality, fall detection and heart rate monitoring of miners, even in offline scenarios. They studied the reliability of communication in the underground with low connectivity. This dual protection approach to health and safety was achieved through an environmental monitoring and respiratory protection system.

Kim et al. [13] developed a smart helmet based personnel proximity warning system in underground mines. Their approach involved the use of wearable sensors to detect the distance between workers and moving equipment and thus give out early warnings to avoid collisions. The research highlighted the importance of wearable technology for spatial awareness and accident prevention. The coal mine safety monitoring and alerting system using smart helmets is shown by Rudrawar et al. [14]. This was accomplished by combining gas detection, temperature monitoring, and sending immediate alerts to the supervisors. In their paper, they conceptualised the potential of using the combination of IoT and wearable devices in emergency situations to drastically reduce response time and the number of accidents occurring in this environment.

Smart helmet is a smart idea postulated by Mali and Sawant [15] which assumed coal mining while the presence of poisonous gas and climate change. Their article's main point, regarding the possibility of real time monitoring and alertness, is that it will be necessary to achieve a safer workplace, which would result in less environmental related accidents. A smart helmet was suggested by Jadhav et al. [16] fitted with IoT technology in coal mining and safety monitoring, with benefits such as hazard detection. and automated alert systems. They used sensor in their system fusion not just to monitor the surroundings but additionally to monitor the health and safety of the employees; hence, it was an entire safety measure that had the ability to avoid accidents.

Thangam et al. [17] developed a smart safety helmet which uses support vector machines (SVM) as the classifier in the system. They used machine learning algorithms to detect unsafe situations and to predict the safety risks. Their work was a successful example of the application of wearable sensors that are powered by predictive analytics in a safety-first approach in the industry. Ghadyani et al. [18] proposed a smart helmet that is equipped with a real-time monitoring and alarm system in an underground coal mine. Their case study at Tabas Coal Mine demonstrated how to combine the use of environmental sensing, worker vitals monitoring and instant notifications to supervisors, and offered a blueprint for widespread deployment.

Jabamani et al. [19] designed a smart safety helmet that has an environmental monitoring and alert system for mining workers. The integration of the multi-sensor module, which includes gas sensors, as well as accelerometers, temperature and humidity detectors, was an effective way to enhance safety in the hazardous industrial environment, thus, their project was approved. In the coal mines industry, Suriyakrishnaan et al. [20] developed a smart safety helmet using Arduino. Their research focused on implementing the project in a cost-effective way, and on real-time monitoring of the environment and providing automatic alerts. This study underlined the possibilities of a solution that could be scaled up for industrial safety tools and wearable IoT devices. Thangam et al.

III. PROPOSED SYSTEM

The SIWS HPS Hybrid Smart Helmet is a wearable technology designed to keep workers safe in high hazard industries such as mining, chemical, construction, subterranean and manufacturing. Unlike conventional safety helmets, the smart helmet monitors the environment, health and liveliness of the labourers, thereby avoiding the occurrence of accidents. This is accomplished by combining multiple technologies, hazard predictions and real-time alerting systems into a single, compact device, unlike traditional safety equipment that provides both preventative and reactive safety.

The ESP32 microcontroller is the brain of the system, which makes it the central unit responsible for fetching, analyzing, and communicating the data from different sensors. The power of the ESP32, the integrated Wi-Fi and GSM modules and its low power usage allow it to process several data streams at the same time. It also records the sensor readings to an SD card that has a real-time clock (RTC) for safe, accurate, readings taken later. The helmet's processing core is the reason it's an online/offline device and can still provide protection in areas of weak network signals.

The HPS, the SIWS is equipped with a variety of sensor modules in order to reach total safety monitoring. The MQ series gas sensors detect the presence of toxic gases such as methane, carbon monoxide and smoke, therefore preventing exposure to such gases. The DHT11 sensor is used to continuously monitor the ambient temperature and humidity and detect any extreme changes in temperature or humidity, which may pose a risk to worker safety. The MPU6050 accelerometer and gyroscope are able to detect falls, severe impacts, and abnormal movements which will keep the emergency staff informed should a fall or severe impact occur. All modules are modular, connecting the sensor, processing, communication, alert, power, and logging units and ensuring seamless functioning.

The sensor data is monitored constantly against the specified safety limits and if an anomaly is detected, it will trigger a response that is immediate, and first. The local alerts such as buzzer, LED strobe and vibration motor also provide instant alerts to the wearer of the gear; the supervisors or safety personnel are alerted in real-time via Wi-Fi or GSM. In addition to this, all the readings are kept with proper time stamps, so that the system can be conveniently used for the in-depth analysis of incidents and trends over time.These three technologies combined make for a robust safety picture for industrial workers—one they can trust. One of the most important innovations of SIWS, HPS system is its capability of forecasting possible dangers.

It continues to track patterns in the environment and in the body, and will alert for any conditions that are only coming into the danger zone – such as a rise in methane, or a sudden drop in temperature. The system is also provided with industry safety mode features, enabling it to be easily adapted for use in coal mines, chemical plants, construction sites or warehouses. A hybrid solution improves the situational awareness of the worker, reduces the time to response in the event of an emergency and enhances workers' safety in general. Furthermore, the system's features and functions when operating in an unnetworked environment, along with its modular design of sensors, and its forecasting algorithms make the SIWS, HPS an extremely scalable and economical answer to the safety problems in the industrial arena.

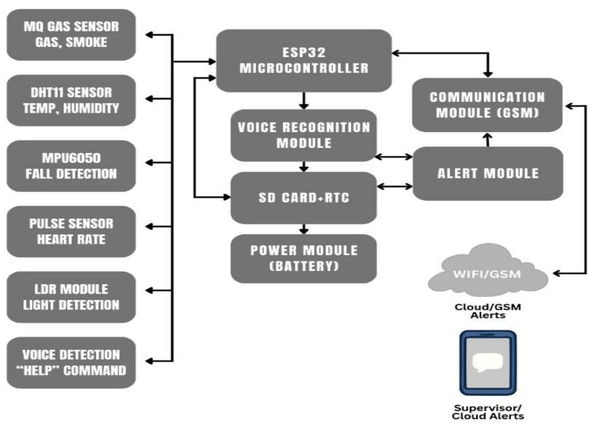

Figure 1: System Architecture

After the data has been processed, it comprises the anomaly flag, adaptive threshold, and filtered peak reading, among other things that are sent to a web-based dashboard via Wi-Fi. The dashboard at any point displays vibration levels, alerts, and an event history with a time stamp for the user to conveniently track events. It's a fine system, because it does everything that's important performed at the edge, with the result of reduced network traffic, quicker reaction times, and steady connectivity circumstances.

This edge-intelligent system can be scaled up, remain flexible and can be deployed at low cost, making it a potential source of continuous and intelligent monitoring for industrial, structural and automotive sectors, that is essential for predictive maintenance and safety assurance.

IV. METHODOLOGY

The methodology of the SIWS, HPS Hybrid Smart Helmet comprises the following four major components: Sensor Integration and Data Acquisition, Data Processing and Analysis, Alert Mechanism and Communication, and Multi-Mode Industrial Deployment and Testing.

1. Sensor Integration and Data Acquisition

Some of the most common and harmful gases in the environment such as methane, carbon monoxide, and smoke are detected by the MQ sensors, and the temperature and humidity are continuously measured by the DHT11 sensor, to determine extreme conditions. When sudden movements, impacts and falls are detected by the MPU6050 accelerometer/gyroscope the worker's heart rate is simultaneously monitored using the pulse sensor to detect abnormalities such as fatigue or stress. Low visibilities are detected by an LDR sensor, and the voice recognition module is used to activate the emergency alert system when the system is not connected to network. Moreover, all the sensors are not only calibrated but they are also wired to the ESP32 microcontroller to make data acquisition in real time with accuracy possible.

2.Data Processing and Analysis

All the sensor data taken from the system (such as temperature, breathing rate etc.) is processed in real time by the microcontroller based on the ESP32 to detect the hazards from the sensor measurements and to compare them against pre-set thresholds for danger. When any hazard is detected at levels above these, the system logs the hazard and classifies risk as low, medium or high. The system will also be able to recognize trends over time (i.e. rising gas levels or rising temperature) and will approve that data, which will then be available for history for off-line analysis. Therefore, the data will be written on an SD card that will be controlled by an RTC to ensure reliable data storage for long-term purposes and retrospective safety analysis in case of potential hazards.

3. Alert Mechanism and Communication

In case of a hazard or other abnormality, the helmet will activate several alarms. First, the alerts on site will be a buzzer alert / LED strobe and vibrating motor to alert the worker. The second level of alerts are those that are sent to the supervisor dashboard or through GSM/SMS alerting the supervisor to the need for immediate action. By wearing the product the user can trigger an emergency message by using one of the words (HELP for example), thereby granting him or her the ability to get help at the moment, even if outside the network or in a weak signal area. Together, these two alerting methods provide comprehensive coverage, thereby minimizing the time required for response in case of an accident.

4. Multi-Mode Industrial Deployment and Test.

The Industrial Safety Wearable System—Head Protection System (SIWS-HPS) is intended to offer safety and protection for workers from various industries such as construction, warehouses, chemical, mining and more. The SIWS-HPS has a different operational mode for each of these industries, with each mode having a different set of threshold levels and alert systems based on the potential hazards found in each of these industries.

The SIWS-HPS was subjected to accuracy, speed and durability tests, in the same conditions as a worker would be in when working with no light, high thermal loads, toxic chemicals or sudden slips/trips. Performance was verified by measuring real-time data, forecasting potential hazards, offline verification of logs and ensuring alert functionality when triggered. The rigorous testing process ensures that the SIWS-HPS is not only adaptable and sturdy, but also reliable and effective in practical use for ensuring safety in industrial settings.

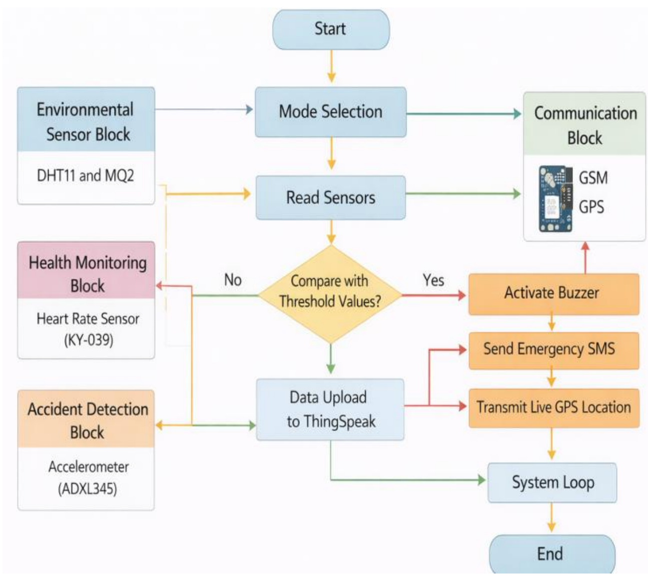

Figure 2: Work Flow

V. RESULT AND DISCUSSION

To assess the hybrid smart helmet's ability to monitor environment, detect safety hazards and assist during emergencies, a prototype of the SIWS-HPS Hybrid Smart Helmet was put through a thorough testing process which used simulated conditions to realistically observe how well it performed. Both the gas sensor (MQ) and temperature/humidity sensor (DHT11) provided accurate and stable measurements regarding the presence of hazardous gases, temperature and humidity levels; both sensors effectively showed unsafe conditions via previously established indicator thresholds (i.e. temperature beyond safe limits, etc.). By detecting a sudden acceleration and/or orientation change (in relation to the latter) and setting an appropriate warning threshold (in relation to the former) the MPU6050 was able to detect falls and sudden impacts effectively. The heart rate monitor provided regular, consistent heart rate readings while in both regular as well as active state, thus permitting ongoing health monitoring of a worker.

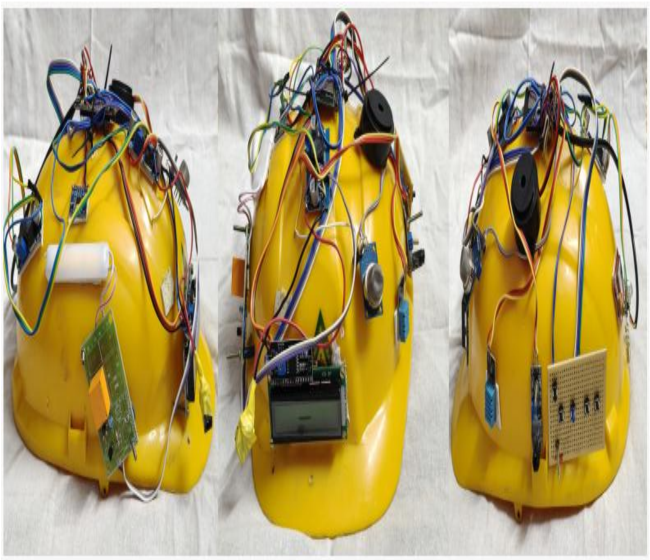

Figure 3: Hardware Prototype of the Proposed Smart Helmet Safety System

Further, the LDR automatic light was capable of sensing low-light levels and was capable of triggering the automatic operation of the LEDs at the same time, hence enhancing the light output in a low-light environment by a worker. In addition, if the gas concentration is below the dangerous level but rises slowly over time, as a function of volume, then the alert for this alert is triggered before the gas concentration reaches the danger level. Furthermore, storing the collected sensor data on the SD card (with RTC time stamping and offline storage) provided an effective means to ensure the security of sensor data for later analysis purposes. The voice recognition unit was able to recognize predefined (i.e. "HELP") emergency requests without the need for an Internet connection thus permitting hands-free emergency activation. Therefore, this proposed system can provide reliable, dependable and effective emergency assistance to workers as proved by the test, accordingly.

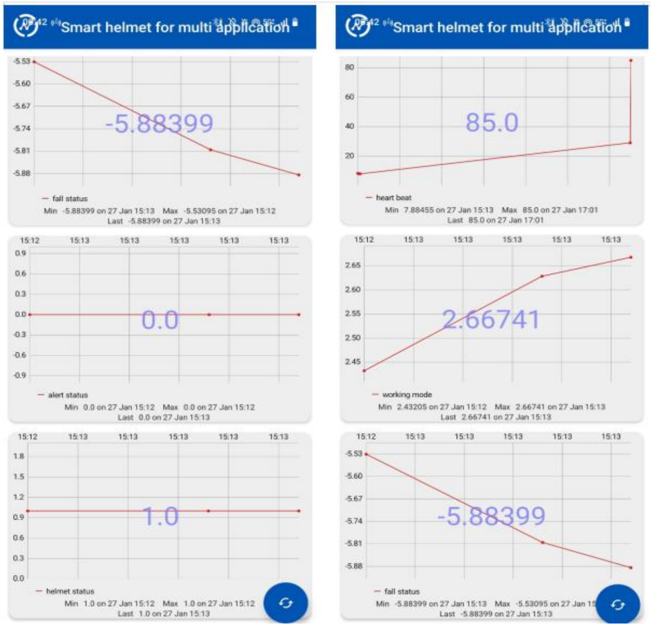

Figure 4: ThingSpeak Cloud Graph Showing Real-Time Sensor Data

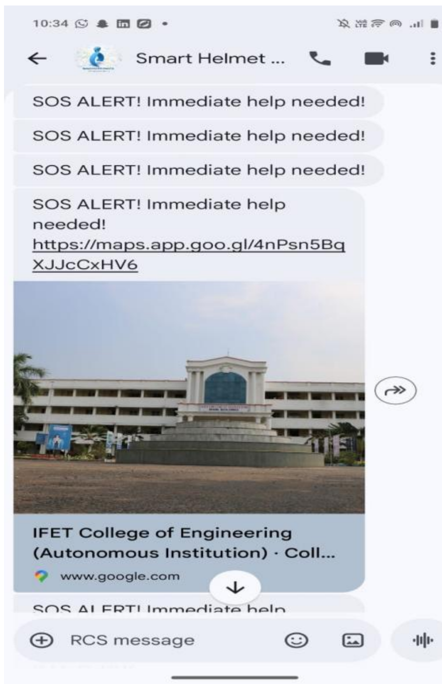

Figure 5: Emergency alert message with live location using GSM communication.

VI. CONCLUSION

The SIWS-HPS Hybrid Smart Helmet combines an environmental sensor, health monitoring devices, fall detection and predictive hazard analysis and an emergency alert system in one helmet to offer a smart, reliable workplace safety product for those working in hazardous industrial environments. In addition, it significantly increases the level of protection for workers over traditional safety helmets. This helmet enables the user to not only track the levels of gas concentrations, but also temperature, humidity and health parameters, and alert the user before the amount of gas reaches a dangerous concentration that compromises the user's health.

The system was found to be able to accurately detect hazards, consistently monitor user health, and give rapid warning in emergencies as automatic (no action) alerts and voice activated (protocol-driven) alerts. The offline data logging with timestimestamping, auto-lighting in low-visibility scenarios and multiple alert channels (phone or text) are some of the best features in this helmet. Its versatility for use in a wide range of industrial settings like mines, tunnels, factories or construction sites is very promising to enhance situational awareness, enable faster response in emergency situations, and minimise injuries in the workplace.

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