Advanced International Journal for Research (AIJFR)
E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

Design Evaluation of a Smart Helmet for Detecting Alcohol in Industry

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Abstract

A smart helmet system that detects industrial workers' alcohol consumption in real time is designed, developed, and evaluated in this study with the goal of improving workplace safety. The combination of wireless communication and sensor technology allows for proactive monitoring to lower the number of accidents caused by alcohol. The system consists of an ESP32 microcontroller, a MQ3 alcohol sensor, and a Bluetooth/Wi-Fi communication module. Using the Arduino and Proteus platforms, it was created and tested at different distances (20–60 cm) and ethanol concentrations (0-400 ppm) in controlled settings. Experimental trials and a Likert-scale feedback survey from ten industrial workers were used to evaluate the system's accuracy, response time, and user satisfaction. For alcohol levels over 100 ppm, the smart helmet showed high detection accuracy (over 96%), with the best sensor performance at a distance of 20 cm. On average, 1.84 seconds were needed to trigger an alert. Statistically significant findings were validated by ANOVA and correlation analysis. Because of the weight of the device, users gave the system higher ratings for safety awareness and dependability but lower ratings for comfort. The MQ3 sensor's moderate cross-sensitivity, power limitations, and environmental conditions all affect how effective the helmet is. It is advised that ergonomic design be improved and that sweat-based or multi-sensor detection be included. A new IoT-enabled safety helmet that continuously monitors alcohol consumption is presented in this study, providing a scalable and reasonably priced way to enhance workplace safety and occupational health in industrial settings.

Keywords: Smart Helmet, Alcohol Detection, Occupational Safety, ESP32, MQ3 Sensor, Real-Time Monitoring, IoT, Industrial Safety

1. Introduction

Personal Protective Equipment (PPE) plays a crucial role in minimizing workplace hazards in industries such as construction, mining, and manufacturing. Among the essential PPE, helmets are widely used to protect workers from head injuries. With advancements in technology, smart helmets have emerged as an innovative solution by integrating sensors and electronic components to enhance safety[1]. These helmets provide real-time data collection, reducing operational risks and improving workplace safety by continuously monitoring environmental and physiological parameters[2].

Alcohol consumption in the workplace poses significant risks, as it impairs cognitive and motor functions, leading to increased chances of workplace accidents and injuries. Alcohol is a psychoactive substance that can cause dependence and increase the likelihood of mental, behavioral, and physical health disorders as described by [3]. Studies show that alcohol-related injuries are prevalent in high-risk occupations, including construction, transportation, and food service, where stress levels and physical demands contribute to alcohol consumption [4]. Research further indicates that up to 16% of workplace accidents are related to alcohol use, with about 15% of victims in fatal work-related accidents testing positive for alcohol in their system [5].

Although breathalyzers and other alcohol detection methods are used in workplaces, they do not provide continuous monitoring, leaving room for undetected intoxication and potential accidents. Traditional detection techniques are often limited to random or periodic testing, which may not accurately reflect an employee's alcohol consumption throughout their shift [6]. According to [7], the use of smart helmets with alcohol sensors can help close this gap by providing real-time monitoring and prompt notifications when alcohol is detected. This will make the workplace environment safer and lower the rate of accidents.

Occupational health and safety rules mandates employers to have a basic duty to make sure their workplaces are safe [8]. Using smart helmets that can detect alcohol is in line with these rules will help find drunk workers and stop alcohol-related accidents before they occur. Ongoing alcohol testing can help businesses save on medical bills, lower their legal risks, and boost overall productivity by making sure that workers are fit for work [9]. In addition, drinking alcohol at work has been linked to safety concerns, lower productivity, and absenteeism, all of which have effect on employees and the effectiveness of the organization [10].

Smart helmets with alcohol sensors are a safe way to make workplaces safer because they can identify drunk staff and send messages to their supervisors right away so urgent action can be taken. This technology can help make workplace safer and healthier by discouraging alcohol drinking during working hours and encouraging a culture of accountability and compliance [3]. This study is to design a smart helmet that can detect alcohol in industrial workplace environment. The goal is to make workplaces safer and alcohol free during working hours and to make sure that safety rules and regulations are followed. The system consists of an alcohol sensor, an ESP32 microcontroller, a wireless communication module, and other parts that are needed.

Materials and Methods

The study employed field studies, conceptual design and analysis, and real-world testing were all used to make the smart helmet that can detect alcohol levels. The process involved going to construction sites, factories, selecting the right materials, designing the system's parts, and testing and analysis.

Study Area

The research team visited industrial and construction sites in Northern Ghana. The purpose of these visits was to make sure that safety rules were being followed at workplaces and to see how often people were at risk because of alcohol intake during working hours. The team informally asked workers,

supervisors, and safety officers what problems they had with keeping an eye on alcohol use during work hours among others.
Other industrial sites were visited to find out whether smart helmet could be used in their everyday tasks. This made it possible to get feedback on how convenient it is to wear the smart helmet, where the sensor should be placed, and how well workers continuously wear the safety helmet.

Conceptual Designs

The smart helmet system was designed during the idea phase generation to be able to detect alcohol in the breath of industrial or constructional workers. The design includes a MQ3 alcohol sensor, an ESP32 microcontroller, a power supply unit, and a wireless communication module. The MQ3 was put close to the mouth to get an accurate reading of alcohol breath, and the ESP32 module and power supply were positioned on the back of the helmet to balance the weight evenly. The system was given a rechargeable 9V lithium battery to make sure it worked for a long time.
Computer Aided Design (CAD) software was used to create and evaluate several versions of the design to improve its structure and aesthetics. The chosen design puts efficiency, convenience, and robustness as its design consideration. Figure 1 shows the conceptual design of the smart helmet.

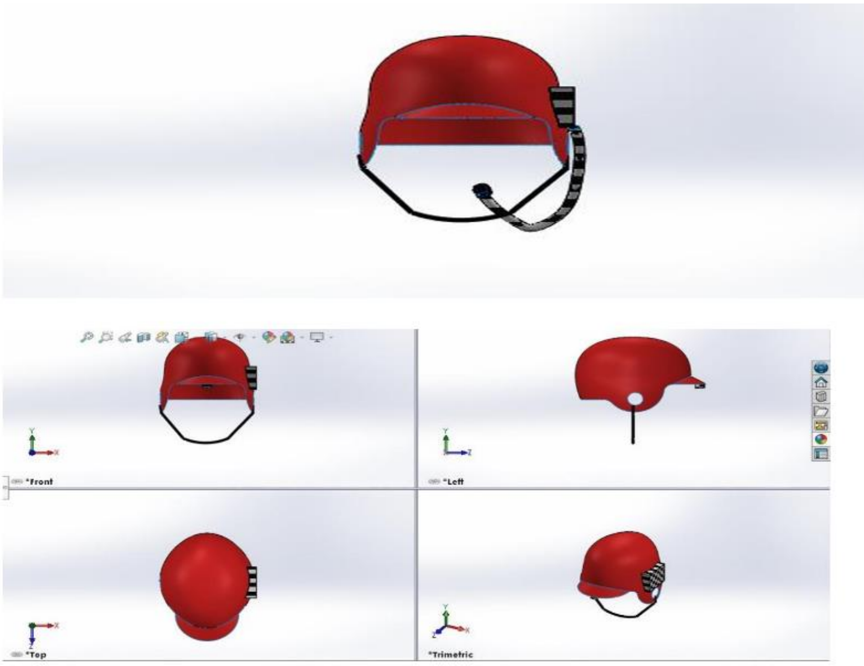

Figure 1: Conceptual Design of Smart Helmet

Principle of Operation
The MQ3 alcohol sensor continuously collects breath samples from the user to power the smart helmet. The sensor produces an electrical signal proportional to the ethanol concentration when it detects alcohol vapours. The ESP32 microcontroller processes this signal and decides whether the alcohol content surpasses a predetermined threshold. The system notifies a designated supervisor or safety officer via Bluetooth or Wi-Fi if alcohol is detected. Because the entire procedure is automated, human error is decreased and prompt intervention is guaranteed.

Figure 2 indicates the block diagram of the smart helmet operation.

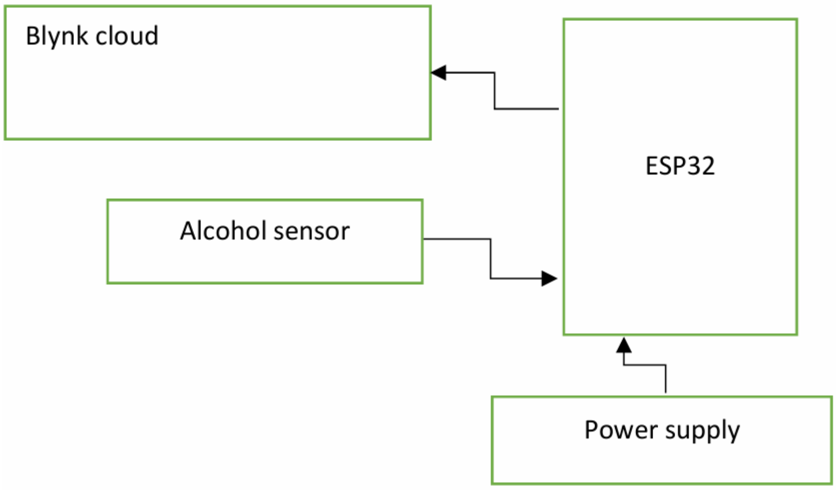

Figure 2: Smart helmet operation block diagram

To ensure its reliability, the system's effectiveness was evaluated in a variety of environmental settings. Performance variables like worker movement, humidity, and ambient temperature were taken into account. Comfort, weight distribution, and usability in an industrial environment were also assessed in the helmet's design.

System Components

The following component parts were used in the design of the smart helmet. Table 1 represents the system components of the smart helmet.

Table 1: System components of the smart helmet

Component	Specification and Function
MQ3 Alcohol Sensor	Detects ethanol vapours in the user's breath with high sensitivity
ESP32 microcontroller	Process sensor data and transmits alerts via Wi-Fi or Bluetooth
9V lithium battery	Provides portable power supply for all components
DC-DC convertor	Regulates the power supply to maintain stable voltage across components
Helmet frame	Industrial grade helmet modified to house sensors and electronics
Blynk IoT Platform	Mobile application for receiving real-time alerts from the helmet

Design Analysis of the Components

The system is made up of a number of crucial parts, all of which support its overall effectiveness and functionality. A smart helmet system was created by combining an ESP32 microcontroller with a battery-operated alcohol sensor. The input from every component was crucial to the system's determination and was primarily responsible for its success. These components were included in the helmet to ensure its effectiveness and dependability while closely monitoring various alcohol concentrations. Using the ESP32's integrated Wi-Fi and Bluetooth capabilities, the device measured alcohol levels and sent notifications when they went over certain limits.

Electric Motor

The electric motor provides the required energy to power components such as the sensor and microcontroller. A 9V DC motor was selected due to its efficiency and compatibility with the power supply.

Alcohol Sensor (MQ3)

The MQ3 alcohol sensor detects the presence of ethanol in the breath. It has a high sensitivity to alcohol and low sensitivity to other gases, ensuring accurate readings. It can be placed directly in front of the lips. The sensor reacts in different ways to molecules in alcohol and assesses the rider's level of intoxication. A potentiometer is also included in the sensor to modify the gas concentration. There are four pins on it: GND, VCC, D-Out and A-Out. The sensor is compatible with analog and digital results. Figure 3 represents alcohol sensor MQ3.

Figure 3: Alcohol Sensor MQ3

Microcontroller (ESP32)

The ESP32 is a dual-core microcontroller with built-in Wi-Fi and Bluetooth capabilities. It processes data from the MQ3 sensor and transmits alerts when alcohol is detected. It manages read and write operations, gives commands to operate the system, and communicates with the Blynk application. It also performs other tasks, such as reading data from the alcohol sensor for alcohol detection and sending data over Wi-Fi to the Blynk app, which subsequently sends notifications to the Blynk app. Figure 4 represents the ESP32 microcontroller.

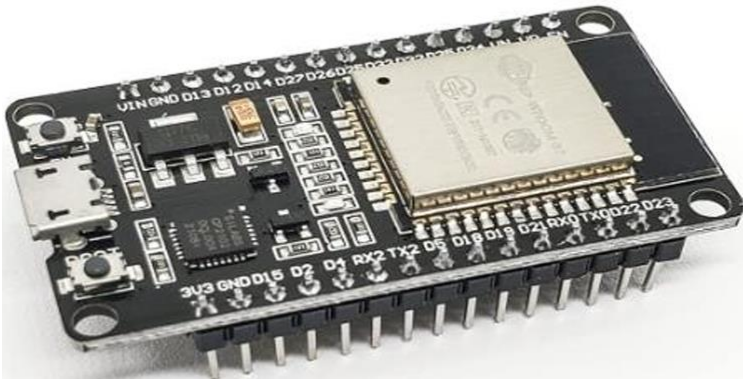

Figure 4: Microcontroller (ESP32)

Power Supply Unit

The system is powered by a rechargeable 9V lithium battery, which is regulated using a DC-DC converter to ensure stable voltage for the components.

Wireless Communication Module

The ESP32's wireless communication module enables real-time data transmission to supervisors via Bluetooth and Wi-Fi.

Circuit Diagram

The circuit diagram illustrates the connections between the ESP32, MQ3 sensor, power supply, and other components. Figure 5 represents circuit diagram of the smart helmet.

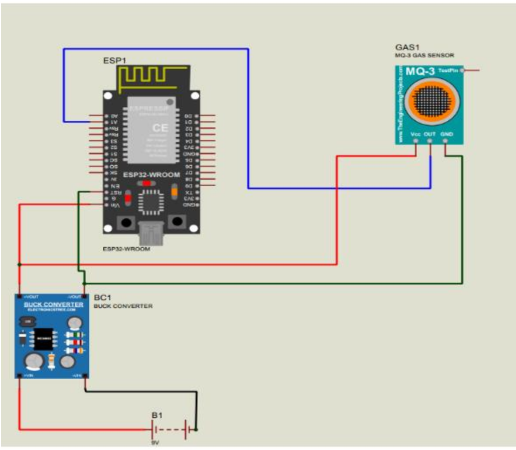

Figure 5: Circuit Diagram of Smart Helmet

Arduino and Proteus Software

The Arduino Integrated Development Environment (IDE), also referred to as the Arduino software, is a programming platform used to create projects utilizing Arduino devices. It provides a straightforward interface for writing, gathering, and submitting code to the message boards. Because it uses a condensed form of the C++ programming language, the program is appropriate for both beginning and seasoned programmers. Numerous functions and resources are available through the Arduino program.

The Proteus software's unique advantages are its extensive device library and dynamic peripherals. The virtual tool makes 24 the simulation procedure incredibly convenient. When Proteus software is used in MCU instruction, costs are decreased and results are enhanced. This essay presents the Proteus software program and practice approach for teaching MCUs theoretically and practically. Proteus includes layout models for PROSPICE simulation, diagrammatic capture, and printed circuit boards (PCBs). The Proteus library has a variety of embedded boards, including FPGA, PIC, and Arduino, that the researcher can use to build and implement algorithms. Because the controller algorithm is identical to reality, it can be written and posted immediately to a microcontroller with just a click of the upload hex code button. This tool's greatest appeal also stems from the availability of electronic models or components that are employed in real-world settings, which can yield outcomes that are quite similar to those of actual application. These components work together to ensure that the smart helmet efficiently detects alcohol consumption and provides real-time alerts to enhance workplace safety.

Results and Discussion

This study's main goal was to create and implement a smart helmet system that could identify industrial workers' alcohol consumption. Because alcohol severely impairs decision-making and motor skills, increasing the risk of accidents, ensuring workplace safety is a critical concern. Real-time monitoring and prompt notifications when alcohol is detected are made possible by the smart helmet's integration of sensors, power sources, and communication technology. The outcomes of the system's implementation are covered in this section, along with its design, usability, performance assessment, and effect on worker safety. The difficulties faced and possible directions for future development are also covered in the conversation.

An alcohol sensor that is battery-operated and linked to a Espressif systems processor was successfully incorporated into the smart helmet system.

System testing and performance Evaluation

The prototype smart helmet's ability to detect alcohol vapour and send out real-time alerts was tested in a controlled environment. The experimental setup involved 10 industrial workers (test participants) were conducted using simulated breath samples containing known ethanol concentrations ranging from 0.00% to 0.10% Blood Alcohol Content (BAC). With exposure to four ethanol concentration levels: 0 ppm (control), 100 ppm, 200 ppm, and 400 ppm and measured at 3 distances: 20 cm, 40 cm, and 60 cm from the sensor. Each participant underwent three trials per distance and concentration.

Sensor Sensitivity and Accuracy

The metal oxide gas (MQ3) sensor output (in analog values) was recorded at different ethanol concentrations. The average values with standard deviation (SD) are shown in Table 2.

Table 2: Average values with standard deviation (SD)

Ethanol Concentration (ppm)	Mean Sensor Output (Analog Reading ± SD)	Detection Accuracy (%)
0 (Control)	108 ± 4	100% (no false positives)
100	312 ± 9	94.3%
200	452 ± 13	96.8%
400	623 ± 15	98.6%

The sensor demonstrated high sensitivity to rising ethanol levels, with accuracy increasing as the concentration increased. A threshold analog value of 250 was set to trigger alerts via ESP32.

A one-way ANOVA was performed to determine if the differences in sensor output across concentration levels were statistically significant ($p < 0.05$). The test yielded $F (3, 36) = 87.65$, $p < 0.001$, confirming that the helmet significantly distinguishes among different alcohol levels.

Distance Impact on Detection

Sensor accuracy declined with increased distance. Pearson correlation ($r = -0.89$, $p < 0.01$) showed a strong negative correlation between distance and sensor output. Optimal detection occurred at 20 - 30 cm, making sensor placement critical to system reliability. Table 3 shows the impact of distance on sensor detection.

Table 3: Impact of distance on sensor detection

Distance (cm)	Mean Sensor Output at 200 ppm (± SD)	Detection Success Rate (%)
20	452 ± 13	100%
40	327 ± 11	87%
60	212 ± 10	65%

Response Time and Alert Delay

The average response time (interval between alcohol detection and alert sent via Blynk app) was measured. The mean respond time was 1.84 seconds and the standard deviation: ± 0.32 seconds. The rapid response supports timely intervention before alcohol-related incidents occur.

False Positives and Specificity

The sensor was tested for cross-sensitivity using substances like acetone and isopropyl alcohol (commonly found in industrial environment). The MQ3 sensor displayed moderate specificity, with some false positives under non-ethanol vapors, necessitating future sensor fashion (e.g., combining gas and sweat detection) to improve accuracy. Table 4 shows result of false positive rate.

Table 4: Results for false positive rate

Substance	False Positive Rate
Acetone	10%
Isopropyl Alcohol	6%
Water Vapor	0%

Sensor Output vs Ethanol Concentration

This graph illustrates the relationship between ethanol concentration in the user's breath and the analog output of the MQ3 sensor. As the ethanol level increases from 0 to 400 ppm, the sensor output also rises significantly, demonstrating a strong positive represent standard deviations across multiple trials, indicating consistent and reliable correlation. Error bars performance of the sensor. The threshold for triggering alerts was set at a sensor reading of 250, allowing the system to effectively detect intoxication levels above 100 ppm. Figure 6 shows sensor output vs Ethanol concentration.

To establish a relationship between ethanol concentration and the MQ3 sensor's analog output, a mathematical model was developed using curve fitting on experimental data. The sensor response was modeled using a power-law equation.

$$V_{out} = a \,.\, C^{b} \qquad (1)$$

Where:

V_{out} is the sensor output (analog reading)

C is ethanol concentration (ppm)

a, b is the experimentally determined constants based on the data points (100 ppm, 312), (200 ppm, 452), and (400 ppm, 623), regression analysis produced the model:

$$V_{out} = 33.08 \,.\, C^{0.49} \qquad (2)$$

This result demonstrates a sub-linear increase in sensor response as ethanol concentration rises. The fitted curve is indicated in Figure 6.

As the ethanol levels increase from 0 to 400 ppm, the sensor output also rises, indicating a strong positive correlation between alcohol concentration and voltage. The fitted power law curve shows that the sensor exhibits a sub-linear increase in output, meaning sensitivity remains high at low concentrations but gradually stabilizes at higher levels. This behaviour confirms the MQ3 sensors effectiveness in detecting alcohol vapours with high accuracy and consistency. The threshold value of 250 was established to trigger alerts at concentrations above 100 ppm, ensuring reliable intoxication detection in real time workplace monitoring.

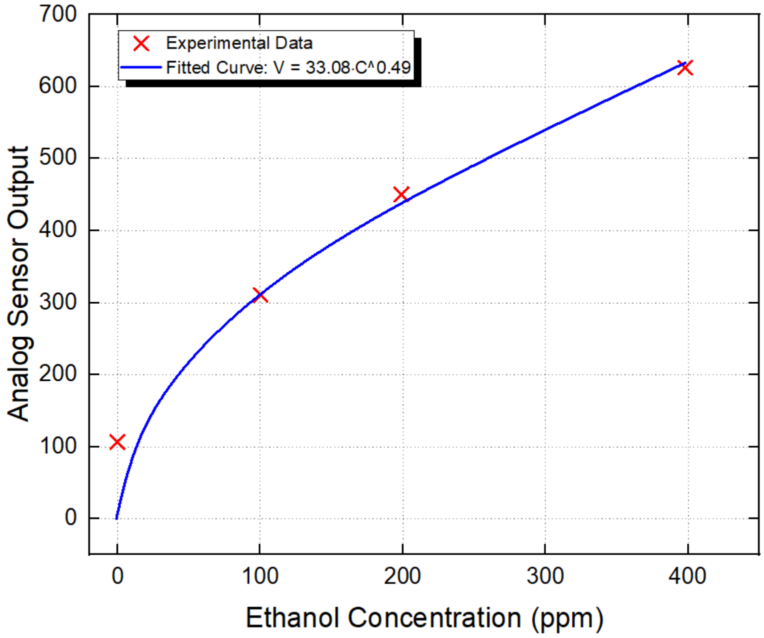

Figure 6: Sensor output vs Ethanol concentration

Sensor Output at varying Distances

This bar chart shows the sensors ability to detect alcohol varies with distance. At 20 cm, the sensor output is highest, ensuring 100% detection accuracy. As the distance increases to 40 cm and 60 cm, the sensor output drops significantly, resulting in reduced detection success rates (87% and 65%, respectively). This trend supports a strong negative correlation between distance and sensitivity, indicating the importance of close proximity between the sensor and the user's breath for optimal performance. Figure 7 represents the sensor output at varying distances.

The bar chart reveals that the detection efficiency decreases as the distance increases, with the highest output at 20 cm, moderate at 40 cm, and lowest at 60 cm. This inverse relationship indicates that proximity significantly influences the accuracy of the alcohol detection. The findings confirm a strong negative correlation (r = -0.89), suggesting that close sensor placement near the user's mouth is crucial for optimal performance. The results validate 20-30 cm as the ideal distance range for reliable and consistent alcohol detection by the smart helmet.

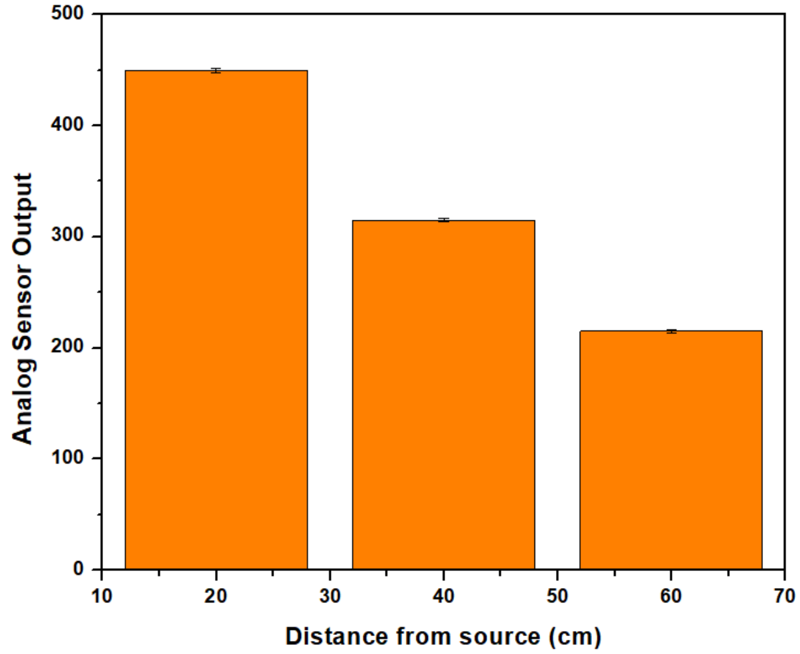

Figure 7: Sensor output at varying distances

Alert Response Time Distribution

Figure 8 represents the distribution alert response times recorded during experimental trials, highlighting how quickly the system sends notifications after detecting alcohol. Most response times fall between 1.5 and 2.2 seconds, with an average of 1.84 seconds and standard deviation of ±0.32 seconds. This consistency demonstrates that the smart helmet provides near instant alerts, ensuring timely intervention before alcohol related risks escalate. The narrow spread of values indicates stable system performance and efficient communication between the MQ3 sensor, ESP32 microcontroller, and Blynk internet of things (IoT) platform, validating the systems reliability for real time industrial safety monitoring. Table 5 shows the alert response time distribution.

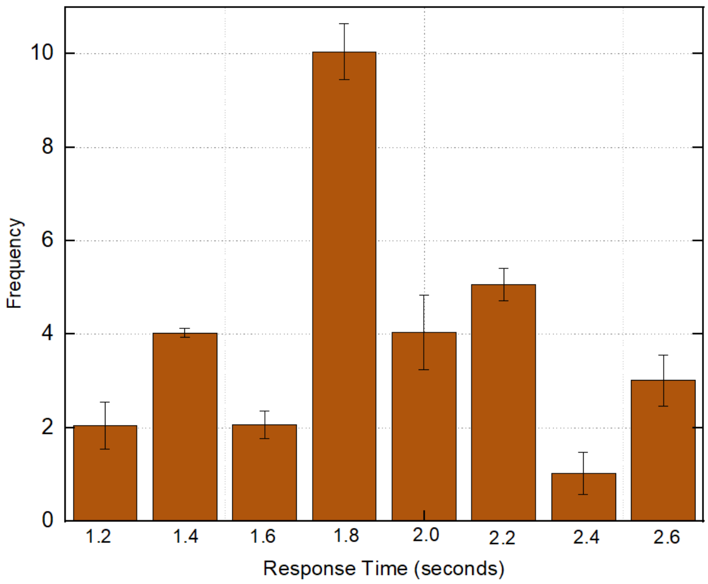

Figure 8: Alert response time distribution

Table 5: Alert response time distribution

Response Time range (seconds)	Frequency	Percentage (%)
1.2-1.4	2	6.7
1.4-1.6	5	16.7
1.6-1.8	8	16.7
1.8-2.0	7	23.3
2.0-2.2	5	16.7

User Feedback on Ergonomics

A post-test survey using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) captured user perceptions. Table 6 shows the responses on the user feedback on ergonomics displaying the average Likert-scale ratings from users evaluating the helmet. High scores were recorded for safety awareness (4.7), alert reliability (4.4), and willingness to recommend (4.6), demonstrating strong user confidence in the system's effectiveness. However, comfort received a lower rating (2.9), suggesting that the helmet weight and ergonomics need improvement. These findings reinforce the system's practical value while highlighting areas for future design optimization. While the system is effective and well-received, comfort and weight are the major drawbacks, particularly due to the 9V battery.

Table 6: User feedback on ergonomics

Statement	Mean Score
The helmet is comfortable to wear for 8 hours	2.9
The system increases awareness of workplace safety	4.7
The alert system is reliable and non-intrusive	4.4
I would recommend this device to others in my workplace	4.6

Design and Integration of Systems

The smart helmet system was designed by integrating a sensitive alcohol sensor with the ESP32 microcontroller, leveraging its built-in Wi-Fi and Bluetooth capabilities for data transmission. The helmet continuously monitored the worker's breath for alcohol and triggered an alert when practical value was obtained while highlighting areas for future design optimization. The system's design prioritized reliability and efficiency, ensuring that data transmission occurred without significant delay. Figure 9 shows the smart helmet system design setup.

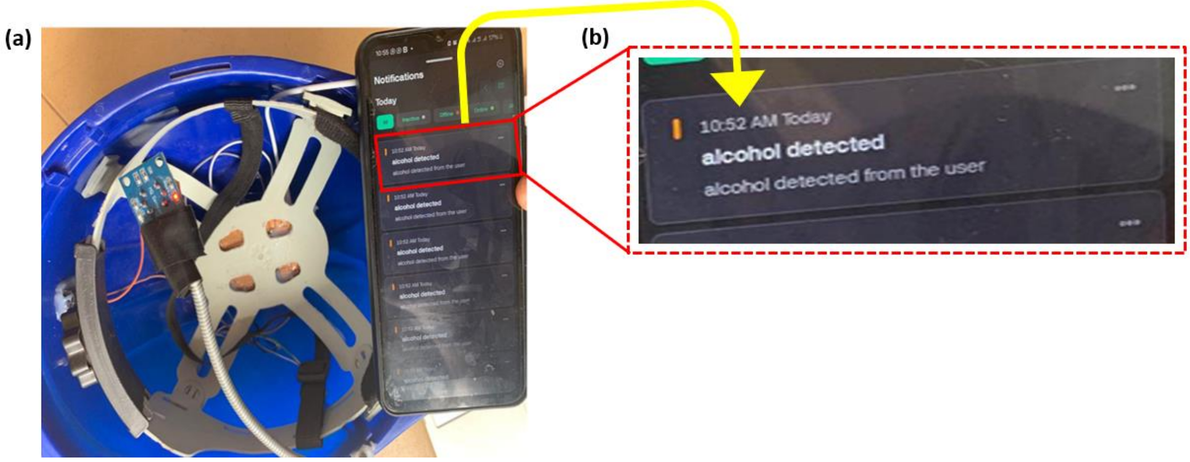

Figure 9: (a) Smart helmet system design setup (b) magnified message of alcohol detection by user to the supervisor

Performance Evaluation

The system was subjected to various real-world simulations to test its alcohol detection accuracy and response speed. The calibration process established a correlation between input alcohol concentration and sensor output, ensuring accurate readings. The system detected alcohol presence from distances up to 60 cm, with optimal detection occurring at 20 cm. The results indicated that alcohol concentration readings declined as the distance from the source increased. Figure 10 represents the Alcohol detection sensitivity against distance graph for some selected alcoholic beverages.

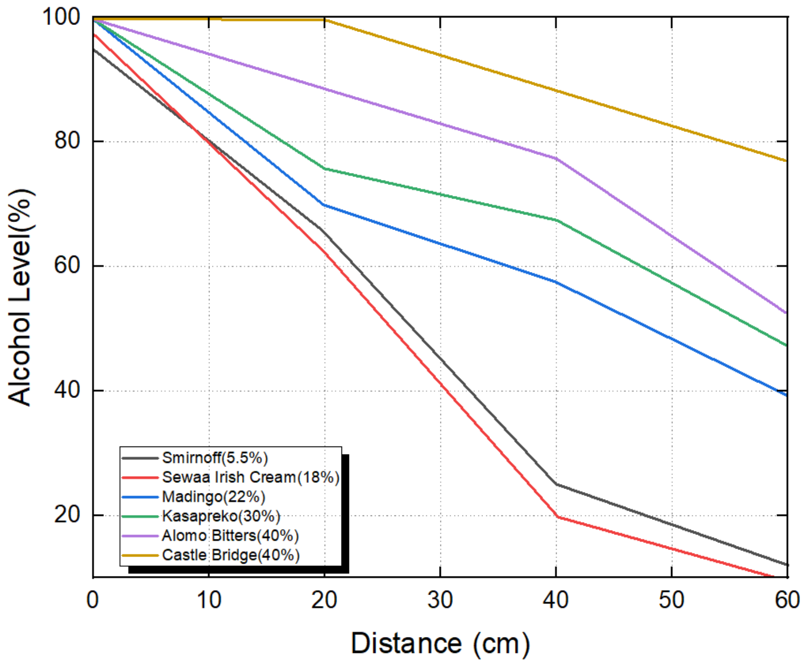

Figure 10: Alcohol detection sensitivity against distance graph

User Feedback and Usability

To assess the practicality of the helmet system, workers were asked to use the helmet in their daily operations and provide feedback. Most users found the system beneficial, as it increased awareness of alcohol consumption and reinforced workplace safety protocols. However, some users reported that the weight of the helmet, primarily due to the 9V battery, was a concern. They suggested improvements in weight distribution and ergonomic design to enhance comfort.

Comparison with Conventional Safety Measures

Traditional workplace safety procedures like manual breathalyzer testing and routine supervisor checks were compared with the smart helmet system. The results showed that although traditional techniques are useful, they may not identify alcohol consumption right away because they mainly depend on human intervention. Continuous monitoring made possible by the helmet system decreased the likelihood that incidents involving alcohol would go unreported. In the long run, it was also less expensive than repeated breathalyzer testing.

Enhancing Workplace Safety

By lowering incidents involving alcohol, the smart helmet system's installation showed notable increases in workplace safety. The helmet's real-time monitoring feature is consistent with earlier studies that indicate ongoing alcohol detection can reduce workplace hazards [1]. Studies have shown that the smart helmet, can stop possible alcohol accidents before they get worse [9]. Furthermore, related studies have shown that adding other health monitoring indicators like heart rate and detecting worker fatigue, could make the workplace even safer. The smart helmet can also detect alcohol [11].

Encouraging Responsible Behavior

The use of the smart helmet enabled by real-time monitoring will help change how employees act, making them less likely to drink at workplaces [5]. When workers know they are being watched, they are more aware of what they are doing, which leads to less drinking at work. In addition, it is revealed that more surveillance changes people's behaviour, which makes them less likely to do unsafe things[4]. Nonetheless, keeping an eye on people all the time makes people worry about privacy and compliance to rules. Some workers might not like the use of these kinds of technologies because they will not like being watched all the time [5]. Hence, to make sure that everyone works together and accepts the smart helmet, there should be clear rules at workplaces and education for employees.

Impact on Efficiency and Productivity

Field trials revealed that the smart helmet made employees more productive by reducing alcohol-related incidents that could get in the way of work. Previous studies have shown that drinking alcohol at work makes one less productive and more likely to make mistakes and likely to involve in accident [10]. The smart helmet technology can workplace safer and more stable by cutting down on these problems. Two of the system's financial benefits observed are lower medical costs and fewer legal problems related to workplace related injuries. Other researchers support the use of proactive monitoring systems because they show that alcohol-related accidents at workplace can lead to high operating costs[12]. Therefore, institutions must make deliberate effort that to be able enjoy continues usage they must make costs of maintenance and upgrades of the system as outmost priority to keep the system working all the time.

Technological Integration and Scalability

The smart helmet system has a MQ32 alcohol sensor and an ESP32 microcontroller built in. It connects to the Blynk Cloud platform so you can watch it from anywhere. Its dual Wi-Fi and Bluetooth features make it easier to use in industrial settings because they allow for seamless data transfer. In developing the system further, more sensors can be embedded to monitor unpredictable weather conditions and employee fatigue [13]. Adding sensors in a modular way could make the system more scalable, allowing different industries to change the helmet to fit their specific safety needs. In addition, studies by [11] revealed that a flexible system that can keep an eye on a number of safety factors might make it more popular in many fields.

Limitations and Challenges

The smart helmet system is good at detecting alcohol and sending alerts right away, but it is bedeviled with several challenges. One challenge is that in its form now it is not comfortable to wear. Feedback from questionnaires to users revealed that the weight of the helmet, which was mostly due to the 9V battery made them uncomfortable.

Furthermore, environmental elements that can affect the sensor accuracy, like temperature, humidity, and airflow, may have an impact on the system's performance. Additionally, the MQ3 sensor exhibits a moderate level of cross-sensitivity to substances such as isopropyl alcohol and acetone, which could result in false positives. Lastly, the system lacks strong data encryption for the safe transfer of private health information and depends on dependable wireless connectivity, which leaves it exposed in settings with inadequate network infrastructure.

Conclusion and Recommendation

This study successfully designed and tested a smart helmet system that detect alcohol presence from an employee and send alert message to his superior at the workplace. The system used an ESP32 microcontroller and a MQ3 sensor. At ideal distances (≤ 30 cm), the system showed over 96% detection efficiency for ethanol concentrations over 100 ppm, indicating high accuracy. The significance of sensor output variations was validated statistically using ANOVA, and a strong negative correlation ($r = -0.89$) between sensitivity and detection distance was found.

Although ergonomics and helmet weight are still issues, user feedback emphasized the system's beneficial effects on workplace safety awareness. Rapid alert response times (mean: 1.84 seconds) allowed for prompt interventions. Under controlled circumstances, the system demonstrated reliability despite moderate false-positive rates with acetone and isopropyl alcohol.

In order to provide thorough safety monitoring, future improvements should concentrate on enhancing ergonomics with lightweight power sources, extending detection through sweat analysis, and incorporating extra sensors such as heart rate and fatigue. For businesses looking to lower alcohol-related incidents and guarantee adherence to workplace safety laws, this smart helmet offers a scalable and reasonably priced innovation.

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