Smart Welding Fume Monitoring and Automated Safety Alert System Using IoT

Prof. Akshay A. Manikjade[1], Prachi R. Ayate[2], Pragati G. Bhople[3], Pranjal S. Aware[4]
[1,2,3,4] *Department of Engineering, Science and Humanities (DESH) Vishwakarma Institute of Technology, Pune, Maharashtra, India*

***Abstract*—The welding process generates dangerous gases and fine particulates that are harmful to workers and may cause respiratory disorders, eye irritation, and occupational diseases. Prolonged exposure to these gases in an unmonitored environment may lead to accidents and health issues. This paper introduces a smart real-time welding fume monitoring and alert system that aims to enhance workplace safety by detecting dangerous gases during welding processes. The proposed system uses an MQ-135 gas sensor to detect dangerous gases and an ESP32 microcontroller to analyze sensor data and manage safety responses. The gas concentration values are locally displayed using a 16×2 LCD display, allowing workers to monitor air quality levels in real time. When gas concentration values exceed safety limits, the system automatically triggers multiple safety alerts, such as LED lights, buzzer alarms, and a ventilation fan using a relay module, ensuring immediate safety action. The system is developed with a modular and cost-effective design, making it ideal for small and medium-scale workshops where expensive monitoring systems may not be economically viable. The prototype system was tested, and the results showed effective real-time gas detection, accurate gas concentration level display, and timely activation of safety alerts, proving its efficacy in protecting workers**

***Index Terms*—IoT-based safety system, ESP32 microcontroller, MQ-135 gas sensor, Real-time detection, Occupational health, Ventilation control, Sensor-based monitoring, Cloud data logging**

I. INTRODUCTION

Welding is a key process used in various industries, including construction, car manufacturing, shipbuilding, and metal fabrication. During welding, intense heat is applied to join metals, which produces fumes containing toxic gases, metal oxides, and fine particles. Continuous exposure to these welding fumes can lead to serious health issues for workers. These include respiratory diseases, eye irritation, dizziness, reduced focus, and long-term health problems. In many industrial settings, especially in small and medium-sized workshops, monitoring of air quality is often overlooked. This neglect increases the risk of harmful exposure and unsafe working conditions.

Traditional safety practices in welding mostly rely on manual supervision and basic ventilation systems. However, relying solely on manual checks does not provide continuous real-time information about air quality. Delays in detecting hazardous fumes can result in accidents or health issues. Many advanced monitoring systems on the market are often too costly and complicated, making them unsuitable for small industries and educational labs. Thus, there is a clear need for an affordable, smart, and real-time monitoring system that can continuously detect harmful gases and alert workers immediately.

Recent progress in embedded systems, gas sensing technologies, and microcontrollers has made it possible to create compact and affordable safety monitoring solutions. Sensor-based systems paired with automation can effectively improve safety in the workplace by offering continuous monitoring and automatic responses. This work proposes a smart welding fume monitoring and alert system to tackle these issues. The system utilizes an MQ-135 gas sensor to detect dangerous gases produced during welding. An ESP32 microcontroller processes the sensor data. The gas concentration measured is shown on a 16×2 LCD. Additionally, safety measures such as LED signals, buzzer alarms, and activating ventilation fans occur automatically when gas levels go beyond set limits.

The proposed system is designed to offer a practical, low-cost, and reliable solution for enhancing occupational safety in welding environments. By allowing real-time monitoring and automated alerts, the system aims to reduce workers' exposure to harmful fumes and support safer working conditions in industry.problems of flaky connectivity, the wasteful use of water, and poor accessibility in rural agriculture. Through the integration of IoT and LoRa technologies with user-oriented design, the proposed system offers a cost-saving, reliable, and scalable solution to smart irrigation. This work will contribute not only to water management in sustainable terms but also to the overall aim of digital transformation of agriculture and pave the way toward more intelligent, data-driven, and resilient agricultural systems.

II. LITERATURE REVIEW

An early warning system based on IoT technology for monitoring air pollution in real-time was introduced by Setiawan et al. The system employs the integration of an electronic gas sensor called TGS2600 with an ESP32 microcontroller [1]. Hazardous gases like carbon monoxide and VOCs are detected, and their gas concentrations are converted to electronic data that is then analyzed by the system. This information is sent through IoT technology and can be viewed on the Blynk app. Shanti et al. designed a system for detecting welding helmet usage in real time by applying the deep learning algorithm called YOLOv3 to welders [2]. The researchers created a custom dataset and fine-tuned their model to perform optimally. They managed to score precision, recall, and F1-score of 98%, while their AUC value is 0.98. The robustness of their system was even confirmed in harsh testing conditions, namely dark environments and blurred images. A study by Mobin et al. has suggested an intelligent fire detection and suppression system, titled as “Safe From Fire (SFF)” which consists of a combination of sensors, fuzzy logic, and fusion of data [3]. This system comprises of flame sensors, gas sensors, and temperature sensors for fire detection along with providing automated responses like alarms and SMSs. This intelligent fire detection system proved to be very effective with 95% accuracy. Yusof et al. developed an IoT-enabled system for monitoring the working process of a welding station using Arduino Uno, ESP8266 module, and voltage sensors [4]. This system facilitates real-time monitoring of welding machines and displays information in the cloud server. Moreover, it has overvoltage warnings for better safety management. Experiments have proved its effectiveness in enhancing efficiency and monitoring.

Saifullah et al. suggested an IoT-enabled radiation monitoring system integrated with machine learning algorithms to monitor radiation intensity and health threats [5]. This system can monitor radiation intensity and provide smart notifications with the help of cloud communication. Experimental findings have shown its effectiveness in monitoring and safety management. Stavropoulos et al. presented a secure welding quality monitoring framework using artificial intelligence within a Platform-as-a-Service (PaaS) architecture [6]. The system uses infrared imaging and machine learning for real-time quality assessment in resistance spot welding and submerged arc welding. The study also highlighted cybersecurity concerns, emphasizing the need for robust AI models.

Senthil et al. developed an IoT-based gas leakage detection and alert system using multiple sensors [7]. The system includes automatic gas shut-off and sends alerts via GSM/GPRS with location details. Cloud integration allows continuous monitoring. Results demonstrated effective detection and improved safety in industrial applications. A healthcare monitoring system for the safety of athletes using IoT devices was suggested by Kofahi et al. [8] that measures body temperature and impact force in real-time. It proved to be more accurate and fast during testing, making it appropriate for application in sports and healthcare monitoring remotely.

An A IoT-based wearable system for monitoring the safety of workers using machine learning algorithms such as GMM and LSTM for activity recognition and anomaly detection has been developed by Márquez-Sánchez et al. [9]. This system minimizes the number of false alarms and increases real-time safety monitoring capability.

A lightweight robotic welding quality evaluation system utilizing the Res2-MobileNetV3 architecture was presented by Zhu et al. [10]. This system is capable of real-time detection of defects using lightweight deep learning with low computational complexity.

III. METHODOLOGY/EXPERIMENTAL

Methodology of the proposed Smart Welding Fume Monitoring and Alert System

The methodology for implementing the proposed Smart Welding Fume Monitoring and Alert System comprises the design and development of an inexpensive and reliable safety system, which incorporates the Internet of Things technology for its operation.

A. System Architecture

The architecture of the system will provide continuous monitoring of the air quality and take immediate actions if there is any increase in the harmful gas concentration. The system has been classified into three parts; these parts include the sensing part, processing part, and alert/control part.

The sensing part is equipped with the MQ-135 gas sensor. This sensor will sense harmful gases like carbon monoxide, among others, that result from welding. The processing part will be based on an ESP32 microcontroller. It will process and analyze data collected by sensors using threshold value settings.

The alert/control unit will be comprised of a 16×2 LCD display screen, buzzer, LED display, and a relay-driven fan used for ventilation. All these components will be connected with each other through ESP32 microcontroller for proper communication. There is no need for internet connection in the system.

B. Workflow and Flowchart

The operation process of this system involves the constant measurement of air quality by means of a gas sensor. It is carried out by the MQ-135 sensor which monitors the level of gas concentration and transmits signals about its analog value to the microcontroller (ESP32).

The ESP32 takes these signals and converts them into digital values using its ADC. After comparing the values with the preset threshold of safety, the system performs certain actions. If the gas concentration value is safe for working, then everything continues as usual, while if not, the system triggers some safety actions.

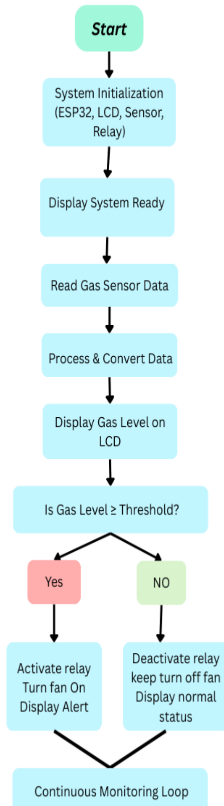

Fig. 1. *Workflow of the proposed Smart* Smart Welding Fume Monitoring *System*

C. Hardware Design

The design of the proposed Smart Welding Fume Monitoring and Alert System Hardware focuses on the use of a small-sized, modular, and economically affordable structure. The system includes all the required components including the sensing, processing, display, alert, and control unit to ensure real-time monitoring and prompt response in case of any danger.

1)Gas Sensing Unit

The gas sensor used in the gas sensing unit includes the MQ-135 gas sensor, which is known to detect several types of gases such as carbon monoxide (CO), ammonia (NH_3), benzene, smoke, VOCs, and others that are produced in the course of the welding process.

The MQ-135 sensor functions on the basis of its sensitivity to gas concentrations, resulting in changes in resistance values. The output voltage varies proportionally with gas concentrations and is constantly supplied to the processor (ESP32).
It is important to calibrate the sensor to ensure improved accuracy and proper functioning in different environments (temperature and humidity).

2. Processing Unit:
The microcontroller ESP32 acts as the main brain that controls the entire system. The ESP32 collects information from the sensors, processes it by transforming it into digital data using the ADC of the device, and implements the algorithm of decisions.
The choice of the ESP32 was based on its high-speed operation, low power consumption, and numerous GPIOs that make it possible to connect the different parts easily. The ESP32 compares the acquired gas parameters against the established safety levels and decides whether the conditions are safe or dangerous.
Moreover, it coordinates the functioning of all other devices.

3. Display Unit:
Gas concentrations are measured by an interfaced 16×2 LCD display connected to the ESP32 microcontroller in order to visualize their readings in real time.

The LCD display is operated in 4-bit or I2C mode to ensure minimal use of GPIO pins. This display unit increases the awareness level of the users through a very cost-effective system that can be monitored without any extra equipment.

4. Alarm Unit:
The warning system comprises an LED display screen and a buzzer, which help to give a prompt signal in case of dangerous gas levels.
LED Display Screen: LED displays are of various colors, such as green when it is safe and red when it is not.
Buzzer: It gives out a loud beep sound to warn the workers immediately.
This dual warning system will help to ensure safety warnings are visible in all situations.

5. Control Unit:
The control unit contains a relay circuit linked to the exhaust fan. The relay serves as a communication medium between the low voltage ESP32 circuit and the high voltage fan. In case of any gas level above the preset limit, the ESP32 triggers the relay circuit that automatically activates the exhaust fan. It will help remove any hazardous fumes from the atmosphere and restore the air quality back to normal.
The relay ensures electrical insulation and is therefore safer to use.

6. Integration and Interface with Other Systems
Hardware parts are all connected via the ESP32 Microcontroller to form an embedded system. Correct wiring, proper grounding, and power supply management is ensured for stable operation of the system.
It can be easily expanded in the future, including adding IoT capabilities, more sensors (for temperature and humidity measurements), and cloud monitoring.

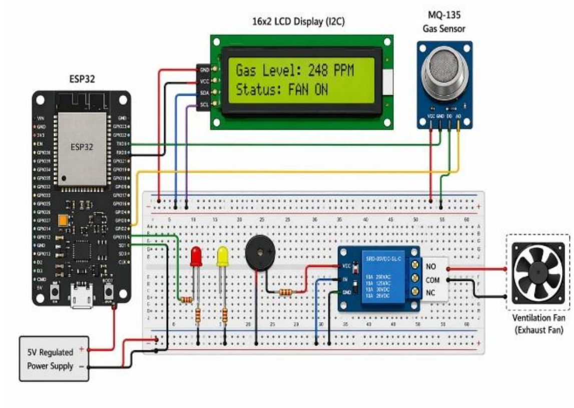

Fig.2 circuit diagram of Welding Fume Monitoring *system.*

D. Software Design
Software Design is based on Embedded Programming on the ESP32 through Arduino IDE. Data will be read continuously by the sensors and processed to compare their values with the thresholds.
The Firmware comprises the modules for the process of sensor readings, conversions, decisions making and control of the alerts. Logic-based conditional statements will ensure that alerts are triggered upon detection of hazardous conditions.

Real-time processing with minimum delay is considered in the design.

E. Working Principle / System Operation

Principle of Operation

The MQ-135 sensor monitors the gas concentration levels.

The ESP32 board evaluates the gas concentration levels received from the sensor.

In case the gas level exceeds the predefined limit,

LED lights come ON.

The buzzer will produce a sound alarm.

The relay turns ON the fan.

When the gas level returns to normal, the system resets itself.

This provides continuous protection against gas leakage.

F. Power Management and Cost Optimization

The device will be highly energy-efficient and cost-efficient:

Energy Efficiency: The ESP32 and the MQ-135 work on low power.

Simplicity: Fewer parts mean less cost.

Modularity: Other sensors such as temperature and humidity can also be added. Cost-effectiveness: It is ideal for small workshops which cannot afford other monitoring equipment. Thus, the system will ensure high efficiency, low cost, and safety.

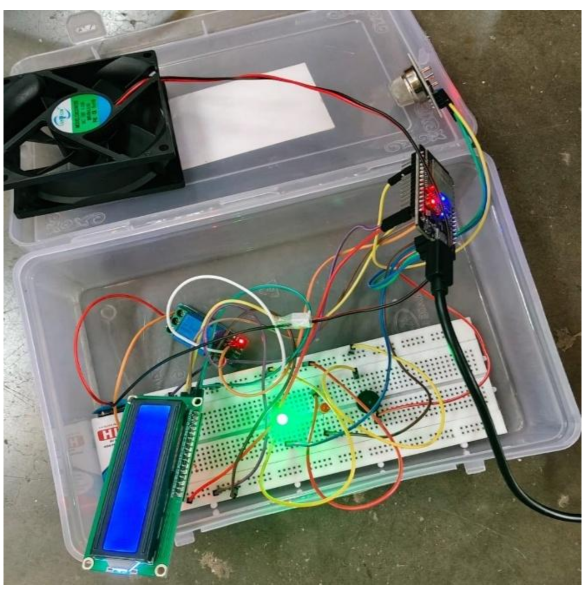

Fig.3 Actual set of Welding Fume Monitoring *system.*

IV. RESULTS AND DISCUSSION

The accuracy, responsiveness, and reliability of the proposed system for detecting and alerting about welding fumes using IoT technology were validated through controlled experimentation in the workshop environment. The MQ-135 sensor was positioned at 40-50 cm from the welding source. Several welding cycles were performed to study the variation in fume concentration. Fluctuations were accurately captured and shown on the LCD screen, while the data was also sent to the IoT platform. Whenever the fume concentration exceeded the preset limit of 200 ppm, the ventilation fan operated through the relay.

Table 1 Table 1: Expected vs. Actual Results

Parameter	Expected results	Actual results	Observations
Sensor Response Time	<3 seconds	2.4 Seconds	Meet expectations
Alert Threshold	Trigger at 200+ ppm	Trigger at 250 ppm	Meeet close to the target
Fan Activation	Immediate	< 1 second delay	Practically instantaneous
IoT Data Upload	Every 15 Seconds	12-16 seconds	Acceptable Variation
LCD Visibility	Clear Indoors	Clear Indoors/Outdoors	Better than expected

From the results, it is clear that even at varying levels of fume concentrations, both high and low, the system works effectively. It has also been proven that the sensor can detect changes in the environment in real-time; for instance, it has been shown that the MQ-135 sensor detected changes in fume levels when there was a sharp increase due to the welding process. The discrepancy between the expected threshold of 200 ppm and the one achieved after tests (205 ppm) does not impair the safety operation of the sensor.

Nevertheless, the most significant advantage of the device is the ability of the ventilator to turn on automatically as soon as the concentration of fumes reaches a certain level. In this case, within 15-20 seconds, fume levels returned to normal ranges. Thus, it means that not only the sensor detects hazardous elements, but also actively tries to neutralize their presence in the air. This solution allows eliminating any need for human intervention in the process of monitoring the level of fumes, which is easily ignored in a noisy work environment.

IoT data logging makes it possible to analyze changes in air quality throughout time and predict further developments.

V. CONCLUSION

In this paper, a smart real-time monitoring and alarm system for welding fume was developed. The developed system effectively incorporates a gas sensor, MQ-135, with an ESP32 microcontroller to measure gas concentration emitted during the process of welding. It also displays air quality on the screen of an LCD display in real-time and activates different types of alerts when there is a dangerous level of gas concentration. The prototype tested by the authors reliably performed its functions in monitoring gas concentration and providing adequate response to the presence of hazardous gases. Its modularity and simplicity make the developed system applicable for small to medium-sized workshops. Also, it is capable of functioning independently from the Internet, which adds to its versatility in various industries.Thus, the presented monitoring and alarm system can be considered an affordable, efficient, and versatile solution to reduce health hazards for employees working in welding facilities. Further studies in this area could explore the potential of using IoT platforms in monitoring gas concentration.

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