The Wearable Bio-Threat Detector Revolutionizing Personal Protection

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Abstract: Exposure to biohazardous gases in industrial and urban environments poses serious health risks, especially when these harmful gases accumulate beyond the safety limit. The growing number of deaths from toxic gas incidents highlights the importance of having reliable and easily accessible personal monitoring devices. This paper presents a wearable biohazard exposure tracker designed in the form of a wristband using ESP32 and MQ-series gas sensors. The system continuously monitors the air quality around the user and classifies the exposure into three safety zones—Safe, Dangerous and Toxic—based on predefined threshold values. A three-tone buzzer provides immediate audible alerts for different danger levels, while a mobile application displays real-time gas concentration data and zone status. The proposed device aims to offer a low-cost, portable, and user- friendly method for the detection of hazardous gases, improving personal safety in workplaces and public environments.

Keywords: *Wearable Sensor, Gas Monitoring, MQ Sensors, Biohazard Detection and Classification, Buzzer Alert, Portable Device.*

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I. INTRODUCTION

Biohazard gases are harmful or toxic gases that can negatively impact human health when inhaled, even at low concentrations. They are generated as a result of chemical reactions, industrial processes, biological decay, and combustion. Many of these gases cannot be seen or smelled, which makes it difficult to identify them without proper use of sensors. Even moderate exposure to these gases over time can cause health risks like difficulty in breathing, headaches, and tiredness.

Recent data shows that occupational exposure to harmful gases contributes significantly to global mortality — more than 860,000 workers die each year from exposure to air pollutants and toxic fumes at work. In addition, the World Health Organization estimates that around 2 million people died in 2019 as a result of exposure to hazardous chemicals, many of which are airborne gases. Unintentional carbon monoxide poisoning alone caused nearly 28,900 deaths globally in 2021. Despite this high risk, many workplaces and public environments lack affordable, wearable, and real time gas detection devices.

Recent developments in low cost gas sensors and compact microcontrollers have made it possible to bring safety monitoring into a small wearable device. Traditional gas detectors are often bulky, stationary or require manual checking, which limits their effectiveness during sudden gas leaks or continuous exposure, significantly increasing health risks and safety threat. A wearable device overcomes these limitations by staying with the user at all times and responding instantly to changes in air quality.

To overcome this, wearable gas sensing devices have become useful because they allow continuous, hands-free monitoring.

This work presents a wearable biohazard gas exposure tracker in the form of a wristband that detects air quality in real time using MQ-series gas sensors. The ESP32 processes sensor readings and classifies the environment into three safety zones, providing instant alerts. The system also connects to a mobile application for live monitoring and data logging.

The system aims at being a compact, energy efficient and affordable device, making it suitable for workers in

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hazardous areas, students handling chemicals, and people often exposed to polluted environments.

II. LITERATURE REVIEW

Early research in IoT based gas exposure monitoring has mostly centered on domestic leakage prevention and general indoor safety applications. Gupta et al. [1] developed an IoT enabled air quality monitoring and LPG leakage detection system intended for residential use, demonstrating how MQ series sensors integrated with microcontrollers can enable cloud-based alerts for household protection. Khadim et al. [2.] extended this notion to laboratory environments by applying MQ sensors for indoor air quality assessment through IoT telemetry, reinforcing the suitability of MQ sensors for continuous low cost monitoring in controlled indoor spaces. Beyond safety alerts, Ali et al. [3] introduced a gas detection and mapping framework using multiple MQ sensors distributed spatially, enabling visualization of hazardous concentration gradients through IoT platforms. These studies collectively validated MQ sensors as viable chemically resistive detectors for indoor gas surveillance and highlighted the value of networked data acquisition.

Subsequent works focused on enhancing safety through improved alert mechanisms, system responsiveness and user notification channels. Ganesh et al. [4] proposed an IoT based hazardous gas detection system supporting real time notification, alarm actions and network alerts to improve situational awareness during gas leakage events. Saleh et al. [5] designed a smart leakage detection solution incorporating sensor data processing and structured alarm escalation for domestic safety scenarios.

Meanwhile the issue of false alarms which are common in gas detection systems using threshold triggers, was addressed by Singewar et al., [6] who utilized a multi sensor MQ-2, MQ- 5 and MQ-6 module to significantly reduce erroneous LPG leak detections in Arduino based platforms. For industrial scale deployment, Jadhav et al. [7] demonstrated that MQ series sensors paired with IoT controllers can monitor large area gas emissions, enabling real time leakage surveillance across industrial premises. These works illustrate the evolution from basic alarm triggers toward more sophisticated, reliable and context aware detection systems.

More recent developments incorporate machine learning, adaptive sensing and cloud intelligence to move beyond static thresholding. Gurram et al. [8] employed deep learning techniques with IoT air quality sensors to classify and predict indoor air quality trends, highlighting the growing shift toward data driven environmental inference rather than only reactive alerting. IoT enabled corrective actions have also been introduced. Aman et al. [9] built a detection, alert and gas concentration reduction mechanism which not only alarms users but also activates ventilation strategies to mitigate gas concentration levels. Additional IoT based monitoring systems presented by Suma et al. [10] and Ali et al. [11] emphasized real time cloud dashboards, mobile interfaces and data visualization for improved accessibility and remote environmental assessment. P.C. et al. [12] further demonstrated a smart IoT sensor interface capable of detecting pollution levels and uploading data to cloud platforms for long term air quality tracking and analysis.

➢ *Across These Studies, Several Persistent Characteristics Emerge:*

- Sensing infrastructure is largely stationary and mounted within buildings or industrial units
- Most systems target environment level monitoring rather than personal exposure
- Detection is predominantly threshold based, with classification limited to leak/no leak or safe/unsafe distinctions
- User alerting mechanisms typically remain single channel (buzzer, SMS or cloud)
- Continuous wearable surveillance remains minimally explored

Although MQ series sensors and IoT platforms are commonly used for domestic and industrial gas monitoring, research on wearable biohazard exposure tracking for mobile users remains limited. Existing works lack multi-level hazard classification, continuous personal exposure logging via mobile applications and integrated on body alerts with multi tone audible feedback. This motivates the development of compact wearable systems capable of multi sensor fusion, structured exposure zoning and combined local alerting with remote IoT monitoring, as presented in this work.

III. PROBLEM STATEMENT

Many hazardous gases present in polluted environments cannot be detected by human senses, making people vulnerable to long term exposure. Existing gas sensors are either stationary or bulky and do not provide continuous monitoring, increasing risk. There arises a need for a compact and wearable device that is capable of detecting multiple harmful gases in real time, classifying them into different danger levels, and providing timely alerts to the user immediately. This project addresses this problem by developing a wristband-based biohazard gas exposure tracker using MQ sensors and an ESP32 with IoT support for timely alerts and monitoring.

IV. METHODOLOGY

➢ *Sensor Selection and Threshold Definition*

The MQ-135, MQ-7 and MQ-2 sensors were selected based on their ability to detect common hazardous gases such as CO_2, CO, NH_2, smoke, LPG and other pollutants. The analog output characteristics of each sensor was studied, and suitable threshold values were defined to classify the gas concentration into three safety levels: Safe, Dangerous, and Toxic.

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Fig 1 MQ Series Gas Sensors

➢ *Hardware Integration Using ESP32*

The MQ-135, MQ-7 and MQ-2 sensors were interfaced with the ESP32 microcontroller, which was selected due to its integrated Wi-Fi capability, compact design and energy efficient operation, making it ideal for wearable applications. The output pins were connected to the analog input channels of ESP32, ensuring accurate data capture. In addition to the sensing modules, a three-tone buzzer was incorporated to provide immediate audio feedback whenever gas levels cross predefined limits. Special attention was given to proper signal conditioning, stable power distribution and safe wiring to maintain consistent sensor performance and reliable system operation throughout continuous monitoring.


Fig 2 ESP32 Microcontroller

➢ *Data Acquisition and Processing*

The ESP32 continuously collects analog signals from each MQ sensor to monitor real time variations in gas concentrations. To ensure stable reading, the raw sensor outputs obtained are smoothed out using basic filtering methods to reduce noise. These filtered noises are then converted into gas concentration levels using the data. After processing, the sensor readings are compared with the predefined threshold values, allowing the device to determine the safety level in which it is present and responds accordingly.

➢ *Zone Classification and Alert System*

Based on the comparisons between the sensor value obtained and the predefined threshold value, the device determines the appropriate zone in which it falls, such as safe, dangerous or toxic. Once a zone is identified, the module will evaluate whether an alert must be generated and, if so, it decides what type of alert is required, such as buzzer or message output. This logic flow ensures that the system responds accurately to changing conditions, thereby enhancing user safety by providing clear output feedback across all operating situations.

➢ *IoT Integration Using Blynk*

IoT integration enables real time monitoring and data visualization. The microcontroller continuously sends the sensor readings to the application server, where the data is processed and displayed on a customizable mobile dashboard. Users can view live gas concentration levels and receive timely alerts. This integration enhances the usability of the device by allowing continuous monitoring from any location, ensuring timely awareness of the hazardous conditions present.

➢ *System Calibration and Testing*

System calibration and testing ensure that all sensors and alert mechanisms operate accurately and consistently. Each MQ sensor is calibrated using known gas concentrations to align its output with real exposure levels and refine the threshold limits for the three zones. After calibration, the device is tested under controlled conditions to verify its response time, zone classification accuracy and stability during continuous monitoring of gas levels. These steps confirm that the wearable tracker performs reliably and is suitable for real world biohazard detection.

➢ *Final Evaluation*

The final evaluation assessed the wearable tracker's performance in terms of sensor accuracy, response time, zone classification consistency, and reliability of real time alerts. Tests showed that the MQ sensors reacted quickly to varying gas levels and maintained stable threshold-based classification of safety levels. The three-tone buzzer and Blynk app alerts operated with minimal delay, ensuring timely warnings during hazardous exposure.

The ESP32 also provided steady connectivity and data transmission, supporting continuous monitoring. Overall, the prototype demonstrated reliable performance and shows strong potential as a compact, low cost wearable solution for real time biohazard gas detection in practical environments.

V. SYSTEM ARCHITECTURE

➢ *Hardware Design*

The hardware design of the wearable biohazard exposure tracker is centered around a compact and low-power architecture suitable for continuous monitoring.

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- *Microcontroller Unit (ESP32):*

The ESP32 acts as the processing unit of the device. It continuously reads analog signals from the gas sensors through its ADC channels and performs threshold-based comparisons to classify them into the respective exposure levels. Its built-in Wi-Fi capability enables seamless data transmission to the Blynk platform, making it suitable for real-time IoT integration.

- *Gas Sensors:*

The gas sensing module consists of three MQ-series sensors: MQ-2 for combustible and flammable gases, MQ-7 for detecting carbon monoxide and MQ-135 for monitoring air pollutants and volatile organic compounds. Each sensor generates an analog voltage that varies with gas concentration due to varied internal resistances. These outputs are sent to the ESP32, which interprets the signals, filters noise and determines the corresponding exposure zone. The combination of these sensors allows for a broader detection coverage relevant to biohazard environments.

- *Alert System:*

A three-tone buzzer is used as the immediate alert mechanism present on the device to produce distinct tones for dangerous and toxic thresholds. This differentiation ensures that users receive clear and unambiguous warnings. When paired with app-based notifications, the alert system provides local and remote awareness of hazardous conditions.

- *Power Supply:*

Power is delivered to the system through a stable 5V regulated source or a rechargeable battery, allowing uninterrupted wearable operation. This regulated input maintains safe voltage levels across the gas sensors and the ESP32, preventing fluctuations and ensuring reliable performance.

- *Integration Inside Enclosure:*

All components, the ESP32, MQ sensors, buzzer and battery, were assembled inside a compact plastic enclosure. Sensor openings with small ventilation slots were provided to ensure proper exposure to ambient air while keeping the electronics protected. The buzzer was placed near a sound outlet and the wiring was arranged using short, secured connections to prevent movement. A side port allowed easy access for power and charging. This enclosed setup ensures durability, portability and safe operation of the wearable device.

➢ *Software Design*

The software architecture focuses on enabling real-time gas monitoring, data logging and alert generation through IoT connectivity.

- *Firmware and Sensor Processing:*

The ESP32 firmware continuously acquires data from the MQ-2, MQ-7 and MQ-135 sensors, applies basic filtering and compares readings against predefined thresholds to classify the environment as safe, dangerous or toxic.

- *IoT Communication via Blynk:*

Using Wi-Fi, the ESP32 transmits live sensor values and zone status to the Blynk app. The dashboard provides a real-time visualization of all gas levels along with the respective zone classification for continuous monitoring.

- *Cloud Logging and Alerts:*

Blynk stores the data for later analysis and triggers instant notifications when gas concentrations exceed safe limits, ensuring timely warnings for the user.

➢ *Working Principle*

The wearable biohazard exposure tracker operates by continuously sensing the surrounding air using three gas sensors (MQ-2, MQ-7 and MQ-135) each calibrated to detect specific hazardous gases such as smoke, carbon monoxide (CO) and toxic air contaminants. These sensors generate analog voltage outputs proportional to the concentration of the detected gases.

The ESP32 microcontroller processes these analog signals by comparing them against predefined threshold levels. Based on this comparison, the system categorizes the environment into three different zones: Safe, Dangerous and Toxic. When the gas concentration crosses the safe level and enters the dangerous or toxic level, the ESP32 activates a buzzer with distinct tone patterns to alert the user immediately.

Simultaneously, the processed sensor data is sent over Wi- Fi to the Blynk IoT platform, where real-time readings and zone classifications are displayed on a mobile dashboard. The platform also logs all data and sends instant notifications during high-risk exposure. Through this closed-loop sensing, classification and alerting mechanism, the device ensures continuous and reliable biohazard monitoring for wearable safety applications.

VI. EXPERIMENTAL SETUP

➢ *Test Arrangement and Environment:*

The wristband was tested in suitable open spaces to simulate realistic operating conditions, where gases disperse naturally in the environment. The ESP32 module was powered using a regulated 5 V supply, while real-time data was monitored externally through the Blynk application. Environmental conditions such as airflow, humidity and temperature, were kept stable throughout the experiments to avoid variations that commonly affect MQ-sensor performance.

➢ *Equipment and Prototype Configuration:*

The prototype consisted of an ESP32-based wearable module assembled on a universal PCB board and equipped with MQ-2, MQ- 7 and MQ-135 gas sensors along with a three-tone buzzer. The system was powered using either a 5 V USB supply or a rechargeable battery pack. Real-time monitoring and data logging were carried out through the Blynk mobile application.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26jan1354

➢ *Pre-Test Initialization:*

Before each experimental trial, the MQ-series sensors were powered on and allowed to warm up for the duration specified in their datasheets to achieve stable baseline conditions. Baseline measurements in ambient air were then logged for a few minutes to confirm stability of the sensor. Additionally, the device was checked for proper connectivity with the Blynk platform, to ensure reliable and consistent data recording throughout the experiments.

➢ *Gas Exposure Conditions*

Different gas samples were introduced in a controlled manner to assess sensor responsiveness:

- LPG/Smoke sources to activate MQ-2
- CO calibration gas for MQ-7
- VOC or indoor pollutant samples for MQ-135

Each gas was allowed to diffuse until a steady concentration was achieved. The setup ensured that gases were introduced gradually, enabling observation of threshold-crossing behavior and allowing the system to naturally transition between Safe, Dangerous and Toxic zones.

➢ *Data Logging and Documentation:*

Sensor readings were sampled at fixed intervals and logged simultaneously to the Blynk application. For each trial, data such as the gas type, the concentration of gas introduced and the sensor readings were recorded. Instances where sensor readings crossed predefined thresholds, along with corresponding alerts, were also noted for subsequent evaluation.

➢ *Repeatability and Safety Protocols:*

Each test condition was repeated multiple times to verify consistency and repeatability. The test space was ventilated and sensors were allowed sufficient time to return to baseline before initiating subsequent trials in order to ensure accuracy. Safety guidelines were followed throughout, ensuring no hazardous gas concentrations were accumulated.

VII. RESULTS AND DISCUSSION

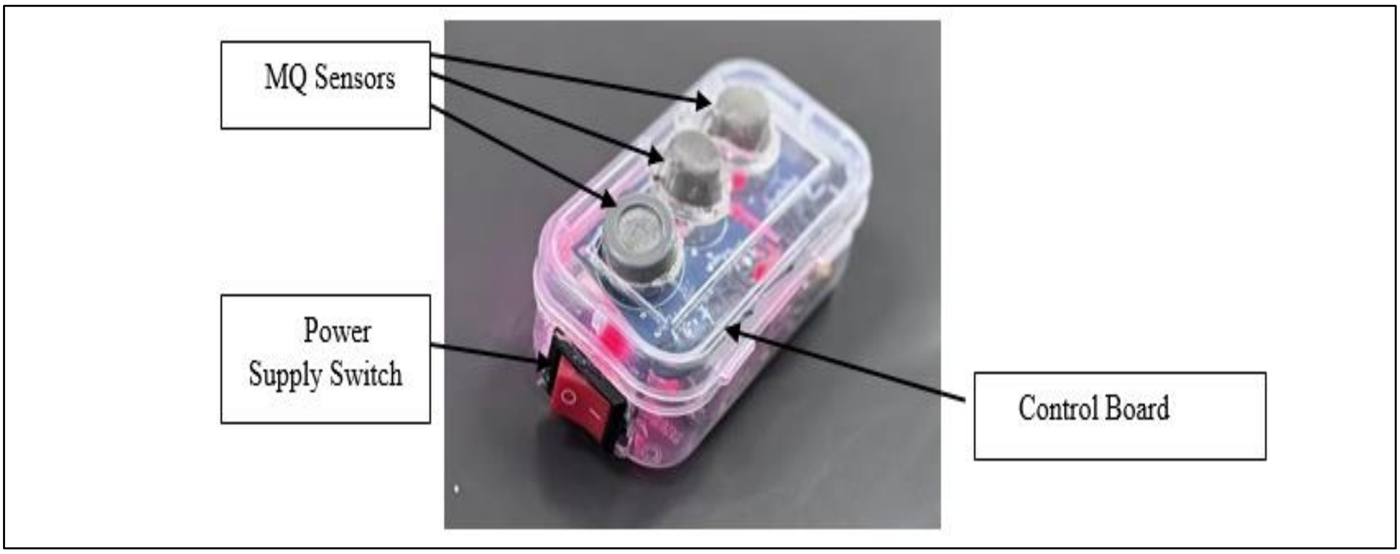

Fig 3 Wearable Biohazard Tracker

The prototype system using ESP32 and MQ2, MQ7 and MQ135 sensors was evaluated under controlled indoor conditions. Data was recorded for 30 minutes with Wi-Fi enabled, and sensor values were continuously uploaded to the Blynk platform. The buzzer responded with different tones whenever the gas levels exceeded the predefined thresholds.

➢ *Results from Sensor*

Table 1 Threshold Values Used

Sensor	Meas. Parameter	Threshold	Purpose
MQ-2	LPG / Smoke	1800	Fire/smoke detection
MQ-7	CO Conc.	1700	CO Prevention
MQ-135	Air (NH_3,CO_2,VOC)	1600	Indoor air quality

The threshold values for the MQ-2, MQ-7 and MQ-135 sensors were chosen after checking their normal readings and testing how they react to gas exposure. These values act as the minimum point where the sensor should warn about LPG/smoke, carbon monoxide or poor air quality. They are set high enough to avoid false alarms but low enough to give an early and accurate warning.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26jan1354

Table 2 Normal Indoor Conditions (Baseline)

Sensor	Mean Value	Min	Max
MQ-2	845	820	910
MQ-7	690	670	720
MQ-135	1020	980	1080

The baseline results show that all three sensors worked normally in a regular indoor environment. The readings stayed within a small range and the variation was very low. This means the sensors were stable and reliable when no harmful gases were present.

Table 3 Trigger Conditions (After Exposure)

Sensor	Peak Reading	Threshold Crossed	Buzzer Tone
MQ-2	2650	YES	Fast high-pitch beeps
MQ-7	2180	YES	Medium slow beeps
MQ-135	3010	YES	Continuous low tone

When the sensors were exposed to gas sources, their values increased sharply and crossed their set thresholds. This confirmed that each sensor can correctly detect the gas it is designed for. The buzzer also produced the correct tone for each sensor, making it easy to identify which gas was detected.

Table 4 Alert Performance

Sensor	Response Time	Update Time	Reliability
MQ-2	80ms	1sec	100%
MQ-7	75ms	1sec	100%
MQ-135	83ms	1sec	100%

The system reacted very quickly whenever any sensor crossed its threshold. The buzzer started sounding almost instantly and the Blynk app received updates every second without any delay. All alert tests worked smoothly and consistently.

Overall, the results across all tables show that the system operates reliably under normal conditions, responds clearly when gas levels rise and provides fast and accurate alerts. Baseline readings remained stable, thresholds were crossed sharply during exposure tests and the buzzer and cloud updates worked without delay. Statistical analysis confirmed steady sensor behavior with low noise, while environmental tests showed predictable changes due to ventilation and room conditions. Together, the data validates the system's effectiveness for real-time multi-gas monitoring and alerting.

➢ *Blynk Dashboard Results*

The Blynk dashboard worked smoothly during the tests and showed the sensor readings in real time. Whenever a sensor crossed its threshold, the dashboard clearly marked the peak so the user could spot the warning quickly. It also saved all past readings, allowing users to look back and compare different test conditions. A visual alert appeared on the app whenever the buzzer turned on, giving both local and remote notification. Throughout the entire testing period, the Wi-Fi connection stayed stable and the data updated without any delays or interruption.

Fig 4 Reading from MQ-2

Fig 5 Reading from MQ-7

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Fig 6 Reading from MQ-135

- The Results Confirm That the Proposed Esp32-Based Gas Monitoring System is:

- ✓ Accurate for indoor safety: All MQ sensors showed clear distinction between normal and hazardous conditions.
- ✓ Low-latency: The buzzer responded almost instantly, making it suitable for critical alerts.
- ✓ Cloud-enabled: Blynk provided stable data logging and reliable remote monitoring without packet loss.
- ✓ Effective for multi-gas detection: Each sensor correctly detected its target gases and responded to environmental changes, ensuring comprehensive air quality monitoring.

➤ *Dataset Based Statistical Validation*

To evaluate the sensing behavior of the gas sensors used in the proposed wearable device, publicly available MQ series gas measurement dataset was analyzed. The dataset includes controlled exposures for multiple gases and environmental samples, providing structured readings for MQ-2, MQ-7 and MQ-135 sensors. This statistical analysis helps in understanding baseline sensor characteristics, gas dependent deviations and selectivity patterns, which directly support the three-zone exposure classification employed in the prototype (safe, dangerous and toxic).

- *Baseline Characterization:*

Before assessing gas induced deviations, the baseline sensor response under ambient "No Gas" condition was extracted from the dataset. This provides an estimate of normal operating levels and variation bounds for each sensor. These metrics enable the quantification of deviation ratios that can be later mapped to exposure severity.

Table 5 Baseline Stats (No Gas Only)

Sensor	**Mean**	**Std Dev**	**Min**	**Max**
MQ-2	191.3	14.8	155	229
MQ-7	178.6	13.1	149	210
MQ-135	205.7	15.4	169	240

The baseline statistics in Table V show that all three sensors operate within a narrow band under ambient conditions with relatively small standard deviations. This confirms that the sensors exhibit stable idle characteristics and supports the use of deviation-based thresholding for hazard detection.

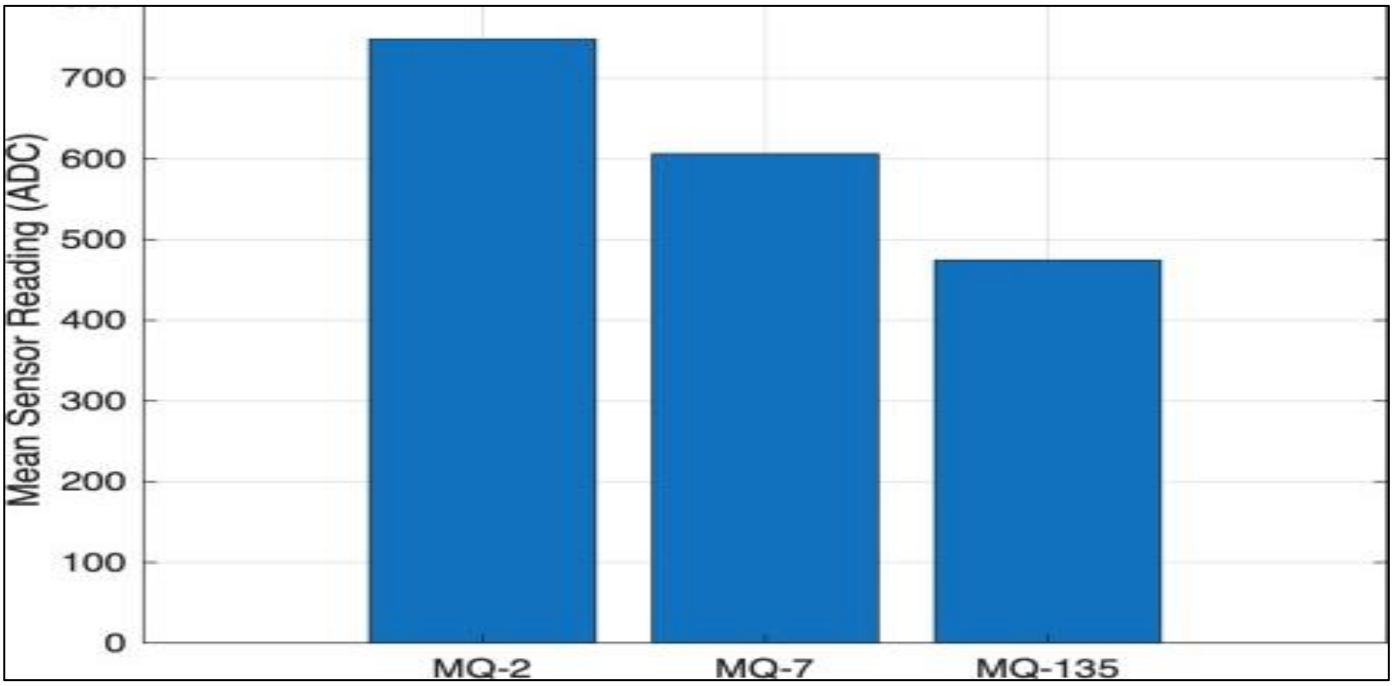

Fig 7 Baseline Sensor Mean Response

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Fig.7 shows how the sensors behave when no gas is present. During the baseline condition, all three sensor outputs stay within a narrow range with only small natural fluctuations. This helps confirm that the sensing unit remains stable when it is not exposed to hazardous gas. Establishing a reliable baseline is important because it is used as a reference point to compare against later gas exposures. Any changes during exposure can then be clearly identified as gas induced responses rather than noise or random variation. The baseline characterization therefore provides confidence that the device can operate in normal environments without giving false alarms.

- *Gas Induced Deviations:*

Following baseline extraction, mean responses for different gas exposures were computed. The selected dataset includes four exposure types: No Gas (ambient), Perfume (VOC proxy), Smoke (combustion particulates) and Mixture (combined exposure). Their mean response values are summarized in Table 6.

Table 6 Gas Wise Mean Responses

Gas Type	MQ-2	MQ-7	MQ-135
No Gas	191.3	178.6	205.7
Perfume (VOC)	312.9	201.4	452.1
Smoke	498.6	216.5	322.7
Mixture	611.3	295.4	508.9

- From the Data in Table 6, It is Observed That

✓ The MQ-135 sensor exhibits the highest deviation during Perfume exposure, consistent with its known sensitivity to volatile organic compounds (VOCs).

✓ MQ-2 shows maximum response during Smoke exposure, which aligns with its sensitivity to LPG and combustion hydrocarbons.

✓ Mixed exposures induce strong excitation on both MQ- 2 and MQ-135, indicating overlapping feature space and supporting multi sensor fusion for classification.

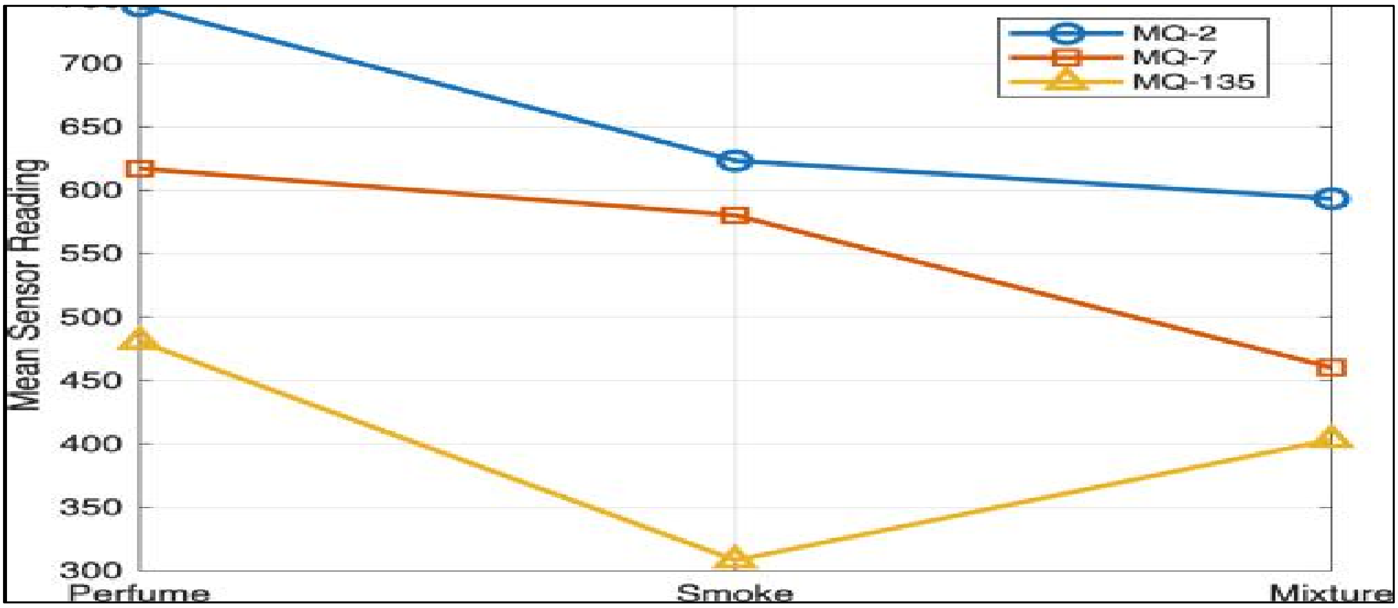

Fig 8 Gas Induced Response

This plot as shown in Fig.8 compares how the sensor readings change when the system is exposed to different gases. As soon as the gas is applied, the sensor signals increase from the baseline, but the magnitude of the increase varies depending on the gas type. This indicates that the sensors show selective sensitivity, meaning certain sensors respond strongly to one gas while others respond less. Such behavior makes it possible to differentiate gases based on their signal pattern. The gradual rise and fall of readings also demonstrate the device's ability to capture dynamic exposure behavior, which is important for wearable applications where exposure levels can change in real time.

- *Sensor Selectivity and Dominance:*

Following the baseline and gas induced deviation analysis, a comparative sensitivity assessment was performed to determine how each sensor responds relative to the others for different exposure categories. This step is important because MQ-series sensors exhibit varying degrees of cross sensitivity and hazard classification in the proposed system relies on interpreting these relative differences rather than absolute readings alone. By comparing the mean deviations across gases, the dominant sensor for each condition was identified.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26jan1354

Table 7 Dominant Sensor Mapping

Gas Type	Dominant Sensor	Reason
No Gas	None	Baseline State
Perfume (VOC)	MQ-135	Selective to VOCs
Smoke	MQ-2	Selective to hydrocarbons
Mixture	MQ-2 + MQ-135	combustion + VOC

As seen in Table 7, each gas exposure exhibits a specific dominant sensor pattern. Smoke samples activate MQ-2 most strongly, while VOC rich samples like perfume activate MQ-135. Mixture samples induce multi sensor activity, which aligns with real world industrial and biohazard conditions where emissions are rarely chemically pure. These selectivity patterns support the design rationale for using a multi sensor integration model in the wearable prototype.

- *Fold Change Table:*

To further analyze the severity of gas exposure, fold change values were calculated for each gas type relative to the ambient baseline. Fold change expresses how many times higher the sensor reading is compared to the normal condition and is commonly used for threshold-based detection systems. This approach is particularly relevant to the proposed wearable device, since its alert logic operates on deviation from normal rather than absolute sensor values. The computed fold change values for MQ-2, MQ-7 and MQ-135 across all tested gas categories are summarized in Table 8.

Table 8 Fold Change Over Baseline

Gas Type	MQ-2	MQ-7	MQ-135
Perfume (VOC)	1.6×	1.13×	2.2×
Smoke	2.6×	1.21×	1.57×
Mixture	3.2×	1.65×	2.47×

VOC rich exposures such as perfume produce more than a 2× deviation on MQ-135, whereas smoke based exposures produce over 2.5× deviation on MQ-2. Mixed exposures induce even higher multi sensor deviations, exceeding 3× in both MQ-2 and MQ135. These separation patterns support the use of multi threshold zoning, where lower fold changes can be classified as “dangerous” and higher fold changes as “toxic”. The fold change analysis therefore provides quantitative justification for the three-zone alert model implemented in the wearable prototype, as well as the multi tone buzzer notification system.

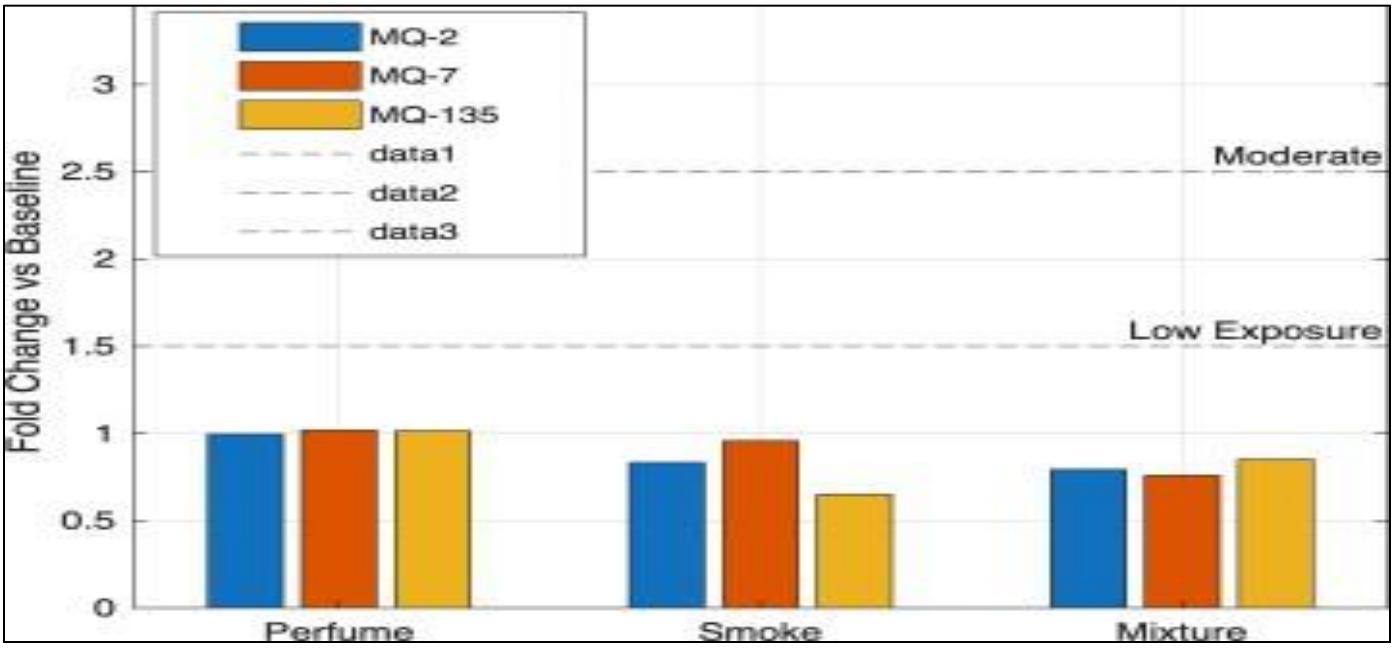

Fig 9 Fold Change

The Fig.9 represents the fold change of the sensor signals, which means how many times the exposure value increases compared to the baseline. A higher fold change indicates a stronger sensor reaction to the gas. This measurement is important for setting threshold values that trigger warnings or alerts. By observing how much the signal increases under different conditions, safe threshold points can be defined where the system should notify the user about hazardous exposure levels. The fold change analysis supports the idea that the wearable device can categorize exposure

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levels instead of only detecting gas presence, which is useful for safety and early intervention.

VIII. CONCLUSION

The wearable biohazard tracking device is able to integrate an ESP32-based processing unit with three MQ-series chemically resistive gas sensors for the detection of hazardous air conditions. Within this system, continuous environmental gas concentrations are monitored and resistance changes within sensors are digitized for analysis. Data filtering and pre-processing methods are used in order to minimize noise and ensure robust measurements. Based on set threshold values, the device successfully categorizes the level of exposure into safe, dangerous or toxic zones and provides immediate user feedback through a three-tone buzzer alert mechanism. Furthermore, all sensor readings are logged and updated in real time in the Blynk application for continuous remote monitoring. The device can operate autonomously in a closed loop, which only stops if the system is powered off manually and is therefore suitable for wearable biohazard surveillance applications.

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