Colorimetric Surveillance of Gas Leaks in Chemical Industries Using Bioindicator Monitoring System

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***Abstract*—Undetected leaks of hazardous gases and vapors in chemical industries pose significant risks to human health, safety, and the environment. This paper proposes a novel, eco-friendly, and scalable system for real-time detection of such leaks by leveraging the bioindicator properties of peat cushion moss. The framework combines biological sensing with computer vision (OpenCV), IoT-based environmental sensors, and a Blynk-enabled alarm system to ensure early detection and rapid response. Target chemicals include acetic acid (CH_3COOH), acetone (CH_3COCH_3), ethyl acetate ($C_4H_8O_2$), concentrated sulfuric acid (H_2SO_4), and ammonium hydroxide (NH_4OH). Moss samples are monitored using an ESP32-CAM module, with HSV-based image processing to detect progressive discoloration indicative of chemical stress. Additional environmental sensors, including DHT22 (humidity/temperature), LM35 (temperature), and KY-038 (sound levels), provide contextual data for accurate monitoring. Preliminary experiments show measurable moss color changes under chemical exposure, validating the system's potential as a sustainable, cost-effective alternative to conventional gas sensors for industrial safety and environmental monitoring.**

***Index Terms*—Bioindicator, Moss, Gas Leak Detection, Computer Vision, Colorimetric Analysis, Embedded Sensors, H_2SO_4, Vapors, Passive Sensing, Internet of Things (IoT), Toxic Gas Detection, ESP32-CAM, OpenCV, Blynk IoT, Predictive Maintenance.**

Introduction

Undetected gas leaks in chemical reactors, especially slow or low-concentration emissions in confined zones such as manhole gaskets, pose significant risks to worker safety, environmental compliance, and process continuity. Conventional detection systems, relying on point-based electronic sensors, often suffer from limited spatial coverage, high installation costs, and frequent calibration requirements. These limitations highlight the need for a more robust, scalable, and eco-friendly gas detection framework for industrial applications.

Background and Motivation Undetected gas leaks in chemical reactors, especially slow or low-concentration emissions in confined zones such as manhole gaskets, pose significant risks to worker safety, environmental compliance, and process continuity. Conventional detection systems, relying on point-based electronic sensors, often suffer from limited spatial coverage, high installation costs, and frequent calibration requirements. These limitations highlight the need for a more robust, scalable, and eco-friendly gas detection framework for industrial applications.

Bioindicators and Moss-Based Sensing Bioindicators are organisms that visually or physiologically respond to environmental stress and offer a promising lowcost alternative for detecting airborne chemical pollutants. Moss species are particularly suitable due to their sensitivity to toxic vapours and visible colour degradation under chemical stress. Notably, moss can partially revert to its healthy green state under favourable environmental conditions, enabling repeated use and enhancing the sustainability of such sensing systems. By monitoring these colour changes using computer vision techniques, moss can serve as a natural, distributed sensor for gas leak detection.

Proposed System Overview This paper proposes a hybrid sensing platform that combines a moss bioindicator with computer vision and IoT-based environmental monitoring to achieve real-time gas leak detection. The moss samples, monitored using an embedded ESP32-CAM module, are analyzed via hue saturation-value (HSV) segmentation techniques to detect color shifts indicative of chemical stress. Environmental parameters—including temperature, humidity, pressure, and sound—are concurrently measured to provide multimodal validation of biological responses.

To enable remote monitoring and rapid intervention, the system integrates a Blynk IoT platform for cloud-based data visualization, sensor dashboards, and event-driven push notifications. Alerts are triggered through thresholdbased sensor analysis and AI-assisted detection of moss colour changes, facilitating responsive and scalable deployment in industrial environments.

Related Work

Gas leak detection in industrial environments has been a focus of extensive research over the years, particularly involving the use of electronic sensors and optical systems. However, biological sensors—especially plant-based indicators—are gaining popularity due to their passive nature, eco-friendliness, and cost-effectiveness. This section summarizes previous research on biological sensing for environmental monitoring, with a focus on moss-based systems and their effectiveness in detecting chemical pollutants. It also reviews recent advancements in computer vision and artificial intelligence techniques for color-based stress detection in plants. These works form the scientific basis for our proposed hybrid gas detection approach and help contextualize the innovations introduced in this paper.

Biological Sensors for Environmental Monitoring

Biological sensors using algae, bacteria, and plants have been widely studied for pollutant detection. Algae show growth or fluorescence changes in response to toxins. Bacterial biosensors offer high sensitivity but require controlled conditions. Higher plants can reflect air pollution through pigment shifts, though they often lack real-time and robust field performance [1], [3].

Moss-Based Air Pollution and Heavy Metal Detection

Mosses, due to their surface-level absorption, are effective passive indicators of air quality. Chen et al. [1] used moss fluorescence to detect heavy metals. Md Yatim and Azman [3] validated moss sensitivity in polluted environments. Chaudhuri and Roy [5] reviewed moss bags as urban air monitors. These studies highlight moss responses (e.g., chlorosis, discoloration) to gases such as SO_2, H_2S, and CO.

Computer Vision in Colorimetric Plant Monitoring

Computer vision enhances plant health diagnostics by automating pigment analysis. Joy et al. [2] applied HSV colour detection to monitor stress. Ma et al. [6] used spectral imaging for leak detection via vegetation. Upadhyay et al. [7] and Harakannanavar et al. [4] showcased artificial intelligence for real-time plant stress recognition.

Gap in Existing Research and Our Contribution

Prior gas leak detection systems rely heavily on electronic sensors, which often face challenges such as frequent calibration, high costs, and limited spatial coverage. While moss-based studies have been explored for passive air quality monitoring and heavy metal detection, they remain observational and lack automation or integration with real-time industrial safety frameworks.

This paper addresses this gap by proposing a hybrid biotechnological system that:

- Implements real-time HSV colour analysis of moss samples using OpenCV and ESP32-CAM modules.
- Combines cork-based moss mounts and drip hydration to ensure resilience and reusability of the biological sensor.
- Integrates IoT-enabled environmental sensors (DHT22, LM35, KY-038) with Blynk IoT for mobile alerts and cloud visualization.

Proposed System

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Methodology

The methodology adopted in this study integrates biological sensing, embedded hardware, computer vision, and IoT-based communication to build a comprehensive gas leak detection platform. The subsections describe the system architecture, hardware and software components, image processing pipeline for moss color analysis, and real-time data communication with cloud platforms. Emphasis is placed on achieving modularity, low cost, and practical deployability in industrial settings. The integration of natural bioindicators with modern electronics supports early detection of hazardous leaks and helps maintain workplace safety.

System Architecture

The system comprises three functional layers:

1) **Biological sensing** using peat moss as a bioindicator.
2) **Electronic monitoring** of environmental parameters.
3) **IoT-based visualization and alerting** for real-time response.

The architecture enables early detection of toxic gas exposure and supports remote monitoring for scalable deployment in industrial settings.

Hardware and Software Implementation

TABLE I: Hardware Components Used

Component	Description
Peat Cushion Moss	Bioindicator for gas detection
ESP32-CAM	Captures moss images in real-time
ESP32	Microcontroller for data acquisition and control
DHT22	Humidity and temperature sensor
LM35	Analog temperature sensor
KY-038	Sound intensity sensor
BMP180	Barometric pressure sensor
Buzzer and LEDs	Audio-visual alert mechanisms

TABLE II: Software Tools Used

Tool	Purpose
Arduino IDE	Programming microcontroller firmware in C++
OpenCV (Python)	HSV-based color analysis of moss images
Python Scripts	Image processing and data forwarding
Blynk IoT	Real-time dashboard and mobile alerts

Temperature from LM35 Sensor

The LM35 sensor outputs an analog voltage proportional to temperature:

$$T(^{\circ}C) = \frac{V_{\text{out}} \times 1000}{10}$$

Where:

V out is the analog output in volts

The sensor has a scale factor of 10 mV/°C

Sensor Circuit Diagram

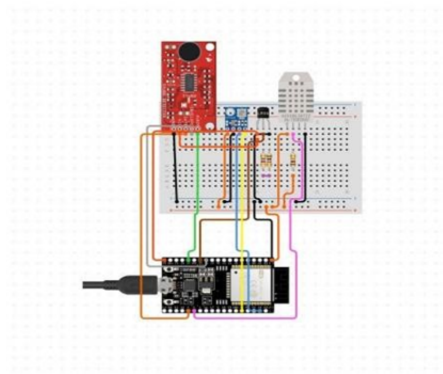

Fig. 1: **Circuit diagram showing** the integration of ESP32 with DHT22, KY-038, and BMP180 sensors for monitoring temperature, humidity, sound levels, and barometric pressure in the moss detection chamber.

Computer Vision and IoT Data Processing

Captured images are processed using OpenCV to analyze moss color variations. RGB images are converted to HSV space, where hue-based segmentation isolates healthy (green), stressed (yellow), and necrotic (brown) regions. The system quantifies discoloration as a percentage of the total moss area. Sensor data and computer vision results are transmitted to the Blynk IoT platform for cloud visualization and event-triggered alerts.

Experimental Setup

The experimental setup consists of a sealed glass chamber designed to create a controlled environment for testing toxic gas exposure on peat cushion moss. The moss sample is mounted on a cork-based substrate, which aids in moisture retention and provides a natural surface for growth. A drip irrigation system maintains the hydration of the moss during long-term experiments to preserve its viability.

Fig. 2: Complete experimental setup including ESP32-CAM, humidifier, drip system, sensors, and control circuitry.

A humidifier is incorporated into the chamber to simulate varying humidity levels and to release controlled quantities of water vapor and chemical vapors for testing. Toxic gases including acetic acid (CH_3COOH), acetone (CH_3COCH_3), ethyl acetate ($C_4H_8O_2$), concentrated sulfuric acid (H_2SO_4), and ammonium hydroxide (NH_4OH) are introduced through calibrated inlets in the humidifier.

An ESP32-CAM module is mounted above the moss to capture real-time images, while an array of white LED lights is positioned strategically within the chamber to ensure uniform illumination and minimize shadows, thus improving the accuracy of the computer vision algorithms.

Environmental sensors, including DHT22 (temperature and humidity), BMP180 (barometric pressure), LM35 (temperature), and KY-038 (sound detection), are embedded within the chamber to monitor environmental conditions in real time. These sensors are connected to an ESP32 microcontroller, which logs data and transmits it to the IoT platform.

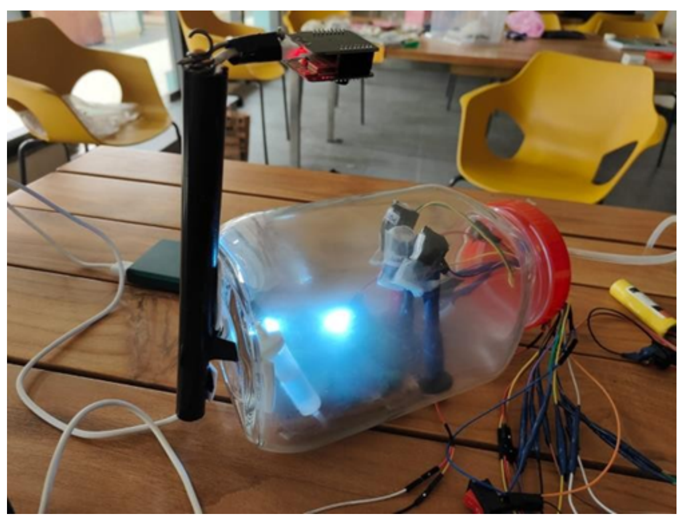

Fig. 3: Close-up of the sealed moss chamber showing cork substrate, white LEDs, and moss sample.

To ensure safety and operational reliability, the chamber is equipped with a pressure relief valve to prevent over-pressurization during chemical vapor release. The airtight design of the chamber ensures that no vapor leaks into the external environment during experiments.

Fig. 4: Drip irrigation system integrated into the chamber to maintain continuous hydration of peat cushion moss during extended exposure trials.

Moss Pigment Degradation via HSV Analysis

Change in moss pigmentation due to chemical exposure is quantified by comparing the green pixel intensity (typically in the V or S channel of HSV):

$$\text{Degradation (\%)} = \left(\frac{P_{\text{green initial}} - P_{\text{green final}}}{P_{\text{green initial}}} \right) \times 100 \quad (1)$$

Where:

- $P_{\text{green initial}}$: Initial green pixel intensity
- $P_{\text{green final}}$: Final intensity after exposure

Results and Discussion

This section presents the results obtained from laboratory experiments conducted on moss samples under controlled chemical exposure. The performance of the proposed system is evaluated based on colorimetric response, sensitivity to chemical concentration, and detection time. Key insights are drawn from pigment intensity measurements, graphical analysis, and comparative benchmarking with human observation. Through these analyses, we demonstrate the feasibility and advantages of using bioindicators for early-stage leak detection. Additionally, we highlight limitations, discuss sensor reliability, and evaluate how well the system performs under realistic environmental conditions.

Preliminary experiments showed measurable moss color changes under chemical exposure. Computer vision algorithms were found to outperform human observation in detecting subtle discoloration, enabling earlier intervention.

A. Chemical Concentration vs Time Response

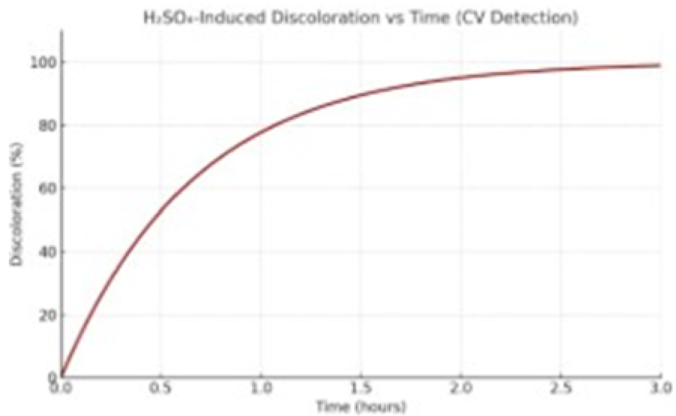

Fig. 5: Moss discoloration vs. time under H_2SO_4 exposure detected via computer vision.

moss samples exposed to sulfuric acid (H_2SO_4) over a 3hour period, as quantified by computer vision algorithms. The horizontal axis represents time in hours, while the vertical axis indicates the percentage of discoloration detected relative to the baseline green coloration. An initial rapid increase in discoloration is observed within the first 1 hour, with values exceeding 80% of total measurable pigment loss. The curve then exhibits a decelerating trend, approaching an asymptotic maximum near 100% discoloration. This saturation behavior indicates the completion of pigment degradation and tissue damage. These results confirm the effectiveness of computer vision techniques for continuous, quantitative monitoring of colorimetric changes in moss under chemical stress conditions. Compared to subjective visual assessment, computer vision provides higher temporal resolution and minimizes observer bias. is thidn too much to explain a graph under result?

B. Graphical Representation of Moss Health Over Time

This section presents the time-resolved colorimetric response of moss samples exposed to sulfuric acid (H_2SO_4), illustrating the progression through three distinct visual states—Healthy Green, Chlorotic Yellow, and Necrotic Brown—as detected by computer vision analysis.

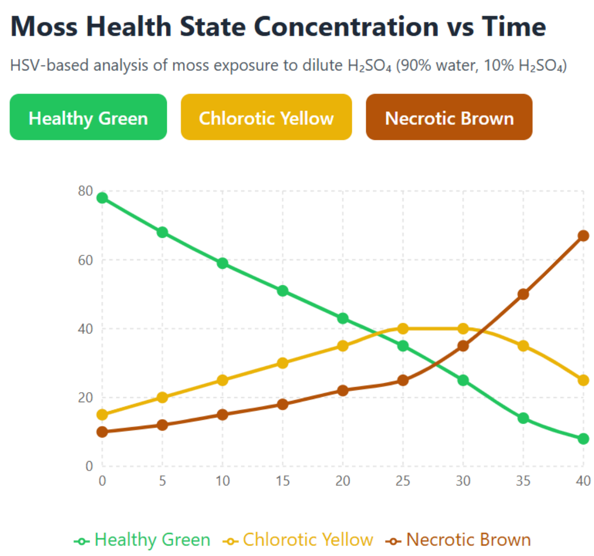

Fig. 6: H_2SO_4-Induced Moss Discoloration Over Time as Detected by Computer Vision.

The Healthy Green line steadily declines as chemical exposure increases, while Chlorotic Yellow rises and peaks during intermediate phases. Necrotic Brown indicates irreversible tissue damage and dominates in later stages.

C. Comparison: Computer Vision vs Human Observation

The effectiveness of the computer vision algorithm was evaluated against human visual observation. The CV system identified moss discoloration at approximately 45% pigment loss, utilizing HSV color segmentation to detect subtle hue shifts often imperceptible to the naked eye. In contrast, human observers recognized visible pigment degradation only after ∼60% discoloration, resulting in delayed detection.

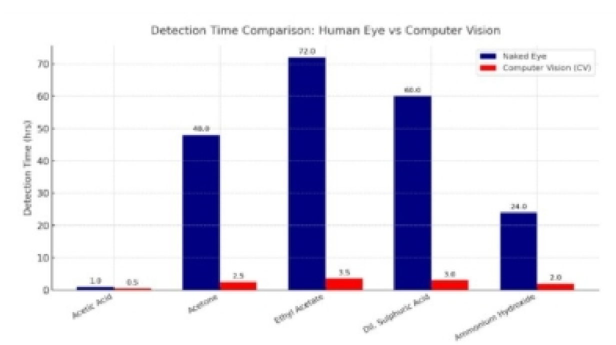

Fig. 7: Comparison of Detection Thresholds: Computer Vision vs Human Observation.

Future Scope

This project provides a strong foundation for safer and smarter gas leak detection using biology and technology together. There are several ways the system can be improved and expanded in the future:

1) **Identifying Specific Chemicals:** With more testing, the system can be trained to not only detect a leak but also identify which chemical is causing it by recognizing unique colour changes in the moss.
2) **Cloud Data and History Tracking:** Future versions can store all sensor data and moss responses in the cloud. This would help industries look at past records, spot patterns, and take better safety decisions.
3) **Large-Scale Deployment:** The system can be easily installed in multiple places inside a chemical plant. These units can all send data to one central dashboard for easier monitoring.
4) **Predictive Maintenance:** By analysing sensor data over time, the system can predict when something might go wrong—like pressure building up or a seal weakening—before a real leak happens.
5) **Industrial Automation Integration:** The system can be connected to existing factory automation systems. For example, if a leak is detected, it can automatically turn on fans or close a valve without waiting for human action.
6) **Better Biosensors:** More types of moss or other plant-based sensors can be studied to improve sensitivity, make the system respond faster, or survive in harsher industrial conditions.

Conclusion

This paper presents a novel gas leak detection system that combines biological sensing with computer vision and IoT-based monitoring. By using moss as a natural bioindicator, the system detects harmful chemical vapors through visible color changes, which are analyzed using HSV-based computer vision. Environmental sensors provide additional validation and improved reliability.

The system is low-cost, scalable, and suitable for areas where traditional gas sensors may fail—such as slow or low-concentration leaks near reactor gaskets. Real-time data and alerts are managed through Blynk IoT, allowing for remote monitoring and quick response. The project successfully demonstrates that integrating living materials with modern electronics can create safer and smarter industrial environments. With further improvements, the system has the potential to be used widely in chemical industries for continuous and intelligent leak detection.

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