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Development of an Innovative Multi-Surveillance Crawler for Confined Space Monitoring in Construction Management

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Abstract - The Confined Space Multi-Surveillance Crawler (CSMSC) is designed to enhance safety and efficiency in confined space operations by reducing human exposure to hazardous environments, minimizing accident risks, and improving data collection. It features a high-resolution camera that enables real-time visual inspection for remote hazard assessment. Additionally, advanced sensors continuously monitor gas levels, temperature, and humidity, providing crucial environmental data for informed decision-making and risk management. The feature of the CSMSC is its magnetic wheels, which allow seamless navigation on metallic surfaces, ensuring smooth movement and enhanced maneuverability in complex and hazardous areas. The crawler is remote-controlled, enabling operators to inspect confined spaces from a safe distance, further reducing risks to personnel. The Arduino IDE software, an open-source platform commonly used, is utilized for the design and testing of the CSMSC. This paper primarily focuses on its development for construction management, offering an innovative solution for confined space inspections by enhancing hazard detection, remote monitoring, and workplace safety. It is used for inspecting pipelines, tanks, and confined industrial spaces for leaks, corrosion, or safety hazards. In manufacturing, it aids in equipment monitoring and process optimization, while in construction, it ensures compliance and safety in underground utilities and tunnels. By integrating real-time surveillance, environmental monitoring, and advanced mobility, the CSMSC significantly improves confined space safety. Its broad applications make it a valuable tool for modern industrial and construction operations, enhancing efficiency, safety, and productivity.

***Key Words*:** Confined-space; Robot; Safety; Surveillance; Hazardous gas detection.

1.INTRODUCTION

Confined spaces in industrial environments remain hazardous due to restricted access, potential accumulation of dangerous gases, and other environmental risks. Despite strict regulations, accidents continue to occur. This project is motivated by the need for innovative solutions to enhance safety protocols. The introduction of mobile gas-sensing robots for inspecting LPG pipelines represents a significant advancement in leak detection technology. These compact, self-navigating robots, equipped with wheels or tracks, move along pipeline routes to function as mobile gas detectors. At the heart of the system lies a microcontroller, which governs the robot's movement while analyzing data collected from gas sensors. Typically, these sensors are either electrochemical or catalytic bead types, specifically designed to identify LPG leaks. Electrochemical sensors detect LPG molecules directly, whereas catalytic bead sensors utilize heat to initiate reactions with flammable gases.

For seamless communication, the robot is equipped with Bluetooth, allowing real-time data transmission to a remote control device, such as a smartphone or tablet running a specialized app. This enables an operator to track the robot's position, assess gas concentration levels, and receive instant alerts regarding potential leaks—all from a safe distance. By automating the inspection process, this robotic system offers a more efficient, cost-effective, and safer alternative to traditional methods, which typically require trained personnel to manually inspect pipelines using specialized tools. Additionally, the robot's ability to navigate through challenging environments makes it highly valuable for various industries, minimizing human exposure to hazardous LPG vapors.

Future advancements in this technology are expected to bring even greater improvements. Enhanced sensor accuracy will allow for more precise gas leak detection and measurement, while advancements in mobility will enable robots to operate in more demanding terrains. Moreover, integrating artificial intelligence will facilitate smarter autonomous decision-making, including automatic responses to detected leaks. These innovations will further strengthen pipeline safety, optimize efficiency, and lower operational costs, ultimately creating a safer work environment and reducing pipeline-related incidents [1] equipped with wheels or tracks, move along pipeline routes to function as mobile gas detectors. At the heart of the system lies a microcontroller, which governs the robot's movement while analyzing data collected from gas sensors. Typically, these sensors are either electrochemical or catalytic bead types, specifically designed to identify LPG leaks. Electrochemical sensors detect LPG molecules directly, whereas catalytic bead sensors utilize heat to initiate reactions with flammable gases.

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2. RELATED WORKS

Enhancing worker safety by reducing exposure to hazardous gas leaks is a critical priority, particularly in confined spaces such as storage tanks and underground tunnels. These environments pose significant risks due to the potential accumulation of dangerous gases. Traditional monitoring techniques often involve large, cumbersome equipment or require personnel to enter these hazardous spaces, increasing the chance of exposure. A revolutionary alternative is the development of a web-based mobile olfaction system, which enables real-time, remote monitoring of confined spaces. Picture a compact, autonomous robot outfitted with advanced olfactory sensors that mimic the human sense of smell, allowing it to identify a broader spectrum of harmful gases compared to conventional gas-specific detectors [2].

At the core of this system is a web-based platform accessible from any internet-connected device. This intuitive interface allows users to control the robot's movements, monitor sensor readings in real time, and configure alert notifications. The robot wirelessly transmits collected data, ensuring that monitoring can be performed remotely from a secure location, without requiring workers to physically enter the confined space.

This web-based solution provides multiple key benefits. Most importantly, it removes the need for direct human presence in hazardous areas, greatly enhancing safety. Additionally, the web interface offers real-time access to data from any authorized device, promoting collaborative monitoring and decision-making. Moreover, the system can integrate with various data analysis and visualization tools, enabling the creation of detailed gas concentration maps. These comprehensive insights are invaluable for accurately identifying leak sources and implementing appropriate safety measures. As sensor precision improves and robotic mobility advances, these web-based mobile olfaction systems have the potential to transform confined space monitoring, significantly enhancing workplace safety and operational efficiency.

Detecting gas leaks in complex industrial environments such as refineries and chemical plants has traditionally been both challenging and hazardous. Workers often spend significant time navigating these sites with bulky equipment, increasing their exposure to dangerous fumes. However, the advent of Autonomous Mobile Robots (AMRs) is transforming gas leak detection. These self-operating robots function as relentless sentinels, continuously monitoring work sites for gas leaks. Outfitted with advanced sensors, AMRs play a crucial role in modern leak detection. Their control system is based on the Android operating system, a widely used platform that ensures ease of programming and user-friendly operation. This system not only facilitates precise navigation but also processes data from the robot's essential components: gas sensors [3].

The AMRs rely on two primary types of gas sensors: electrochemical and catalytic bead sensors. Electrochemical sensors specialize in detecting specific gases, such as methane or propane, by reacting to their unique molecular properties. In contrast, catalytic bead sensors operate using a heated element that triggers a reaction with a variety of combustible gases, making them effective for detecting multiple types of leaks. These robots do not work in isolation. They wirelessly transmit sensor data using Bluetooth, enabling seamless communication with a remote control device such as a smartphone or tablet. Through a dedicated app, workers can track the robot's position on a digital map of the work site, view real-time gas concentration levels, and identify potential leak areas. Most importantly, the system can be configured to send immediate alerts if a leak are detected, allowing workers to respond swiftly while maintaining a safe distance. By enabling continuous remote monitoring, AMRs greatly enhance worker safety, reduce human exposure to hazardous environments, and improve the overall efficiency of gas leak detection.

Maintaining safety in environments where Liquefied Petroleum Gas (LPG) is present is of utmost importance. Conventional leak detection methods for horizontal pipelines, commonly found in refineries and storage facilities, are often labour-intensive and inefficient. Workers may spend hour's manually inspecting extensive pipeline networks, increasing their risk of exposure to harmful gas leaks. To address this challenge, an innovative approach has been introduced: an LPG leak detection robot utilizing the Arduino Uno platform. Picture a compact, mobile robot navigating along horizontal pipes, systematically scanning for leaks.
This robot operates using the Arduino Uno microcontroller, a widely used and user-friendly platform that controls its movement, processes sensor readings, and wirelessly transmits data for real-time monitoring. At the core of its detection system is an LPG sensor, typically an electrochemical type designed to identify specific LPG components such as propane. As the robot moves along the pipeline, the sensor continuously scans for any gas leaks, ensuring thorough and precise detection [4].

One of the most valuable features of this system is its wireless data transmission, often achieved via Bluetooth. This enables workers to monitor the robot's position and gas concentration levels remotely through a smartphone or tablet application. By eliminating the need for direct human presence near potentially hazardous leaks, this robotic solution significantly enhances workplace safety while improving the efficiency and reliability of LPG leak detection.

Mobile robots are revolutionizing gas leak detection by replacing conventional methods that are often hazardous and time-consuming. Instead of workers manually inspecting sites with handheld detectors, these autonomous robots efficiently patrol industrial areas, continuously scanning for leaks. Operating on an Android-based system similar to those used in smartphones and tablets, the robot's software manages both navigation and sensor data processing. Its sensors, which include electrochemical and catalytic bead types, are designed to detect leaks in different ways—electrochemical sensors identify specific gases, while catalytic bead sensors rely on heat to detect a broader range of combustible gases.

The robot wirelessly transmits real-time sensor data using Bluetooth, enabling remote monitoring through a smartphone or tablet equipped with a dedicated app. Workers can track the robot's position on a digital map, observe gas readings, and receive instant alerts if a leak is detected—all from a safe distance. A compact yet powerful Microcontroller Unit (MCU) processes the sensor data, interprets gas levels, and directs the robot's movements. One of the key benefits of this system is its cost-effectiveness compared to traditional gas detection methods, which often require expensive specialized equipment and personnel for manual inspections. The mobile robot's ability to autonomously navigate large areas, combined with the accessibility of the Android operating system and common technologies like Bluetooth, makes this solution both affordable and practical for a wide range of industrial sites.

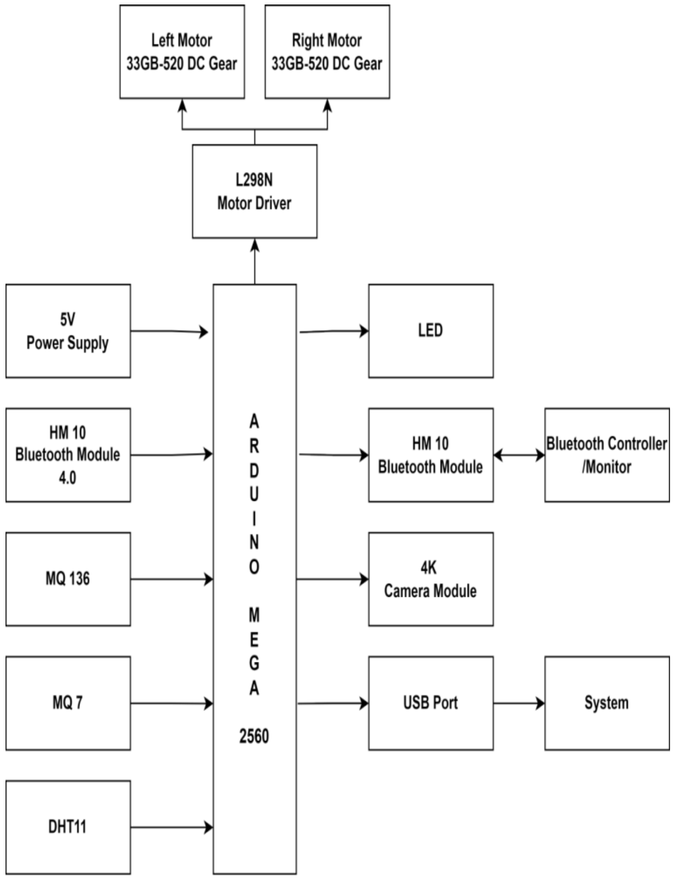
By reducing human exposure to hazardous environments, these robots significantly enhance worker safety. Future innovations in sensor technology will lead to even more precise gas detection and leak measurement. Improvements in robot mobility will allow them to operate effectively in complex terrains, while the integration of artificial intelligence will enable real-time decision-making and autonomous leak responses. These advancements will contribute to a safer, more efficient, and cost-effective approach to gas leak detection, reducing pipeline failures and improving workplace safety [5].

3. METHODOLOGY

The system operates using a 5V power supply, which ensures stable energy distribution to all essential components, including the Arduino Mega 2560, various sensors, and motors. This power source enables continuous monitoring and efficient functionality of the system. The primary data inputs come from three critical sensors, each designed for specific environmental monitoring tasks. Fig. 1 shows block diagram of proposed system.

The MQ-136 gas sensor plays a crucial role in detecting hazardous gases such as hydrogen sulphide (H_2S), converting gas concentration levels into proportional electrical signals that the Arduino Mega 2560 can analyse. Similarly, the MQ-7 sensor continuously measures the presence of carbon monoxide (CO) in the surrounding environment, providing real-time readings to ensure early detection of harmful gas exposure. Additionally, the DHT11 sensor records temperature and humidity levels, offering digital data that allows the system to assess atmospheric conditions and detect any environmental changes that may indicate a potential hazard.

Fig -1: **Block Diagram of system**



Efficient communication is a key feature of this system. The HM-10 Bluetooth module facilitates wireless connectivity by receiving commands from an external Bluetooth-enabled device, such as a smartphone or tablet. This enables users to control various system functions remotely, including motor movement, status requests, and sensor calibration. A USB interface further enhances functionality by allowing direct computer connections for programming the Arduino, updating firmware, and troubleshooting through serial communication. The system's outputs are managed through a combination of actuators, communication modules, and peripheral components, ensuring efficient operation and real-time feedback. The L298N motor driver converts control signals from the Arduino into appropriate voltage levels needed to power the left and right DC motors. These motors enable precise movement, allowing the system to navigate forward, move in reverse, or rotate based on received instructions.
For communication, the HM-10 Bluetooth module wirelessly transmits processed data to an external device, such as a smartphone or another Bluetooth-compatible system. This ensures real-time monitoring of sensor readings and system performance. Additionally, the USB interface functions as another output channel, enabling the Arduino to send logs, sensor data, or even camera footage to an external computer for further analysis or record-keeping.

HM-10 module was integrated, which significantly improved performance, achieving a tested range of 130m compared to its theoretical limit of 200m. This enhancement allows for more reliable long-range communications, reducing signal dropout and ensuring continuous data transmission in confined and industrial environments. Future improvements could focus on optimizing Bluetooth signal stability in highly obstructed environments and exploring alternative communication protocols for extended-range applications.

The system also integrates peripheral components to enhance functionality. LED indicators provide visual cues, such as blinking for warnings or steady illumination for normal operations. A high-resolution 4K camera module captures images and videos, which can either be processed within the system or transmitted to an external device for further examination. By combining these outputs, the system becomes a highly versatile tool for environmental monitoring, autonomous motion control, and remote surveillance, significantly improving efficiency and safety in various applications.

4. RESULTS AND DISCUSSION

The integration of the MQ2 and MQ136 sensors successfully demonstrated their ability to detect a variety of toxic and flammable gases in a simulated confined space environment. The test setup involved exposing the sensors to controlled concentrations of target gases, such as methane, propane, hydrogen sulphide, and carbon monoxide. The recorded sensor responses were analyzed in real-time to evaluate their sensitivity, accuracy, and response time. It addresses key challenges related to confine space monitoring, including gas leak detection, environmental hazards, and real-time surveillance. The use of remote-controlled robotics to minimize human exposure to hazardous environments aligns well with modern workplace safety trends

MQ2 Sensor Performance:

Capable of detecting flammable gases, including methane, propane, and hydrogen.

Response time: Approximately 10-15 seconds upon gas exposure.
Sensitivity varied based on gas concentration; higher readings were observed at increased gas levels.

MQ136 Sensor Performance:
Specialized in detecting hydrogen sulphide (H_2S).

Response time: Approximately 8-12 seconds.

Provided consistent readings, with minimal fluctuations under stable environmental conditions. By automating confined space inspections, the system significantly lowers the risk of human injury from toxic gas exposure, oxygen deficiency, or structural failures.

Overall System Functionality: The real-time data transmission via Bluetooth ensured seamless monitoring on a remote device. Sensor fusion improved detection reliability by cross-verifying gas presence.

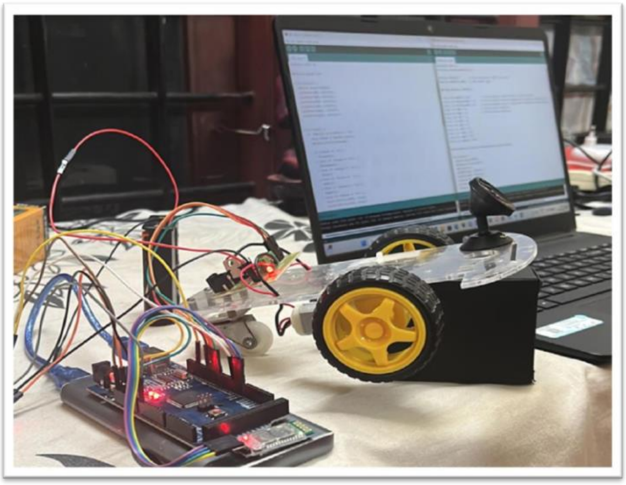


Fig. 2a Testing Phase of the System

The system effectively identified gas leaks within seconds, allowing for quick intervention.
The results confirm that the MQ2 and MQ136 sensors are highly effective for gas leak detection in confined spaces. Their relatively fast response times make them suitable for real-time applications where immediate alerts are necessary. However, some challenges were identified, such as sensor drift in the MQ2 and minor cross-sensitivity in the MQ136. These limitations could be mitigated by periodic recalibration and advanced filtering algorithms. Further improvements can be made by incorporating additional sensors, such as MQ7 (for carbon monoxide) or MQ135 (for air quality monitoring), to enhance the range of detectable gases. Moreover, integrating machine learning algorithms could help predict potential leaks by analysing patterns in sensor data over time.

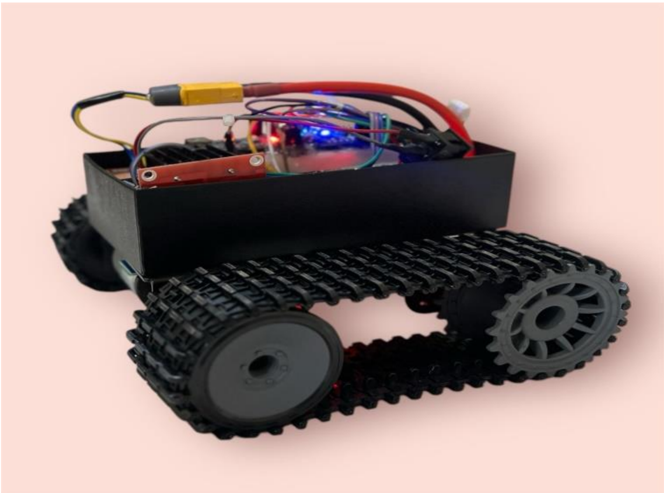


Fig. 2b Hardware set up

From a practical perspective, the successful implementation of this sensor suite in industrial or hazardous environments could significantly enhance worker safety and reduce the risk of gas-related incidents. Future advancements should focus on improving sensor accuracy, reducing power consumption, and increasing mobility for broader applications.

5. CONCLUSION

The Confined Space Multi-Surveillance Crawler project offers a promising step forward in enhancing confined space safety protocols. Traditional confined space entry methods expose personnel to high-risk environments, including toxic gas exposure, oxygen deficiency, and potential structural failures. Through rigorous research and development, the CSMSC project addresses these risks by creating a prototype capable of remote environmental monitoring and real-time surveillance, minimizing the need for human entry into hazardous areas. Key achievements of the project include the successful testing and integration of critical sensors, such as the MQ2 and MQ136, to ensure accurate real-time gas detection. Additionally, the Bluetooth module has been tested successfully, providing reliable communication within the design's voltage constraints. Further development, including magnetic wheel enhancement and potential control system refinements, will ensure even greater adaptability in complex environments. With these advancements, the CSMSC holds immense potential to create safer work environments by reducing human exposure to confined space hazards

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