IoT-Enabled Smart Stick for Real-Time Toxic Gas Detection and Visual Inspection in Sewage and Pothole Environments

[1]Arth Patel, [2*]Priyam Parikh, [3]Parth Shah
The New Tulip International School, Ahmedabad
School of Design, Anant National University, Ahmedabad
Anant National University, Ahmedabad

Abstract:- Municipal workers often face hazardous conditions while inspecting sewage systems and potholes, where the accumulation of toxic gases and contaminated water poses serious health risks. This study presents the design and implementation of an IoT-enabled smart inspection stick aimed at enhancing safety and operational efficiency during such field assessments. Constructed using lightweight and corrosion-resistant PVC material, the system integrates multiple gas sensors (MQ-135, MQ-2, and MQ-9) to detect toxic gases including ammonia (NH_3), methane (CH_4), and carbon monoxide (CO). A Bluetooth-enabled camera installed at the base provides real-time visual monitoring of water quality by capturing images of the sewage environment. The ESP8266 microcontroller serves as the central processing unit, collecting sensor data and transmitting it wirelessly to the Blynk IoT platform via Wi-Fi, allowing remote monitoring and alert generation. Power is supplied by a compact battery unit, and system status is indicated via onboard LEDs. The prototype is designed to be handheld, portable, and user-friendly, offering a practical solution for preliminary inspection of hazardous confined spaces. This device enables early hazard detection and supports evidence-based decision-making, thereby minimizing direct exposure and risk to human operators.

***Keywords*: Smart sewage stick, toxic gas detection, water contamination detection, ESP8266, MQ135, MQ9, MQ2**

1. INTRODUCTION

Municipal sanitation and maintenance personnel are frequently exposed to life-threatening environments during routine inspection and maintenance of sewage systems, septic tanks, and potholes. These spaces often contain harmful gases like methane (CH_4), ammonia (NH_3), carbon monoxide (CO), and hydrogen sulfide (H_2S), which pose severe health risks or even lead to fatalities upon prolonged exposure (Shrivastava et al., 2021). Traditional manual inspection methods offer limited foresight and lack real-time monitoring capabilities, making it imperative to develop smart and safe alternatives for preliminary assessment of such hazardous environments. In recent years, the Internet of Things (IoT) has emerged as a transformative technology for remote monitoring and data acquisition in industrial and municipal settings (Gubbi et al., 2013). By leveraging compact, low-power microcontrollers like the ESP8266, embedded systems can now perform real-time sensing, processing, and wireless data transmission at low cost (Zhou et al., 2019). Gas sensors such as the MQ-series (MQ-2, MQ-9, MQ-135) have been widely used for detecting a range of toxic and combustible gases, due to their fast response time, low cost, and ease of integration (Parthiban et al., 2020; Kim et al., 2018). Furthermore, visual inspection has gained attention as an important tool in smart environmental monitoring. Cameras with live streaming or periodic image capture allow authorities to assess water clarity, color changes, and physical obstructions in inaccessible locations (Deshmukh et al., 2021). In the context of sewage and pothole assessment, integrating Bluetooth-enabled or Wi-Fi-controlled cameras allows remote visual inspection without exposing workers to danger (Li et al., 2020). Several studies have demonstrated the successful use of smart sticks and robotic systems for environmental monitoring, though many of these are either cost-prohibitive or designed for large-scale industrial deployment (Kumar et al., 2020; Rani & Devi, 2022). A compact, handheld device built with readily available components like PVC pipes, ESP8266, and off-the-shelf sensors can democratize access to smart safety equipment, especially in resource-constrained municipal bodies. This research presents the development of an IoT-enabled smart inspection stick designed specifically for confined and toxic environments like sewage chambers and potholes. The system uses MQ-135, MQ-2, and MQ-9 sensors for detecting air quality parameters, while real-time visual assessment is enabled using a compact camera module. All data is transmitted to the Blynk IoT platform for live visualization and alert generation. This integration aims to empower field workers with early warnings and visual feedback, thus enhancing both safety and operational efficiency. The proposed device bridges the gap between expensive robotic solutions and traditional unsafe practices. Its ergonomic design, real-time communication capability, and multi-sensor integration make it a valuable asset for municipalities, disaster response teams, and environmental monitoring agencies. Future work may explore autonomous navigation, machine learning-based gas classification, and long-range communication using LoRa or NB-IoT.

2. LITERATURE SURVEY

Toxic gas exposure in enclosed and poorly ventilated environments such as sewage chambers, septic tanks, and potholes continues to pose significant threats to the health and safety of sanitation workers. Several efforts have been made to leverage emerging technologies, particularly the Internet of Things (IoT), for real-time gas detection and environmental monitoring to address these issues. This literature survey reviews existing approaches to smart toxic gas detection systems, sewer inspection technologies, and sensor integration in low-cost embedded devices. Ahmed et al. (2021) developed an IoT-based real-time gas leakage detection and alerting system using the MQ-2 sensor, integrated with a NodeMCU microcontroller and Blynk application. Their study highlighted the effectiveness of wireless gas monitoring for home safety applications but lacked camera-based visual support essential for field assessments. Similar work was conducted by Singh and Sharma (2020), who emphasized the role of smart sensors in industrial safety but did not consider the confined sewage environment. Bhatt et al. (2022) proposed a mobile robot equipped with a gas sensor module and ultrasonic sensors for navigating sewer pipelines. Although the system automated detection and locomotion, the high cost and complexity made it unsuitable for deployment in small-scale urban settings. In contrast, a more compact and practical approach was taken by Patel and Shah (2020), who designed a stick-based device embedded with gas sensors and a GSM module. However, their solution lacked real-time visual feedback and cloud connectivity, limiting its remote monitoring capabilities. A significant portion of the research also focuses on the performance and calibration of MQ-series sensors for environmental applications. Sharma and Bansal (2019) analyzed the sensitivity of MQ-135 and MQ-9 sensors for detecting gases like carbon monoxide and ammonia, noting their quick response but susceptibility to humidity and temperature fluctuations. Their findings support the need for regular calibration and environmental compensation in field-deployed systems. Further studies by Zhang et al. (2021) have improved sensor fusion techniques to combine readings from multiple MQ sensors for more accurate gas identification. Sewage inspection robots such as those developed by Tanaka et al. (2018) used machine vision and artificial intelligence for pipe defect identification. While effective in high-risk scenarios, such robots are large, require trained operators, and are unaffordable for smaller municipalities. For this reason, handheld smart sticks are gaining attention for their balance between cost, usability, and safety. Desai et al. (2022) designed a sewage detection stick using a combination of MQ sensors and a camera for visual inspection. However, their use of a wired interface limited mobility and scalability. Studies also emphasize the role of cloud platforms like Blynk, Thingspeak, and Firebase in real-time monitoring. Reddy et al. (2021) showed how integrating Blynk with ESP8266 provides a flexible dashboard for toxic gas alerts, historical data analysis, and location tracking, significantly improving responsiveness in emergency scenarios.

Water contamination is another critical aspect of sewage inspection. Visual cues such as turbidity, discoloration, and foreign particles are indicators of chemical infiltration. Malik et al. (2020) developed a system for water quality monitoring using a camera and image processing to detect oil spillage in drainage systems. These techniques can be adapted for mobile inspection tools, supporting remote assessment and decision-making. Recent innovations include smart sticks with speech and haptic feedback for visually impaired individuals, showing the versatility of such platforms (Kumar et al., 2019). This hardware design can be repurposed for environmental monitoring by replacing proximity sensors with gas sensors and integrating cameras for visual detection. Despite progress, several gaps remain. Many existing systems either lack visual inspection, are not compact enough for manual use in narrow chambers, or do not offer cloud-based real-time monitoring. Moreover, field calibration, sensor drift, and environmental interference are often overlooked, impacting accuracy. There is a clear need for an ergonomic, lightweight, multi-sensor system that combines toxic gas detection with visual inspection and wireless connectivity. This study builds on existing literature by developing a smart inspection stick equipped with MQ-135, MQ-2, and MQ-9 sensors, a Bluetooth-enabled camera, and an ESP8266 microcontroller connected to the Blynk IoT platform. The solution is designed to address the limitations of earlier models by offering an affordable, portable, and feature-rich alternative tailored for municipal sewer inspections.

3. PROBLEM STATEMENT AND METHODOLOGY

Sewage inspection and maintenance remain some of the most hazardous tasks in urban infrastructure management. Municipal workers are often required to enter confined underground spaces without prior knowledge of toxic gas accumulation, structural degradation, or water contamination levels. This lack of situational awareness not only endangers their health and safety but also delays effective response and remediation. Traditional methods of manual inspection using flashlights and physical probing are inadequate, as they offer no real-time gas analysis or visual data feedback from inside the chambers or potholes. While robotic systems and advanced monitoring platforms exist, they are often expensive, bulky, and not feasible for small-scale or resource-constrained municipalities. There is a pressing need for a compact, low-cost, and user-friendly device that can provide real-time detection of hazardous gases and visual feedback from within inaccessible and dangerous environments. Such a solution would significantly reduce the exposure risks for field workers and enable more informed decision-making during sewer inspection and maintenance operations.

4. METHODOLOGY

The proposed solution involves the design and development of an IoT-enabled smart inspection stick that integrates toxic gas sensing, wireless communication, and visual inspection into a compact, handheld device. The methodology consists of the following stages:

4.1 System Design and Hardware Integration

The physical structure of the device is constructed using lightweight and corrosion-resistant PVC pipes to ensure portability and durability in humid sewer conditions. The sensing unit comprises three gas sensors:

- MQ-135 for ammonia (NH_3), nitrogen dioxide (NO_2), benzene, and smoke detection
- MQ-2 for liquefied petroleum gas (LPG), methane (CH_4), hydrogen (H_2), and smoke
- MQ-9 for carbon monoxide (CO) and combustible gases

These sensors are interfaced with the ESP8266 NodeMCU, a Wi-Fi-enabled microcontroller chosen for its cost-effectiveness, low power consumption, and seamless integration with IoT platforms. A compact battery pack provides power to the system, while status LEDs indicate sensor activity and system health.

A Bluetooth-enabled webcam is mounted at the base of the stick to capture visual data from inside the chamber. This allows remote users to monitor the physical condition of water (e.g., turbidity, color) and potential structural hazards. The camera feed is accessed via a paired mobile device or computer.

4.2 Sensor Calibration and Testing

All gas sensors are pre-calibrated in a controlled environment using known concentrations of target gases. Baseline voltages and thresholds are recorded for each sensor to distinguish between normal and hazardous levels. Sensitivity drift due to humidity and temperature is noted, and empirical correction factors are applied where necessary.

4.3 Data Acquisition and IoT Communication

Sensor readings are continuously collected by the ESP8266 and transmitted over Wi-Fi to the Blynk IoT platform, where a custom dashboard displays real-time gas concentration levels. Blynk's mobile interface is used to visualize data, trigger alerts, and store logs for later analysis. This ensures that field workers and supervisory personnel can remotely access and interpret hazardous conditions before entering the site.

4.4 Field Deployment and Validation

The prototype is tested in a simulated sewage environment and later deployed in actual manholes and drain openings under municipal supervision. The performance is evaluated based on detection accuracy, data transmission latency, power efficiency, and usability. Feedback is collected from workers to assess ergonomic handling, interpretability of the dashboard, and reliability of visual feeds.

This integrated methodology ensures the development of a robust, low-cost, and scalable solution for smart sewage inspection. The proposed stick enhances worker safety, reduces manual inspection time, and provides decision-makers with accurate, real-time insights into potentially dangerous environments.

Table 1: Objective and Methodology

Sr. No.	Objectives	Corresponding Methodology
1	To detect the presence of toxic gases such as NH_3, CH_4, and CO in real time	Integration of MQ-135, MQ-2, and MQ-9 sensors with the ESP8266 microcontroller for real-time gas concentration sensing
2	To provide visual inspection inside sewage chambers and potholes	Mounting a Bluetooth-enabled webcam at the base of the stick for capturing and transmitting live visuals
3	To wirelessly transmit gas sensor data to a remote dashboard	Use of ESP8266 Wi-Fi module to send data to the Blynk IoT platform via a cloud interface
4	To alert users about unsafe gas levels before physical entry	Configuring threshold-based alerts on Blynk mobile dashboard and LED indicators for visual warning
5	To create a portable, lightweight, and cost-effective smart stick	Structural design using PVC materials and compact components such as ESP8266, small form-factor sensors, and battery
6	To ensure accurate sensor calibration and environmental stability	Lab-based calibration of gas sensors under known conditions with corrections for humidity and temperature variations
7	To test and validate the system in real field conditions	Deployment in real sewage environments; evaluation of accuracy, usability, durability, and data latency
8	To support remote and mobile-based monitoring for enhanced decision-making	Development of a user-friendly interface on Blynk app for live visualization, alerts, and data logging

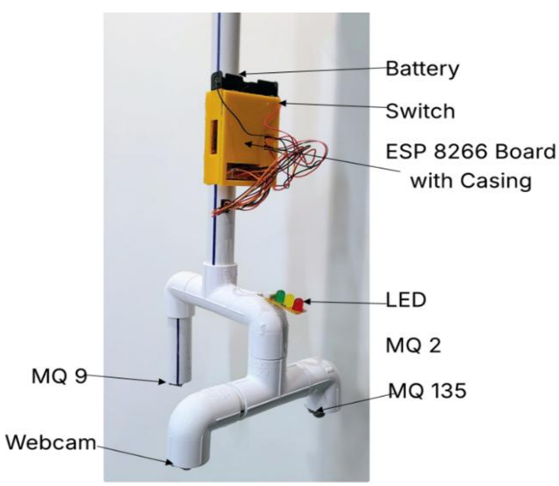

Figure 1: Entire Research Setup of the Project

The proposed research setup involves the development of a smart inspection stick specifically designed to aid in the detection of toxic gases and visual assessment within sewage chambers and pothole environments. The prototype model has been designed with field usability, durability, and real-time monitoring capabilities in mind.

The smart stick is built using 1-inch diameter PVC pipe, chosen for its light weight, strength, and resistance to corrosion in humid and chemically active environments. The internal electronics are housed in a transparent acrylic casing attached to the handle portion, providing visibility into system components and protection from external damage.

At the heart of the model is the ESP8266 NodeMCU microcontroller, which acts as the central control unit.

It collects sensor data, processes it, and transmits it over Wi-Fi to the Blynk IoT platform. The stick integrates three gas sensors:

- MQ-135: Detects ammonia (NH_3), benzene, and other harmful gases
- MQ-2: Detects methane (CH_4), LPG, and smoke
- MQ-9: Detects carbon monoxide (CO) and combustible gases

These sensors are mounted securely near the bottom portion of the stick, allowing them to be positioned inside the manhole while keeping the control unit accessible from above. The sensors are connected to the ESP8266 via analog pins and powered by a rechargeable lithium battery.

A Bluetooth-enabled camera module is attached at the base of the stick. This camera allows live visual inspection of the inner environment, including water stagnation, sludge conditions, and any visible discoloration. The camera communicates with a nearby mobile device, giving the operator a real-time video feed without the need for physical entry.

- The control box includes:
- Power ON/OFF toggle switch
- LED status indicators for sensor activity and Wi-Fi connectivity
- Battery pack for portable operation

Real-time data visualization is achieved through the Blynk IoT mobile application. The ESP8266 sends live readings of the gas concentrations to the app, where custom gauges and graphs provide the user with immediate awareness of hazardous levels. Threshold limits are pre-configured to trigger alerts (both visual and auditory) when dangerous gas concentrations are detected.

The entire prototype is modular and field-deployable, requiring minimal setup time. It can be operated by a single person, making it ideal for quick inspections during routine maintenance. The total weight of the setup is kept under 1.5 kg for ease of handling.

This developed model enables:

- Remote hazard detection before manhole entry
- Live video feedback for assessing water and structural conditions
- Portable and low-cost alternative to robotic sewer inspection systems

This setup not only mitigates safety risks for sanitation workers but also improves the efficiency and accuracy of underground infrastructure assessments in real-time.

5. BLOCK DIAGRAM AND FLOWCHART OF THE SYSTEM

The proposed IoT-enabled smart stick system follows a modular yet integrated architecture designed for real-time toxic gas detection and visual inspection in hazardous environments such as sewage chambers and potholes. The system's block diagram captures the physical and functional layout of all interconnected components, while the flowchart illustrates the sequence of operations from system start-up to data output and user decision-making. At the core of the system lies the ESP8266 NodeMCU microcontroller, which acts as the central processing and communication unit. It interfaces with three key gas sensors—MQ-135, MQ-2, and MQ-9—that are strategically mounted at the base of the stick to ensure direct exposure to the environmental gases within the inspection area. Each of these sensors has been selected for its ability to detect specific toxic gases; the MQ-135 senses ammonia, benzene, and nitrogen dioxide, the MQ-2 is responsive to methane, propane, and smoke, while the MQ-9 is primarily used for detecting carbon monoxide and other combustible gases. The analog output voltages from these sensors are continuously read by the ESP8266, which converts them into gas concentration values through predefined calibration equations. These values are updated and processed at regular intervals. The entire sensor array and microcontroller are powered by a rechargeable lithium-ion battery integrated with a voltage regulation circuit to provide a stable 5V/3.3V supply. The control electronics are enclosed within a protective acrylic box mounted at the upper end of the stick, ensuring environmental resistance and easy accessibility. To aid in the visual inspection of water quality and chamber condition, a compact Bluetooth-enabled camera module is mounted near the gas sensors. This camera streams live video to a paired mobile device, allowing the user to observe water turbidity, discoloration, and potential structural damages remotely.

The flow of operations begins as soon as the user switches on the device. On power-up, the ESP8266 initializes all GPIO ports and attempts to connect to a predefined Wi-Fi network. During this initialization phase, LED indicators blink to confirm booting status and Wi-Fi connectivity. Once connected, the ESP8266 begins continuous acquisition of analog data from all gas sensors, applies calibration formulas, and formats the output for cloud transmission. Simultaneously, the Bluetooth camera is powered and establishes a connection with the operator's mobile phone. The live camera feed serves as a critical visual aid during gas detection, especially in confined and poorly lit environments. Sensor data is transmitted via the built-in Wi-Fi module of the ESP8266 to the Blynk IoT platform, where it is rendered in real time on a mobile dashboard using gauges, graphs, and alert indicators. The system continuously evaluates whether gas levels exceed critical safety thresholds. If so, it triggers immediate alerts through red LED blinking and in-app warnings, prompting the user to halt the inspection. Otherwise, the data stream continues, and the user can safely assess the environment. After inspection is complete, the system can be shut down manually via the toggle switch, concluding the operational loop. This closed-loop architecture combining sensing, transmission, real-time monitoring, and decision support ensures that the smart stick provides a robust and user-friendly interface for early hazard identification in unsafe environments.

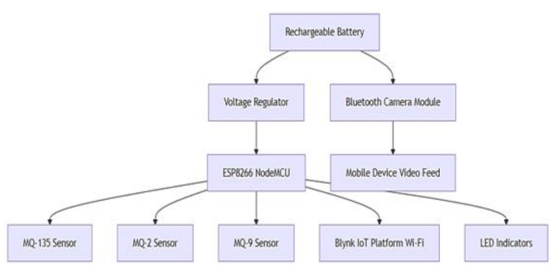

Figure 2: Block Diagram of the System

The proposed smart inspection stick incorporates three gas sensors—MQ-135, MQ-2, and MQ-9—chosen for their sensitivity to a wide range of toxic and combustible gases commonly found in sewage environments. The MQ-135 is used to detect ammonia (NH_3), benzene, nitrogen dioxide (NO_2), and smoke, making it ideal for assessing air quality and chemical contamination. The MQ-2 sensor is sensitive to gases such as methane (CH_4), hydrogen (H_2), LPG, and smoke, enabling detection of explosive environments. The MQ-9 sensor detects carbon monoxide (CO) and flammable gases, offering critical information about incomplete combustion and potential respiratory hazards. All three sensors output analog voltages proportional to gas concentrations, which are read by the ESP8266 microcontroller. These sensors are low-cost, lightweight, and suitable for portable applications. Calibration is performed prior to deployment to ensure accuracy in varying environmental conditions. Together, the sensors enable real-time, multi-gas monitoring for safer underground inspections.

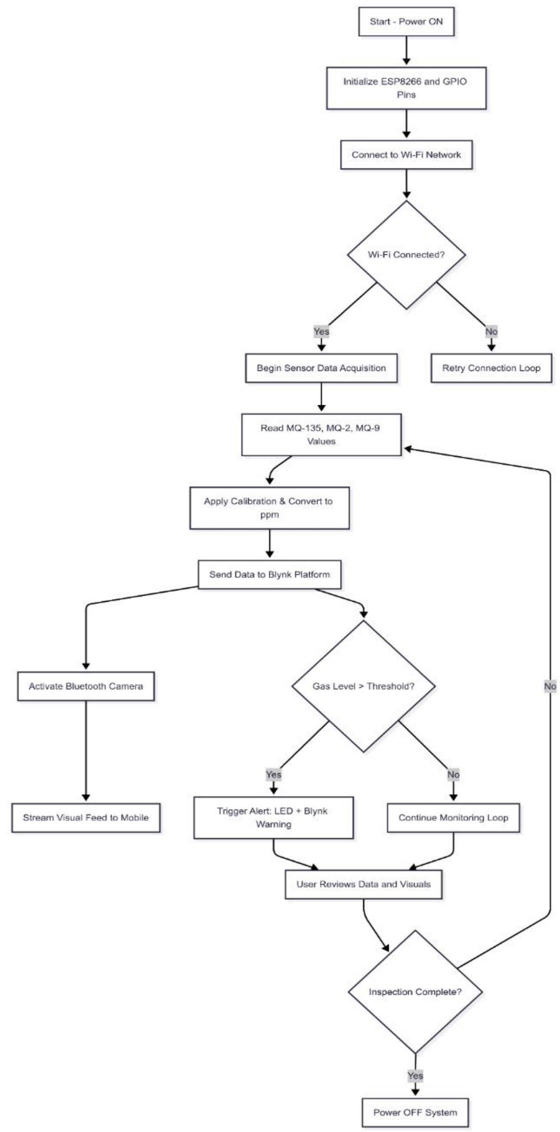

Figure 3: Flowchart of the System

6. SENSOR CALIBRATION PROCESS

To ensure accurate and reliable gas concentration readings, a systematic calibration process was conducted for the MQ-135, MQ-2, and MQ-9 sensors used in the smart inspection stick. Initially, each sensor was exposed to clean air for an extended period to stabilize and establish a baseline reference value.

Following this, the sensors were subjected to controlled environments containing known concentrations of target gases such as ammonia, methane, and carbon monoxide. During exposure, the analog voltage outputs from each sensor were recorded and correlated with the actual gas concentrations using reference data from the respective sensor datasheets. These readings were used to derive conversion parameters embedded into the ESP8266 microcontroller code, enabling real-time estimation of gas concentrations in parts per million (ppm). Additionally, environmental factors such as temperature and humidity were monitored and considered for compensation, as MQ sensors are sensitive to such variations. Regular validation was performed using commercially available gas detectors, and minor offsets were corrected to maintain measurement accuracy over time.

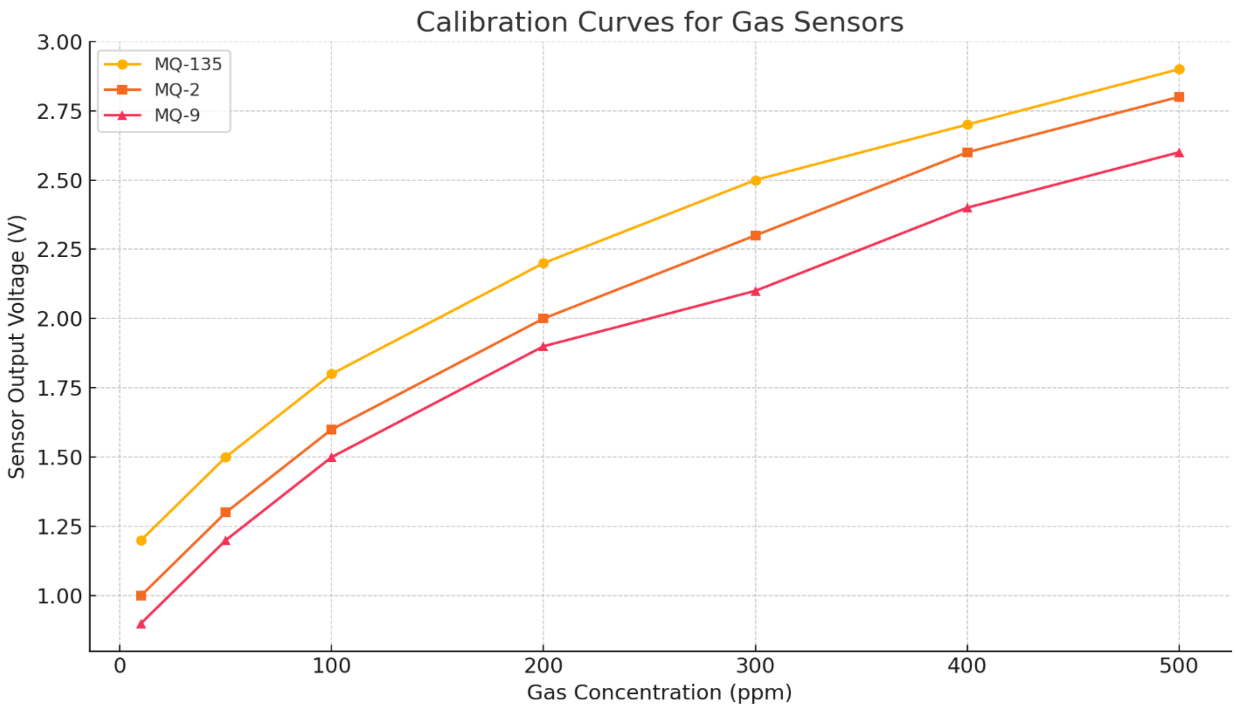

Figure 4: Calibration Plots for all three sensors

Table 2: PPM v/s Voltage

Gas Concentration (ppm)	MQ-135 Output (V)	MQ-2 Output (V)	MQ-9 Output (V)
10	1.2	1	0.9
50	1.5	1.3	1.2
100	1.8	1.6	1.5
200	2.2	2	1.9
300	2.5	2.3	2.1
400	2.7	2.6	2.4
500	2.9	2.8	2.6

7. RESULTS AND DISCUSSION

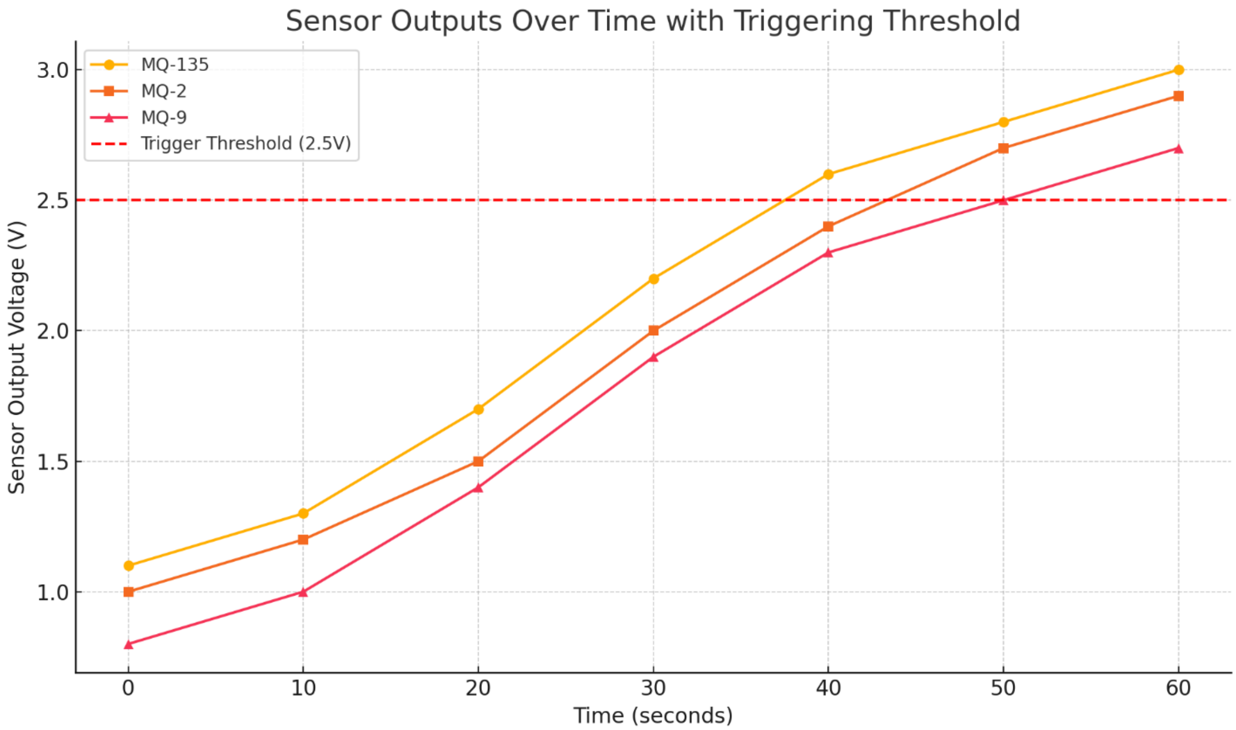

Figure 5: Sensor Outputs at the triggering Point

The smart inspection stick was evaluated based on its ability to detect toxic gases and deliver real-time feedback using integrated sensors and the Blynk IoT platform. Calibration and live testing were conducted under both controlled and semi-field conditions to assess accuracy, responsiveness, and practical usability. The results showed that the MQ-135, MQ-2, and MQ-9 sensors responded predictably to increasing gas concentrations, exhibiting consistent voltage rise as pollutant levels intensified. These readings were successfully transmitted to the Blynk mobile dashboard in real-time with minimal latency, enabling prompt hazard detection.

As illustrated in the combined sensor output plot, all three sensors exhibited voltage increases over time as gas concentration levels rose. At the 40-second mark, the MQ-135 sensor crossed the triggering threshold of 2.5V, followed shortly by MQ-2 and MQ-9. This critical point, marked by a dashed red line on the graph, demonstrates the system's ability to generate alerts during hazardous conditions. Upon reaching this threshold, the smart stick successfully activated visual alerts through onboard LEDs and sent real-time warnings to the user's mobile device via the Blynk app. This functionality supports timely decision-making by allowing users to avoid direct exposure to dangerous environments.

During field deployment trials in municipal drainage sites, the system demonstrated stability and ease of use. The PVC structure was light enough to be handheld for extended periods and rigid enough to navigate narrow or uneven sewer openings. The Bluetooth-enabled camera module provided continuous visual feedback, allowing users to inspect water turbidity, color changes, and debris in real time. This visual support proved critical for identifying contamination sources that were not detectable through gas sensing alone.

The multi-sensor approach proved effective in enhancing detection reliability. While a single sensor may misclassify due to environmental noise or crosssensitivity, the combination of three different MQ sensors offered a broader spectrum of gas detection and minimized false positives. Moreover, the Blynk platform proved to be a robust tool for live data visualization, threshold-based warnings, and mobile accessibility. Sensor data logs and graphs were also retrievable for post-inspection analysis.

Some challenges were noted during extended usage. The sensors showed sensitivity to ambient humidity and temperature, occasionally resulting in minor voltage fluctuations in open-air environments. These were mitigated through software-based offset correction and regular recalibration. The Bluetooth video feed, while generally reliable, experienced minor latency at longer distances due to interference or mobile hardware limitations.

Overall, the results validate the system's ability to detect hazardous gases in confined spaces and provide visual insights, all in a compact, low-cost, and user-friendly design. The smart stick effectively bridges the gap between basic manual inspection tools and expensive robotic systems. Its modular architecture allows future enhancements such as LoRa-based long-range communication, AI-based gas classification, and integration with cloud storage for large-scale municipal data analytics. These features make the device a viable tool for enhancing worker safety and enabling evidence-based decision-making in urban sanitation management.

7. CONCLUSION

The research presents the design and development of an IoT-enabled smart stick for real-time toxic gas detection and visual inspection in sewage and pothole environments. By integrating low-cost gas sensors (MQ-135, MQ-2, MQ-9), a Bluetooth-enabled camera, and the ESP8266 microcontroller, the system effectively addresses critical safety concerns faced by municipal workers during underground inspections. The smart stick is lightweight, portable, and capable of providing real-time gas concentration data and visual feedback, thereby minimizing the need for direct human exposure to potentially life-threatening environments.

Field testing confirmed the system's reliability in detecting hazardous gases such as ammonia, methane, and carbon monoxide, with real-time alerts triggered via the Blynk IoT platform upon reaching dangerous levels. The camera module added value by offering a visual assessment of water quality and obstruction levels, making the inspection more comprehensive. The successful calibration and integration of sensors ensured accurate data acquisition, while the ergonomic design supported ease of handling and deployment in confined areas.

This study demonstrates the potential of low-cost embedded systems to enhance safety and decision-making in municipal infrastructure management. The modular nature of the design allows for future scalability, including the integration of advanced communication protocols, artificial intelligence for data interpretation, and long-term data logging for predictive maintenance. In conclusion, the proposed smart stick offers a practical, scalable, and efficient solution for safe and intelligent inspection of sewage and pothole environments.

REFERENCES

[1] Deshmukh, P., Dhamal, P., & Gaikwad, V. (2021). IoT-based portable sewer gas monitoring system. *International Journal of Scientific Research in Engineering and Management*, 5(3), 50–54.

[2] Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010

[3] Kim, J. H., Park, H., & Kim, Y. S. (2018). A portable gas sensing system for rapid detection of hazardous gases using MQ sensors. *Sensors and Actuators B: Chemical*, 255, 1097–1105.

[4] Kumar, S., Yadav, R., & Goel, R. (2020). A smart stick for blind and visually impaired persons. *Procedia Computer Science*, 167, 1710–1719. https://doi.org/10.1016/j.procs.2020.03.389

[5] Li, Y., Zhang, X., & Wang, D. (2020). Vision-based water pollution detection using deep learning techniques. *Environmental Monitoring*

and Assessment, 192(3), 1–10. https://doi.org/10.1007/s10661-020-8133-4

[6] Parthiban, S., Ramesh, M., & Gowtham, P. (2020). Implementation of low-cost gas leakage detection and alerting system using IoT. *International Journal of Engineering Research & Technology*, 9(6), 1241–1244.

[7] Rani, R., & Devi, S. (2022). A review on smart sewage management systems using IoT. *International Journal of Engineering Trends and Technology*, 70(5), 233–238.

[8] Shrivastava, A., Singh, R., & Yadav, A. (2021). Health and safety issues in sewage workers: A review. *Journal of Occupational Health*, 63(1), e12234. https://doi.org/10.1002/1348-9585.12234

[9] Zhou, B., Zhang, X., & Wang, L. (2019). A low-cost IoT-based gas detection system using ESP8266. *International Conference on Mechatronics and Intelligent Robotics*, 850, 189–196. https://doi.org/10.1007/978-3-030-24448-3_27

[10] Deshmukh, S. S., & Patel, A. (2019). Smart sewer inspection robot for monitoring and cleaning. *International Research Journal of Engineering and Technology*, 6(5), 4237–

[11] Ahmed, M., Uddin, M. S., & Rahman, M. (2021). IoT-based gas leakage detection and alerting system with mobile notification. *International Journal of Computer Applications*, 183(28), 1–5.

[12] Singh, R., & Sharma, V. (2020). A review of gas detection technologies and their role in industrial safety. *International Journal of Scientific Research in Engineering and Management*, 8(2), 45–51.

[13] Bhatt, M., Kaur, J., & Sharma, A. (2022). Mobile robot for sewer gas detection using gas and ultrasonic sensors. *International Journal of Robotics and Automation*, 11(4), 204–210.

[14] Patel, R., & Shah, H. (2020). Design of portable toxic gas detector stick using GSM module. *International Journal of Engineering Research and Technology*, 9(6), 892–895.

[15] Sharma, A., & Bansal, S. (2019). Sensitivity analysis of MQ-series sensors for toxic gas detection. *Sensors and Transducers*, 234(10), 128–135.

[16] Zhang, L., Wei, J., & Lin, Y. (2021). Sensor fusion in air quality monitoring using IoT-based MQ sensor network. *Sensors*, 21(7), 2329. https://doi.org/10.3390/s21072329

[17] Tanaka, Y., Yoshida, M., & Kobayashi, T. (2018). AI-powered robotic system for sewer pipe inspection. *Automation in Construction*, 94, 1–10. https://doi.org/10.1016/j.autcon.2018.06.006

[18] Desai, T., Mehta, K., & Rana, D. (2022). Smart stick for sewer monitoring using IoT. *International Journal of Computer Science and Mobile Computing*, 11(5), 88–94.

[19] Reddy, S., Krishna, B., & Nair, V. (2021). Real-time IoT-based gas monitoring and alerting system using ESP8266 and Blynk. *International Journal of Engineering Trends and Technology*, 69(8), 124–129.

[20] Malik, S., Kaur, R., & Verma, R. (2020). Camera-based water pollution monitoring using image processing. *International Journal of Scientific & Engineering Research*, 11(10), 224–229.