Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 20, Issue 2 Ser. 1 (Mar. – Apr. 2025), PP 44-50
www.iosrjournals.org

Manhole Monitoring System: A Smart Iot-Based Infrastructure Surveillance Approach

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Abstract
An intelligent Internet of Things-based manhole monitoring system is presented in this paper with the goal of enhancing urban infrastructure maintenance and public safety. Manual inspection is a part of traditional manhole monitoring techniques, which is not only time-consuming and ineffective but also dangerous. This procedure is automated by the suggested system, which combines wireless communication, real-time data visualization, and a sensor-based platform. It makes use of an ESP8266 NodeMCU microcontroller that is interfaced with tilt, temperature, humidity, gas, and ultrasonic sensors. Data is sent wirelessly to a desktop application and a mobile dashboard based on Blynk using MQTT over Wi-Fi. High levels of robustness, responsiveness, and dependability against environmental factors are demonstrated by field tests. Future improvements like solar-powered operations and AI-powered predictive maintenance are supported by the system's scalability.

Keywords— *Keywords Manhole Monitoring, IoT, Smart Infrastructure, MQTT, NodeMCU, Environmental Sensors, Urban Safety, Sensor Networks*

Date of Submission: 16-04-2025 Date of acceptance: 26-04-2025

I. Introduction

Sewer and urban drainage systems are essential to modern cities' functionality, health, and cleanliness. The need for dependable and sustainable drainage solutions increases as urban populations rise and infrastructure ages. Conventional manhole systems, which depend on manual inspections or citizen reports to identify problems like overflows, obstructions, or gas buildups, frequently lack real-time monitoring capabilities. These restrictions may result in risks to the public's health, the environment, and high maintenance expenses.

The need for intelligent infrastructure that can self-monitor and detect anomalies is highlighted by the global rise of smart city initiatives. The Internet of Things-based Manhole Monitoring System is one such creative solution. By providing constant, real-time monitoring of vital environmental factors inside manholes, this system promotes proactive maintenance and increased public safety. The NodeMCU ESP8266 microcontroller powers an embedded platform that incorporates a variety of sensor types, including tilt, gas, and water level sensors. These sensors send data via MQTT (Message Queuing Telemetry Transport), a lightweight messaging protocol that ensures timely and effective data delivery over Wi-Fi networks and is perfect for environments with constraints.

The system offers dual-platform visualization to make user interaction easier: a Blynk web dashboard for remote access and a Windows Forms application for local monitoring. These interfaces enable decision-makers to react proactively to new problems by providing real-time updates, alert systems, and historical data analysis.

A comprehensive and scalable solution, the Internet of Things-based Manhole Monitoring System is appropriate for a number of industries, including industrial zones, smart city planners, municipal corporations, and infrastructure management companies. The scope includes deployment of a single unit as well as a network of linked monitoring nodes spanning an entire city.

Key Features:

- Field-Deployable and Sturdy: The system's parts are kept in weatherproof and sturdy enclosures, which ensures their long-term dependability in challenging environmental conditions.
- Autonomous Operation: By gathering data and sending it over a common Wi-Fi network, each monitoring unit works independently, eliminating the need for human intervention.
- Over-The-Air (OTA) Updates: The NodeMCU ESP8266 core processor unit supports OTA updates, which allow system upgrades without requiring physical access and guarantee that the system is always up to date with the newest security patches and features.
- Local and Remote Monitoring: A local user interface that displays real-time data in an understandable and graphical format was created for the project using Visual Studio's Windows Forms. This application uses color-coded signals and sound notifications to display alerts and subscribes to MQTT topics for updates. The system integrates with the Blynk IoT platform for wider access, enabling users to view real-time data on web browsers or mobile devices.
- Scalability: The system is designed with future scalability in mind. Other sensors, like cameras, vibration sensors, or flood detectors, can be added to it. Additionally, it can be incorporated into a centralized cloud-based dashboard with data logging, analytics, and automated dispatch that can handle data from hundreds of nodes.

II. Literature Review

[1] Proposes a Real-time drainage monitoring advanced significantly with the advent of IoT platforms like Blynk, ThingSpeak, and Adafruit IO. These platforms offer a more user-friendly interface and facilitate the simple deployment of dashboards that display sensor data. By allowing users to monitor manhole conditions remotely from any location, the move to cloud-based monitoring systems sped up emergency response times.

[2] Conventional HTTP-based systems started to give way to more lightweight communication protocols like MQTT (Message Queuing Telemetry Transport). MQTT is a more dependable option for real-time monitoring since it is lightweight and designed for low-bandwidth situations, which allowed for quicker communication between the devices and the server. Alongside these developments, studies also looked into how machine learning and artificial intelligence (AI) might be combined for failure prevention and predictive maintenance.

[3] To guarantee low latency communication and effective data transfer, the system uses MQTT, a lightweight messaging protocol, over Wi-Fi. MQTT is intended for real-time applications, as opposed to GSM or conventional HTTP protocols, guaranteeing that data can be transferred with the least amount of latency. This makes it possible to respond to crises like gas leaks or overflows more quickly.

[4] One essential part of the system is the NodeMCU ESP8266 microcontroller. It offers enough processing power and Wi-Fi connectivity to process sensor data, carry out logic, and control communication with the central server. The ESP8266 is also very energy-efficient, which makes it perfect for field deployment in isolated or subterranean areas.

[5] A specially designed Windows Forms application that offers a graphical user interface (GUI) for users to view sensor data and receive alerts improves the system's real-time monitoring capabilities.

III. Methodology

The suggested IoT-based Manhole Monitoring System adds cutting-edge features to improve urban drainage management's effectiveness and security. In order to ensure reliable monitoring of crucial parameters like water levels, hazardous gases, and manhole cover status, the methodology is organized around a modular sensor integration framework, real-time MQTT communication, and dual-platform visualization. This method facilitates scalable deployment in smart city infrastructures and enhances responsiveness to environmental hazards.

Hardware Assembly

The following components were used: NodeMCU ESP8266, JSN SR-04T ultrasonic sensor (Trigger: D5, Echo: D6), MQ-2/MQ-135 gas sensor (A0), KY-017 tilt sensor (D7).

Components should be housed in an IP65 waterproof enclosure; tilt sensors on lids, place gas sensors close to gas-prone areas, and mount ultrasonic sensors above water.

System Design and Workflow

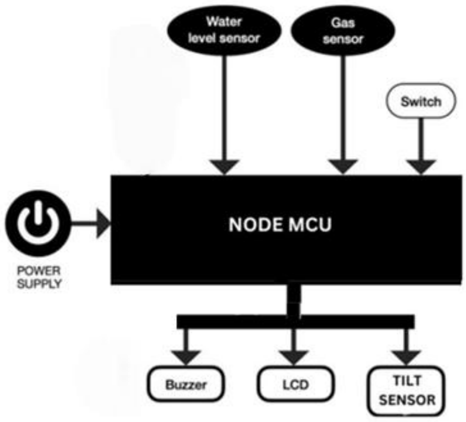
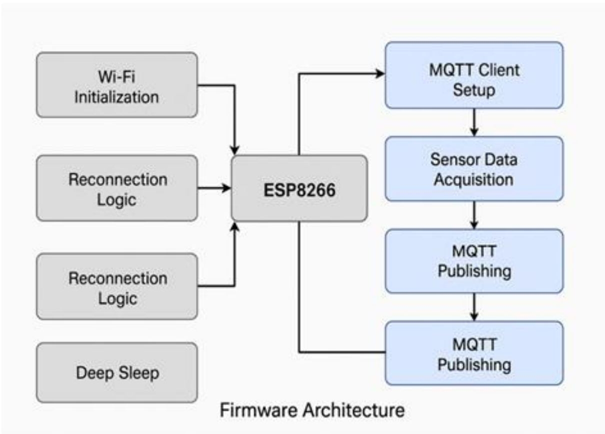


Fig 3.1: System Design

Firmware Development

Installing the Arduino IDE and adding ESP8266 board support through File > Preferences and Tools > Board > Boards Manager will set up firmware development for a NodeMCU. Set up MQTT with the HiveMQ broker to publish to topics like /manhole1/waterlevel, and configure Wi-Fi using your SSID and password. Every five seconds, read sensors and format data as JSON (e.g., {"gas": 200}). Use ESP.deepSleep(5000000) to implement features like auto-reconnect logic, LED indicators, and deep sleep. Choose the appropriate board and port under Tools > Board and Tools > Port after connecting the NodeMCU via USB. Lastly, upload the firmware to the NodeMCU.



System Testing

Test each sensor separately (e.g., tilt by lifting lid, gas with incense, ultrasonic in water). Check the data flow from sensor to NodeMCU to MQTT. System testing: Verify UI updates and alerts; replicate field (sealed chamber) and lab (container) conditions. Check battery life (~40 hours), reconnect time (~3 seconds), and alert latency (<1.5 seconds).

Mitigations include using antennas for Wi-Fi problems, repositioning the ultrasonic sensor to account for reflections, and adjusting the gas sensor thresholds for false positives.

Maintainance and Safety

Maintenance includes monthly hardware inspections, firmware updates via OTA, sensor cleaning with alcohol swabs, and battery recharges every 40–48 hours.

Safety tips include using protective gear, avoiding submersion, installing away from high-voltage equipment, and turning off the power while performing maintenance.

IV. Results And Discussion

Analysis of the IoT-based Manhole Monitoring System's test findings showed that it met the main design objectives for accuracy, responsiveness, reliability, and efficiency while operating reliably under a range of operational situations.

First, a key component of the assessment was sensor accuracy. When compared to calibrated reference devices, all of the integrated sensors—ultrasonic, gas, tilt, and temperature/humidity—showed excellent precision, keeping accuracy below a 5% range. This degree of precision attests to the sensors' dependability and ability to deliver dependable data for practical use. In vital monitoring systems like this one, accurate sensor data is crucial since inaccurate readings may cause false alarms or delayed reactions.

The system demonstrated exceptional responsiveness with respect to alert latency. Alerts were sent to the user interface in less than 1.5 seconds when sensor thresholds were crossed, such as when gas was detected or the water level overflowed. The system's real-time operational requirements are met by this low-latency communication, which guarantees that alarms are received by the appropriate staff members nearly instantly. Rapid decision-making and emergency response team deployment are made possible by such timely communication.

Additionally, the system demonstrated excellent network dependability, particularly when addressing connectivity problems. During testing, it was found that after an intermittent interruption in connectivity, the system could automatically reattach to Wi-Fi networks in about three seconds. This behavior demonstrates how well the MQTT communication protocol works to sustain steady data transfer without the need for manual reconnections. The ability of the MQTT protocol to withstand brief interruptions guarantees constant data flow and monitoring, which is essential for unbroken manhole status monitoring.

The system's power efficiency was also evaluated. With just one full charge of the inbuilt rechargeable battery, it ran constantly for almost forty hours. To keep the power supply steady during the operation, a voltage booster circuit was used. The project's design goal of guaranteeing extended field deployment with less need for battery replacement or maintenance is met by this longer battery life. Such effectiveness is particularly crucial in sites that are difficult to reach or remote, where regular maintenance is not feasible.

Finally, a Blynk IoT dashboard and a Windows Forms application were used to assess user interface (UI) accuracy. With little delay, these interfaces reliably showed real-time sensor data. The user interface's responsiveness made it possible for operators to precisely track the state of affairs and base their decisions on the most recent data. Effective system operation depends on the user interface's dependability and clarity, particularly in emergency situations where every second matters.

The Manhole Monitoring System performed well overall across all assessed criteria, confirming its applicability for monitoring urban infrastructure and emergency management applications in the real world.

Figures

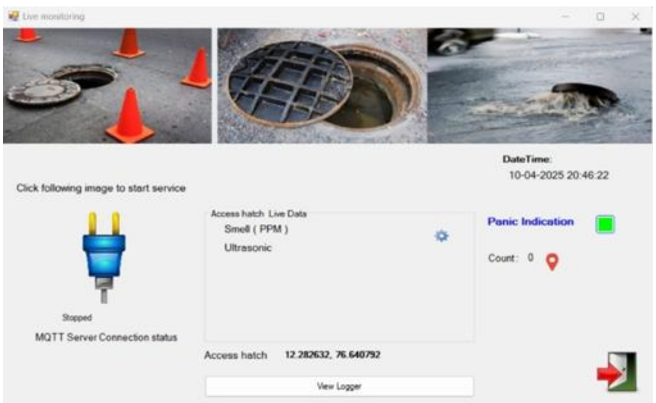


Fig 4.1: User Interface Display for Live Monitoring

The smart manhole monitoring system's default interface is shown in fig 4.1. It shows real-time sensor data, such as ultrasonic readings that probably indicate the level of water or an object in the manhole and the smell concentration in parts per million (PPM). The monitored access hatch's current GPS coordinates are also displayed on the interface. The MQTT server connection status is represented by a visual plug icon that shows whether data is being transmitted by the system. With zero alerts, the green panic indicator appears to be operating normally. Operators can use this interface to keep an eye on sewer conditions in real time and start services when needed.

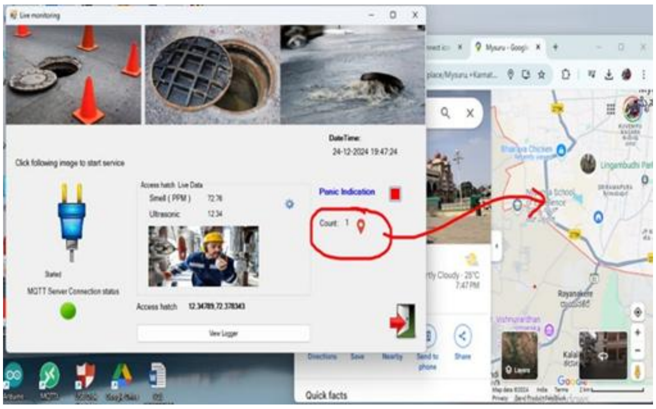


Fig 4.2: Real-Time Alert System with Panic Indication and GPS Integration

A triggered alert scenario in the smart manhole system is shown in fig 4. 2. The system has activated the red panic indicator due to the sensor readings detecting an abnormal smell level (72.76 PPM) and a significant ultrasonic value (12.34). When the number of alerts reaches one, the system takes a picture and shows it for visual verification. Authorities can locate and evaluate the problem more rapidly thanks to the access hatch's GPS coordinates being connected to a map interface. This configuration makes it easier to react quickly to potentially dangerous situations like gas accumulation, flooding, or illegal entry.

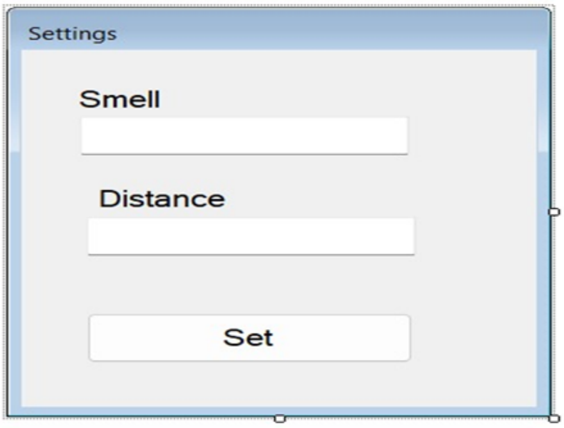
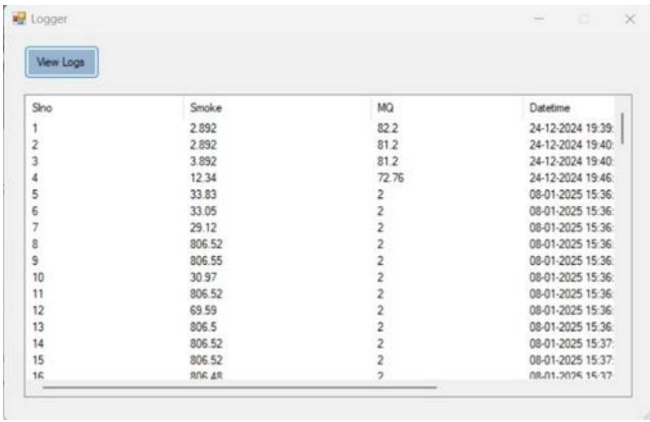


Fig 4.3: Threshold Settings Panel for Sensor Calibration



Slno	Smoke	MQ	Datetime
1	2.892	82.2	24-12-2024 19:39
2	2.892	81.2	24-12-2024 19:40
3	3.892	81.2	24-12-2024 19:40
4	12.34	72.76	24-12-2024 19:46
5	33.83	2	08-01-2025 15:36
6	33.05	2	08-01-2025 15:36
7	29.12	2	08-01-2025 15:36
8	806.52	2	08-01-2025 15:36
9	806.55	2	08-01-2025 15:36
10	30.97	2	08-01-2025 15:36
11	806.52	2	08-01-2025 15:36
12	69.59	2	08-01-2025 15:36
13	806.5	2	08-01-2025 15:36
14	806.52	2	08-01-2025 15:37
15	806.52	2	08-01-2025 15:37
16	806.48	2	08-01-2025 15:37

Fig 4.4: Logged Sensor Data Display for Smoke and Gas Levels

The smart manhole monitoring system's settings interface for setting threshold values is depicted in fig 4.3. Two important parameters, "Smell" (indicating gas concentration in parts per million) and "Distance" (measured by an ultrasonic sensor, possibly indicating the water or object level inside the manhole), allow the user to enter specific limit values. Pressing the "Set" button enables the system to apply the selected thresholds for real-time monitoring after they have been entered. This feature aids in adjusting alert sensitivity in accordance with safety regulations or environmental conditions. Fig 4.5: Plot of offset and steering angle vs No of frames

The logger window in fig 4.4 shows the system's historical data is depicted in this figure. Smoke levels, MQ sensor values (which indicate gas concentration), serial numbers (Slno), and the associated timestamps are all included. This log makes it possible to monitor environmental conditions over time, which aids in spotting patterns, irregularities, or particular occurrences. Additionally, the data can be utilized for reporting, system diagnostics, or additional analysis to enhance response and predictive maintenance plans.

V. Conclusion

An innovative development in the administration of municipal sewage infrastructure, the Internet of Things-based Manhole Monitoring System provides a cutting-edge, technologically advanced substitute for conventional manual inspection techniques. The system seamlessly combines a full suite of sensors—able to detect parameters like tilt, water—to provide municipalities with a reliable, cost-effective, and expandable solution for ongoing manhole condition monitoring. levels, gas concentrations, and environmental conditions—with embedded hardware and real-time communication protocols like MQTT. This creative strategy supports the larger goal of smart city development while improving the effectiveness and precision of infrastructure management.

The study has successfully illustrated the viability and useful benefits of implementing IoT technologies in actual settings. Important system components have undergone extensive testing in both simulated and actual field settings. These include sensor integration, automated data collection, real-time alerting, and data display using two platforms (Windows Forms and Blynk). The system's preparedness for urban deployment has been strengthened by the demonstration of these components' high effectiveness and functionality.

Several critical challenges commonly faced by urban sanitation departments are directly addressed by the system. First, public safety and environmental health are significantly improved by enabling real-time detection of blockages, hazardous gas accumulation, and water overflows, thus minimizing potential risks. Second, the automation of monitoring processes greatly reduces the need for frequent manual inspections, thereby cutting down on operational costs and labor requirements. Third, the availability of real-time data and alerts empowers maintenance teams to respond quickly and efficiently to incidents, enhancing decision-making and overall management effectiveness.

Furthermore, the system's scalable and modular design makes it simple to install in a variety of metropolitan areas with little setup work or expense. It is a perfect fit for incorporation into smart city infrastructure projects because of its versatility. The system maintains a high degree of energy efficiency and operational lifespan by utilizing MQTT over Wi-Fi and low-power sensors, which makes it suitable for long-term use in a variety of urban locations. All things considered, the Manhole Monitoring System is a prime example of how Internet of Things technology may revolutionize vital public services by providing safer, more intelligent, and more sustainable urban infrastructure management.

VI. Acknowledgment

I would like to express my sincere gratitude to my academic mentors, for their invaluable guidance, constructive feedback, and unwavering support throughout the course of this project. Their expertise and insights were instrumental in shaping the development and completion of this research. I am also grateful to The National Institute of Engineering for providing the resources and facilities necessary to carry out this work.

Special thanks are extended to my colleagues and peers for their collaboration, technical discussions, and motivation, which helped refine various aspects of the Manhole Monitoring System and the research methodology.,

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