IES International Journal of Multidisciplinary Engineering Research

IOT-Based Manhole Detection and Monitoring System

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Abstract

The IoT-based manhole detection and monitoring system is an innovative solution that aims to enhance public safety by monitoring the condition of manholes in real time. The proposed system consists of sensors inside the manholes and can detect various parameters. This project focuses on developing a sensing system for manholes, incorporating temperature, gas, water level, and tilt sensors. These sensors provide realtime data to ensure safe working conditions, detect hazardous gases, monitor water accumulation, and assess structural stability. The integrated system enhances infrastructure management by enabling remote monitoring and timely interventions, thereby improving safety and operational efficiency in urban environments. The sensor data is transmitted through IoT technology to a digital device. Hence, the system has the potential to reduce the risk of accidents and improve the efficiency of maintenance tasks by providing valuable insights into the condition of the manholes. The implementation of this system significantly improves safety by allowing for early detection of hazardous conditions and preventing potential accidents. Additionally, it optimizes maintenance schedules and resource allocation, leading to cost savings and more effective urban infrastructure management.

Keywords: Monitoring system, Real-time monitoring, Public safety, Infrastructure management.

DOI: https://doi.org/10.5281/zenodo.15130022

1. Introduction

Urban drainage systems are vital for public health and infrastructure, but issues like overflows, blockages, and hazardous gases pose serious risks. Traditional inspections are slow and error-prone, necessitating smart solutions. The IoT-Based Manhole Detection and Monitoring System enhances safety and efficiency through real-time sewage monitoring using sensors, a mobile app, and cloud connectivity.

The system integrates gas (MQ-2, MQ-7, MQ-135), temperature (LM35), water level, and ultrasonic sensors to detect toxic gases, temperature shifts, water levels, and obstacles. A gearbox-based lifting mechanism (L298 Motor Driver) keeps hardware functional in floods, while ESP8266 NodeMCU transmits data to the cloud. Alerts are triggered via a buzzer and GSM module (SIM800L) when hazards are detected.

The software includes a Flutter mobile app, Python Django backend, and SQLite database, offering real-time visualization, historical data analysis, and an interactive dashboard. Operating 24/7, the system improves safety, response time, and drainage management efficiency. By automating detection and response, it reduces the risk of accidents and optimizes maintenance operations. This smart monitoring solution contributes to building safer and more sustainable urban environments.

2. Related works

Natu, Deshpande, Chavhan, and Kshirsagar (2024) proposed an IoT-based manhole monitoring system that integrates sensors for detecting gas leaks, water accumulation, and potential structural damage. The system provides real-time alerts to authorities, ensuring quick responses to hazardous situations. This multi-sensor approach enhances urban safety by monitoring both environmental and infrastructure conditions [1].Monishree, Maneshwaran, Nandhini, and Monika (2023) developed a real-time monitoring system for manholes using sensors to detect water levels, gas concentration, and temperature. Their system offers early detection of hazardous gas leaks, improving public safety through real-time communication with authorities [2].Arunkumar, Prasath, and Karthiki (2023) expanded manhole monitoring by adding structural integrity sensors to detect damage to manhole covers. Their system sends alerts when misalignment or movement is detected, preventing accidents caused by faulty covers [3].Devi and Bala (2022) created a smart drainage system using IoT sensors for water flow and quality monitoring, combined with predictive analytics for maintenance. This approach helps prevent flooding and optimizes drainage systems in smart cities [4].Ganpat and Bansoe (2022) enhanced urban safety by using IoT sensors to detect gases like methane and hydrogen sulfide in manholes. The system includes an automated alert feature to warn nearby workers of hazardous conditions, ensuring safety during maintenance [5].

Ruheena and Shereen (2021) developed a reliable manhole monitoring system with redundant communication channels and backup power to ensure consistent data transmission, even during failures. Their system is designed for high-reliability urban infrastructure applications [6].Papageorgiou and Papandrianos (2021) integrated weather data into their IoT-based manhole monitoring system, combining internal sensor readings with external weather conditions to predict potential hazards. This multi-layered approach enhances urban safety by preventing accidents based on real-time data and environmental trends [7].Vijay, Sanjay, Babaso, Dundappa, and Saundatte (2022) introduced an IoT-based monitoring system for manhole health, allowing real-time tracking of environmental conditions and immediate alerts for maintenance actions. Their system improves the efficiency of urban maintenance by reducing manual inspections [8].Parameshachari B D, Umar M, Kruthika T R, Melvina Aranha, Pallavi R, and Poonam KS (2023) developed an autonomous drainage monitoring system using IoT and AI for real-time hazard detection and predictive maintenance. The system sends alerts to authorities, ensuring quick responses and reducing the risks of urban drainage failures [9].Rasheed and Abdulla (2023) designed a smart manhole cover monitoring system using IoT sensors to detect irregularities and prevent accidents. Their system integrates predictive maintenance to identify weaknesses in manhole covers before they become hazardous, enhancing urban infrastructure resilience [10].

3. Objectives

The **IoT-Based Manhole Detection and Monitoring System** is designed to enhance urban infrastructure by providing real-time monitoring, proactive hazard detection, and efficient maintenance solutions. The key objectives of this system include:

- **Real-Time Monitoring:** Implement a system that continuously monitors manholes using IoT technology to provide up-to-date information.
- **Hazard Detection:** Use sensors to detect potential risks such as gas leaks, overheating, water accumulation, and structural shifts to prevent accidents.
- **Enhanced Safety:** Ensure that manholes are safe for both the public and maintenance personnel by providing early warnings of potential issues.
- **Efficient Maintenance:** Improve maintenance scheduling and resource allocation by using real-time data to address problems beforehand.
- **Data Insights:** Offer valuable insights into the condition of manholes to help manage and optimize urban infrastructure more effectively.

4. Methodology

The IoT-based manhole monitoring system follows a structured workflow that enables effective and real-time monitoring of urban infrastructure. This multi-stage process begins with sensor data acquisition and progresses through data transmission, processing, decision-making, alert generation, and finally, continuous monitoring. Each step is carefully designed to provide timely and reliable data, enabling maintenance teams to respond to issues proactively and enhance public safety.

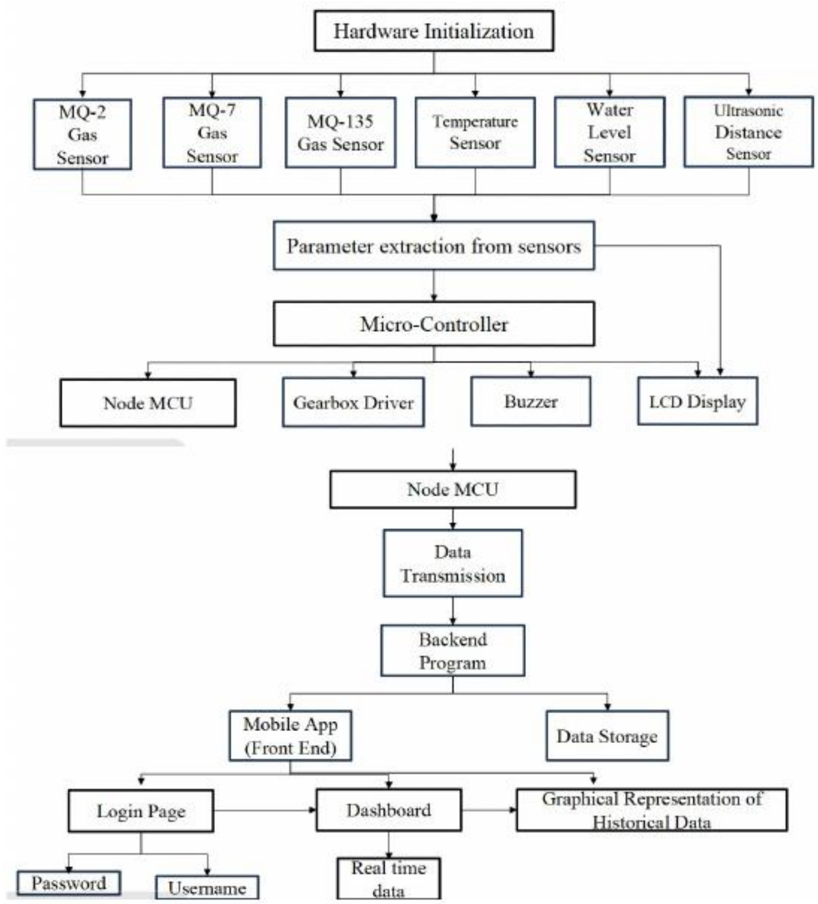

Figure 1: Workflow diagram

4.1 Sensor Initialization and Data Collection

When the system is powered on, all sensors are initialized. This involves calibrating the sensors and setting them up to start collecting data. The system continuously monitors the environment using various sensors:

- **MQ-2 Gas Sensor** continuously monitors the environment for flammable gases like LPG, propane, and methane.
- **MQ-7 Gas Sensor** specifically detects carbon monoxide (CO) levels.
- **MQ-135 Gas Sensor** monitors for harmful gases such as ammonia, sulfur dioxide, and benzene.
- **Temperature Sensor** measures the ambient temperature in real-time.
- **Water Level Sensor** tracks the water level in a tank or any other container.
- **Ultrasonic Distance Sensor** measures the distance to objects using ultrasonic waves, which is useful for applications like liquid level detection or obstacle avoidance.

4.2 Data Processing by Microcontroller (NodeMCU)

The Node MCU receives raw analog signals from each sensor. These analog signals are converted into digital data by the microcontroller, making it suitable for processing. The Node MCU then processes this digital data to interpret the readings, such as calculating the concentration of gases, temperature values, water levels, and distances. The microcontroller also checks if any of the sensor readings exceed predefined thresholds, such as a high gas concentration or low water level. If a threshold is exceeded, it triggers an alert.

4.3 Local Output and Alerts

If any sensor detects a critical condition (such as high gas concentration or water levels), the Node MCU activates the buzzer to provide an audible alarm. The processed data is displayed on an LCD screen in real-time. This display includes current readings from all sensors, the system status, and any alerts that are triggered.

4.4 Data Transmission to Backend

The Node MCU uses its built-in Wi-Fi capabilities to transmit the processed data to the backend system. This is typically done using protocols like MQTT or HTTP. The microcontroller packages the data into a format suitable for transmission, often including timestamps and sensor IDs to make it easy to identify the data source.

4.5 Backend Processing and Data Storage

The backend program, running on a server, receives the data packets from the Node MCU. The backend system parses the incoming data, performs additional analysis if needed, and prepares it for storage. The processed data is then stored in a database (either relational, like MySQL, or non-relational, like MongoDB), which allows for historical data analysis and retrieval.

4.6 User Interaction via Mobile App

Users access the system through a mobile app, where they can log in using their credentials (username and password). This ensures that only authorized users can access the data. Once logged in, users are directed to the app's dashboard, which provides a comprehensive view of the system's current status, including real-time data from all sensors. The app continuously updates the displayed data, ensuring that users always have access to the most current information.

4.7 Historical Data Visualization

The app retrieves historical data from the backend database. This data is presented in graphical formats, such as line charts, bar graphs, or pie charts, which helps users visualize trends and patterns over time. The app also allows users to customize the time range and parameters they wish to view, enabling detailed analysis of specific periods or conditions.

4.8 Alerts and Notifications

If the backend detects any abnormal conditions, such as high levels of harmful gases, it sends real-time alerts to the mobile app. Users receive push notifications on their mobile devices, ensuring they are immediately aware of any critical issues. Additionally, depending on the system's configuration, alerts can be sent via email or SMS for added redundancy.

4.9 Security and Maintenance

The system ensures secure access by requiring user authentication. The login page ensures that only authorized users can interact with the system. Furthermore, the data transmitted between the Node MCU, the backend, and the mobile app is encrypted to prevent unauthorized access and ensure the security of the information.

5. Performance Analysis

The IoT-Based Manhole Detection and Monitoring System was tested under various conditions to evaluate its performance, accuracy, and efficiency. The results indicate that the system successfully detects hazardous gas levels, water accumulation, temperature variations, and missing manhole covers in real time. Alerts and notifications were accurately delivered through the mobile application and SMS-based communication, ensuring a rapid response. The system also demonstrated high reliability, low latency, and effective power management, making it a viable solution for smart urban infrastructure.

5.1. Sensor Accuracy and Response Time Analysis

One of the key performance metrics evaluated was sensor accuracy and response time. The table below summarizes the observed accuracy levels and response times of different sensors used in the system:

Sensor Type	Accuracy (%)	Response Time (Seconds)
Gas Sensor (MQ-135)	94.2%	3.5s
Gas Sensor (MQ-7)	92.8%	4.0s
Temperature Sensor (LM35)	96.5%	2.2s
Water Level Sensor	95.3%	2.8s
Ultrasonic Sensor	97.0%	2.5s

Table 1: Sensor Accuracy and Response Time

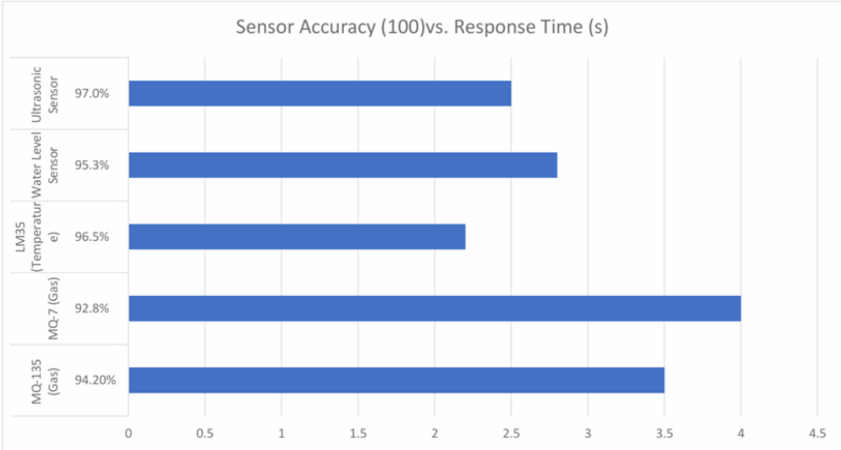

Figure 1.1: Sensor Accuracy and Response Time Analysis.

Higher accuracy and lower response time indicate better performance. Ultrasonic and temperature sensors performed best, while gas sensors had slightly higher response times due to stabilization time.

5.2. System Performance Analysis (Alert Triggering Efficiency)

The efficiency of the alert mechanism was tested by analyzing how quickly the system detects and communicates hazardous conditions to users.

Condition Detected	Detection Time (Seconds)	Notification Time (Seconds)
High Gas Level	4.0s	1.5s
Water Overflow	3.2s	1.2s
High Temperature	2.8s	1.0s
Open Manhole Cover	3.0s	1.3s

Table 2.1: Alert System Efficiency.

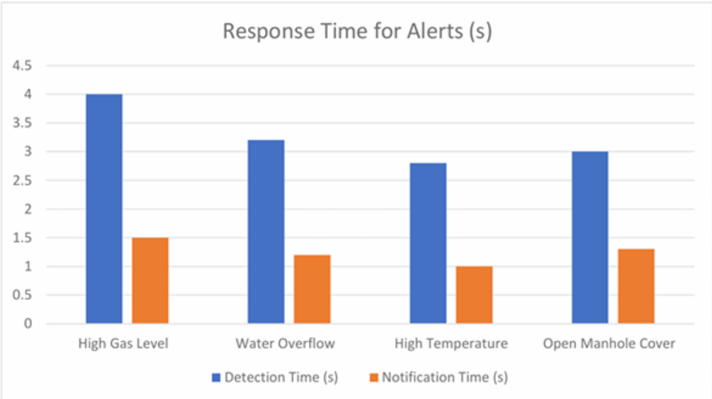

Figure 2.1: Response Time for Alerts

5.3. Power Consumption Analysis

Since the system operates continuously, power efficiency was evaluated under different scenarios.

Component	Power Consumption (mA)	Battery Backup (Hours)
Microcontroller (Arduino Mega)	50mA	48 hours
Wi-Fi Module (ESP8266)	200mA	12 hours
Sensors (Average Total)	100mA	24 hours
LCD Display	80mA	30 hours

Table 3.1: Power Consumption Analysis.

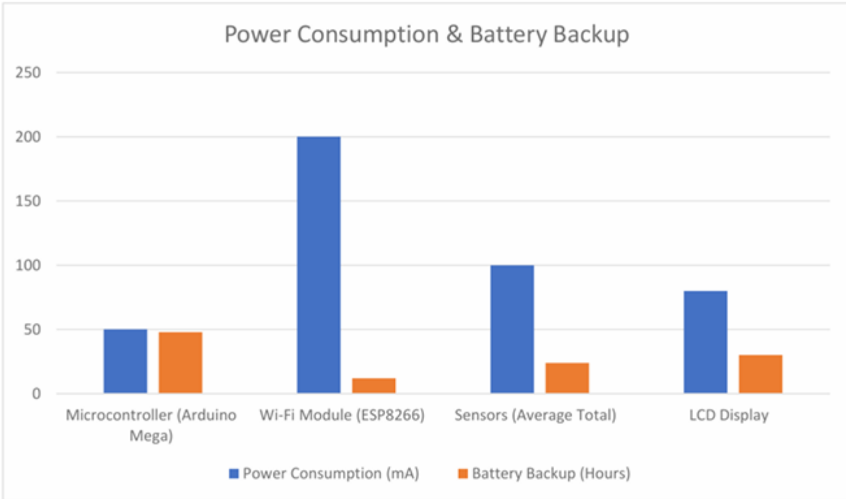

Figure 3.1: Evaluating Component Efficiency and Battery Backup in the System.

Microcontroller (Arduino Mega) consumes 50mA and provides 48 hours of battery backup. Wi-Fi Module (ESP8266) has the highest power consumption at 200mA, leading to only 12 hours of battery backup.

5.4. System Performance Comparison with Existing Methods

To validate the efficiency of the IoT-Based Manhole Detection and Monitoring System, a comparison with traditional and existing monitoring methods was conducted.

Feature	Traditional Manual Inspection	Existing IoT Systems	Proposed System
Real-Time Monitoring	No	Yes	Yes
Automated Alerts	No	Yes	Yes
Wireless Communication	No	Yes	Yes
Response Time	Hours/Days	Minutes	Seconds
Cost Efficiency	High (Labor Costs)	Medium	Low (One-time Setup)
Energy Efficiency	Not Applicable	Medium	High

Table 4.1: Performance Comparison

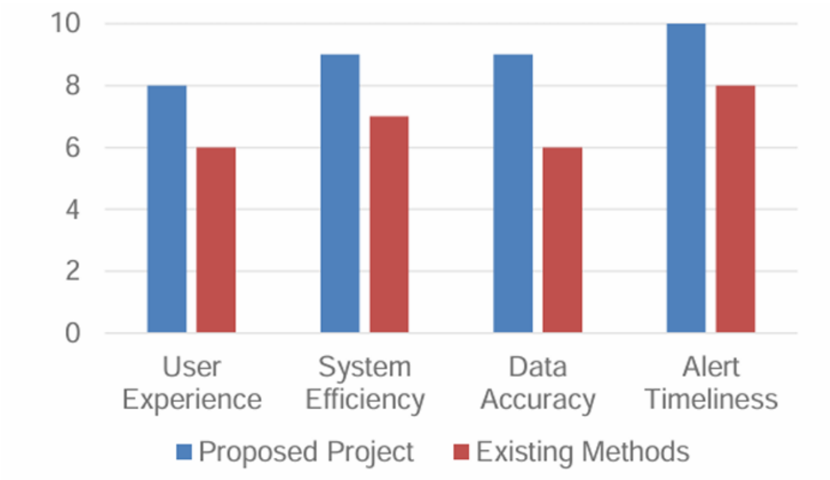

Figure 4.1: Performance Metrics: New Solution vs. Existing Methods Across Key Parameters

The new approach provides a more intuitive and enjoyable experience for users The system operates more effectively, improving speed and resource management.Data han dling is more accurate, reducing errors and enhancing reliability. Alerts are generated more promptly, ensuring timely responses.The new method excels in all measured areas, indicating a notable improvement over current practices.

6.Conclusion

The IoT-based manhole detection and monitoring system offers an innovative solution for urban infrastructure management, providing timely alerts, continuous monitoring, and crucial insights into manhole conditions. By leveraging real-time data from various sensors, it enhances safety and minimizes risks associated with hazardous gases, water overflow, and temperature anomalies. This proactive monitoring reduces the need for constant human intervention, promoting a safer and more efficient environment for urban planners and maintenance teams.

Scalability and integration with data analytics platforms allow this system to store and analyze historical data, which supports predictive maintenance and trend analysis. Urban planners can use these insights to optimize drainage and sewage systems, prioritize repairs, and address issues before they escalate. Furthermore, the system's hybrid power setup, which includes solar and battery backup, ensures uninterrupted functionality even in remote areas, expanding its application potential.

Ultimately, this IoT-based solution represents a critical advancement toward smarter, more sustainable cities. Its real-time alerting, remote access to data, and automated monitoring make it a valuable tool for modern urban infrastructure, reducing costs and enhancing safety. As cities evolve toward smarter ecosystems, this project contributes significantly to creating resilient, responsive urban spaces.

7. Future Scope

7.1 AI-Driven Predictive Analytics

Integrating AI and ML algorithms to analyze historical data and environmental conditions can help predict manhole-related incidents before they occur, enabling proactive maintenance and reducing risks.

7.2 Integration with Smart City Infrastructure

The system can be expanded to work with other urban systems like traffic management, waste disposal, and water networks, allowing for synchronized responses and more efficient urban management.

7.3 Self-Sustaining Power Sources

Incorporating renewable energy sources like solar panels will make the system self-sustaining, reducing reliance on the grid and ensuring continuous operation, especially in remote or off-grid areas.

7.4 Drone-Assisted Inspections

Drones equipped with cameras and sensors can perform remote inspections of manholes and hazardous areas, enhancing monitoring and safety while reducing the need for manual labor in dangerous environments.

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