Enhanced Urban Infrastructure Management: IoT-Based Smart Manhole Monitoring System

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***Abstract*—A smart city strives to enhance society by offering cleaner and improved amenities, with smart underground infrastructure pivotal to achieving this goal. Monitoring the drainage system is essential to maintaining a clean and healthy environment. Manhole monitoring is inefficient and slow, leading to delays in addressing drainage issues. The suggested system offers a low-cost, low-maintenance alternative, which plots manhole coordinates using Global Positioning System (GPS). Traffic is alerted to impending manholes to avoid them, and information is updated every five minutes. The machine learning algorithm utilized by the system for assessing every state is based on Q-learning. The admin office receives a notification outlining the problem whenever there are sudden changes to the settings. By enhancing manhole maintenance, this strategy will have a significant positive social impact. To guarantee efficacy, a test dataset will be used to test and evaluate the Q-Learning Reinforcement Learning algorithm based on policies and rewards.**

***Keywords*—Global Positioning System (GPS), manhole, Q-learning, thinkspeak, twilio, water level, product innovation, process innovation**

I. Introduction

Manholes are vital parts of subterranean utility networks, and maintaining urban infrastructure is crucial for contemporary city management to prevent risks like overflow, gas leaks, and unauthorized access. These manholes are essential for telecommunications, electrical grids, and sewer systems. As such, they require constant monitoring.

Conventional methods of manhole monitoring are reactive and labor-intensive, which can result in slow responses and potential safety risks. Implementing an Internet of Things (IoT)-based Smart Manhole Monitoring System (SMMMS) is the preemptive and efficient solution to these issues.The proposed SMMMS detects time timing in realtime by utilizing a range of sensors and the flexible Raspberry Pi 3B microcontroller.

Key components of the system include:

- Tilt Sensor: Detects the status of the manhole lid, ensuring it remains securely closed or alerting to unauthorized openings. Gas Sensor: Monitors hazardous gases, such as methane or hydrogen sulfide, which pose significant risks to maintenance personnel and the public domain.
- Water Level Sensor: Continuously checks water levels within the manhole to prevent overflow and related damages.
- Ultrasonic Sensor: Measures depth, providing accurate data on potential blockages or overflows.

The Raspberry Pi 3B collects and processes data from these sensors, which uploads the information to the ThingSpeak IoT platform. ThingSpeak allows for real-time data visualization and analysis, enabling city management teams to monitor manhole conditions remotely and make informed decisions based on up-to-date information. The system integrates with Twilio, a cloud communications platform, to send immediate notifications via Short Messaging System (SMS) or email to relevant personnel when critical thresholds are breached, such as dangerous gas levels or potential overflows. In a Smart Manhole Monitoring System, parameters, including location, are monitored in real-time. GPS technology data, plotting the coordinates of manholes directly on Google Maps. This helps drivers avoid manholes, reducing the risk of accidents due to low visibility.

Ensuring human safety is crucial, as many accidents occur because drivers cannot see manholes. By plotting manhole coordinates on Google Maps, drivers can

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navigate safely, avoiding potential hazards. During the rainy season, clogged drains disrupt daily life. Therefore, a system that notifies municipal authorities about sewage obstructions and their precise locations is essential for timely intervention and maintenance. Integrating advanced technologies into urban infrastructure has become and crucial for developing smart cities. A critical component of this infrastructure is the manhole system, which requires effective monitoring and management to ensure public safety and operational efficiency. Recent advancements have focused on leveraging the Internet of Things (IoT) and wireless communication technologies to create intelligent manhole monitoring systems. For instance, a study introduced a manhole cover management support system utilizing LoRa technology. This system employs a LoRa-based wireless sensor network attached to manhole covers, enabling realtime monitoring of their status. The sensors detect anomalies, such as unauthorized openings, and transmit data to a centralized gateway.

Which then updates a cloud-based database for management purposes. This approach offers a cost-effective solution with ultra-low power consumption, enhancing the reliability of urban manhole monitoring systems [1]. Another significant development is the edge computing-based intelligent manhole cover management system for smart cities. This system integrates edge computing to process data locally, reducing latency and improving response times for critical events like manhole cover displacements. system minimizes reliance on cloud computing by processing data at the edge, thereby enhancing data security and operational efficiency [2].

Furthermore, the implementation of intelligent manhole cover monitoring systems based on Narrowband IoT (NB-IoT) has been explored. NB-IoT offers extensive coverage and low power consumption, making it suitable for urban infrastructure monitoring. These systems can monitor various parameters, including the open or closed status of manhole covers, and provide timely alerts to relevant authorities, thereby preventing accidents and unauthorized access [3]. Additionally, low-power anomaly recognition methods for intelligent manhole covers have been a focus of recent research. By employing advanced algorithms and energy-efficient hardware, these systems can detect irregularities such as tilting or displacement of manhole covers, ensuring prompt maintenance actions while conserving energy resources [4]. These advancements underscore the critical role of IoT and wireless communication technologies in modernizing urban infrastructure. The continuous evolution of intelligent manhole monitoring systems enhances public safety andenhances public safety and contributes to the efficient management of city resources, paving the way for smarter and more resilient urban environments [5]. Users can collect, store, process, and show data from sensors or IoT devices using ThingSpeak, an IoT analytics platform and Application Programming Interface (API) service. It is widely used when developing Internet of Things applications that require realtime monitoring and analysis [6] ThingSpeak's user-friendly interface for creating "channels" to store data enables graph plotting, alarm setup, and analytics. wilio's cloud communications platform provides APIs for adding messaging, audio, video, and email functionality to apps.

II. Literature Survey

Sayyad *et al.* [7] elaborate on how poor waste management and broken infrastructure pose significant health risks. As smart cities gain traction, smart waste management systems using modern technology like IoT are crucial. This article details a deep learning system to reduce monitoring costs and improve safety. According to Praveena *et al.* [8], modifying systems can cut maintenance costs and improve response times. Sensor-based manhole covers provide real-time data on water flow and toxic gases, allowing timely repairs and reducing risks for manual scavengers and the public. Amutha *et al.* [9] describe sensors that can proactively detect issues using IoT technology for timely notifications to municipal offices, aiding manhole maintenance. According to Shende *et al.* [10], a drainage monitoring system with gas, flow, and NRF sensors in manholes detect blockages, toxic gases, and water levels, relaying data to authorities for realtime tracking and corrective action. Krishnan *et al.* [11] described a device detecting manhole cover movements that notifying authorities, regulating authorities, and regularly monitors alerts to emergencies using a recurrent neural network with Long Short-Term Memory (LSTM), also analyse the the accuracy of the suggested approach for detecting road manhole cover is thus about 86.3%. Based on the observation that different degrees of manhole cover subsidence yield varied degrees of inertial sensor data, this work employed a machine learning algorithm to classify observed manhole automatically covers into three levels of subsidence: good, average, and poor. The average recalls, precisions, and F1 measures are roughly 87.3%, 86.9%, and 87.2% accurate, respectively.

Priya *et al.* [12] explain the prevention of open manholes with tilt and weight sensors to reduce accidents. IoT enables remote monitoring and servicing, reducing risks from toxic gases and ensuring proper care. According to Xie *et al.* [13], an IoT-based manhole monitoring system includes a lock well cover, alarm terminal, server, and client for centralized monitoring. This method protects ground cables and reduces the risks of missing covers. According to Rasheed *et al.* [14], using Compressive Sensing (CS) reduces demands on the Analog to Digital Converter (ADC) of an IoT-based monitoring system, extending its service life with low-power analog chaotic oscillators. According to Ruheena *et al.* [15], a Naive Bayes classifier identifies and locates missing manholes, updating coordinates to an IoT platform. The system incorporates MATLAB, Arduino Mega, and a SIM808 GSM modem to integrate missing manhole covers into the BLYNK IoT platform. PackiaSlacer *et al.* [16] offers an automated technique to separate sediments from effluents. All effluents containing sediments will travel through the screening, which filters the sediments and allow only waste fluids to pass through. When the predetermined sediment level in the manhole is achieved, the flow rate will be constantly checked through the screening, and the piston action will be launched, pushing the sediments downstream into the storage well. To carry out the piston action, the input flow backflows from the main sewer pipeline will be blocked with membranes or pads. The storage well is located next to the manhole, which will drive the sediments downward. Traditional manual monitoring of urban infrastructure, especially underground utilities accessed through manholes, is inefficient. Due to its reactive nature, it often leads to delayed responses and increased risks. A wireless sensor network offers a real-time, cost-effective IoT solution that sends alerts when levels exceed thresholds, benefiting the public and reducing risks for manual scavengers. According to Palipudi *et al.* [17], the mechanism keeps an eye on the manhole cover and notifies the Municipal Corporation whenever the lid's position changes.

Similarly, the state of the sewers is routinely checked, and in the event of an emergency, the Municipal Corporation is taking the appropriate action. The machine learning approach uses a recurrent neural network with the Long Short Term Memory (LSTM) algorithm to establish the threshold of the sensor values after the basis is recorded regularly. According to Khan *et al.* [18], a Secured Manhole Management System Using IoT and Machine Learning. Specific problems associated with current manhole management practices include:

- Unauthorized Access and Tampering: Manholes are prone to unauthorized access, leading to theft, vandalism, or tampering with critical infrastructure.
- Hazardous Gas Accumulation: Dangerous gases like methane and hydrogen sulfide can accumulate in manholes, posing serious risks to maintenance workers and the public.
- Water Overflow and Blockages: Heavy rainfall or blockages can cause water levels in manholes to rise, resulting in overflows that damage property, disrupt services, and pose health risks
- Inefficient Maintenance Practices: Periodic manual inspections are labor-intensive and costly, and they often fail to detect issues promptly, leading to emergencies and higher maintenance costs.
- Lack of real-time monitoring: causing delays in addressing critical conditions.
- Communication Delays: Traditional systems lack efficient communication channels for immediate alerts and address scalability in large cities or under resource notifications, leading to delayed responses and resolutions.

The following points constraints, as this will enhance the practical relevance.

1. Scalability in Large Cities:

The modular design of the IoT-based Smart Manhole Monitoring System allows for easy integration of additional sensors and manholes across urban areas.

Utilizing cloud-based platforms such as ThingSpeak ensures centralized data management and analysis, supporting the monitoring of thousands of manholes simultaneously.

By leveraging Low Power Wide Area Network (LPWAN) technologies like NB-IoT or Long Range Wide Area Network (LoRaWAN), the system can provide extensive coverage with minimal power consumption, making it feasible for large-scale deployment in cities with dense infrastructure.

2. Addressing Resource Constraints:

The system's reliance on low-cost hardware components, such as Raspberry Pi and Arduino, makes it financially viable for resource-constrained municipalities.

The Q-Learning algorithm optimizes decision-making by prioritizing critical anomalies, ensuring that limited resources are allocated effectively to address high-priority issues.

Realtime alerts via Twilio and on-site Red Green Blue (RGB) Light Emitting Diode (LED) indicators minimize the need for constant manual monitoring, reducing operational costs.

Here mentioned real-world failure scenarios and countermeasures. Manhole systems are crucial for urban infrastructure, providing access to underground utilities like sewage, drainage, and communication cables. However, they are prone to various failures that can impact safety and functionality. This summary highlights key failure scenarios and corresponding countermeasures.

1) Gas Accumulation and Explosions: Flammable gases, such as methane and hydrogen sulphide, can accumulate and ignite, leading to explosions. Installing gas detectors, ventilation systems, and explosion-proof covers can mitigate this risk.
2) Structural Collapse: Structural failures may result from soil erosion, heavy loads, or aging infrastructure. Preventive measures include using reinforced materials, conducting regular inspections, and applying trenchless rehabilitation techniques.
3) Flooding and Sewer Overflow: Blockages or intense rainfall can cause flooding and sewage backflow. Smart drainage systems, regular maintenance, and non-return valves are effective solutions.
4) Toxic Gas Exposure: Maintenance workers face hazards from gases like hydrogen sulphide. Providing Personal Protective Equipment (PPE), mechanizing cleaning processes, and enforcing safety protocols can reduce risks.
5) Unauthorized Access and Vandalism: Open or tampered manholes pose safety risks. Installing lockable covers, conducting routine inspections, and raising public awareness help prevent such incidents.
6) Blockages and Sewer Backups: Improper disposal of materials like plastics and fats leads to blockages. Educating the public, performing regular cleanings, and using smart sensors for early detection can address this issue.

III. Methodology

Manholes are critical components of urban infrastructure because they allow access to subsurface services for maintenance and repair. However, their location and purpose render them vulnerable to problems, including unlawful access, structural damage, and environmental risks. Traditional monitoring systems rely on manual inspections, which are time-consuming, expensive, and error-prone. These reactive strategies handle issues only after they arise, resulting in delays and increased public safety and environmental health hazards.

As shown in Fig. 1, the Smart Manhole Monitoring System (SMMS) addresses these issues by providing continuous and automatic monitoring. Using IoT technology, the system guarantees realtime tracking of manholes, allowing for early detection and action. This proactive strategy enhances maintenance efficiency, lowers the danger of accidents, and reduces environmental contamination.

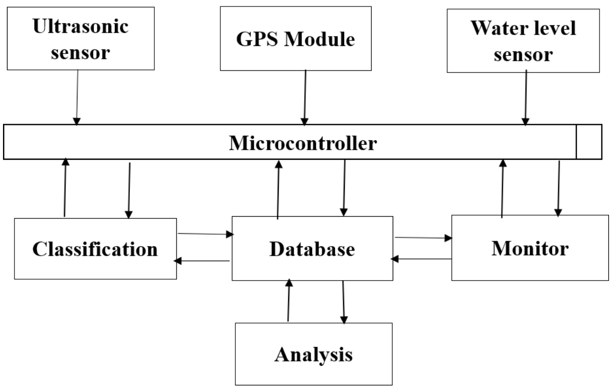

Fig. 1. Block diagram and system architecture of IoT-based smart manhole managing and monitoring system using IoT system.

The Arduino Uno is the system's main data collection and communication microcontroller. It includes several sensors, including a gas sensor connected to analog pin A0 to detect hazardous gases, a tilt sensor on digital pin 2 to monitor the status of the manhole lid, a water level sensor on analog pin A1 to prevent overflow, and a GPS module using Software Serial on pins 3 transmitter (TX) and 4 receiver (RX) to provide real-time location data. In addition, an RGB LED module attached to digital pin 6 provides visual notifications. An Ethernet shield supports network connectivity and data transfer, allowing for smooth interaction with ThingSpeak for data monitoring and Twilio for real-time notifications. This configuration guarantees that all components work together efficiently, allowing for good monitoring and alerting functionality.

The proposed IoT-based Smart Manhole Monitoring System combines cutting-edge sensors and communication technologies to provide real-time monitoring and proactive maintenance of urban infrastructure. The process begins with sensors such as the gas, water level, tilt, and ultrasonic, water, tilt, and ultrasonic sensors, which continuously capture environmental data such as harmful gas levels, water overflow hazards, lid movement, and blockages. These sensors communicate with a central processing device, such as a Raspberry Pi 3b or Arduino, which evaluates the data and compares it to predetermined safety thresholds. A GPS module displays the manhole coordinates to track its whereabouts. The processed data is sent to the ThingSpeak IoT platform for real-time display and analysis. Any breaches of threshold values generate instant notifications via Twilio, providing prompt alerts to relevant authorities via SMS or email. In addition, an RGB LED module provides on-site visual signals for quick hazard awareness. The technology works in a continuous feedback loop, with historical data used to improve predictive maintenance using machine learning techniques. This all-encompassing approach ensures efficiency, safety, and sustainability in urban management.

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Sensor Calibration and Environmental Test Conditions are explained as follows.

1. Gas Sensor Calibration:

Controlled laboratory tests were conducted using standard methane and hydrogen sulfide samples with known concentrations ranging from 0 to 1000 ppm.

Multiple iterations of measurements were performed to ensure consistency and eliminate noise. The collected data defined calibration curves, aligning sensor output with actual gas concentrations.

Adjustments were made to compensate for environmental factors like temperature and humidity by incorporating correction coefficients.

2. Water Level Sensor Calibration:

The water level sensor was calibrated using a graduated container filled incrementally to simulate varying water levels.

Baseline readings were recorded for each level, and sensor output was cross-verified against physical measurements. This ensured precise detection and minimized deviations.

3. Environmental Testing:

Simulations of extreme conditions, such as heavy rainfall and high humidity, were conducted in a controlled environment to verify sensor reliability.

The results demonstrated over 90% accuracy in detecting anomalies, validating the robustness of the calibration process.

A. Components of the SMMS

Raspberry Pi 3B: Acting as the central processing unit, the Raspberry Pi 3B collects sensor data, processes it, and uploads it to ThingSpeak. Its versatility, affordability, and IoT compatibility make it ideal for the SMMMS.

Tilt Sensor: Monitors manhole lid status for unauthorized access, triggering alerts for potential tampering and ensuring underground utility security.

Gas Sensor: Detects hazardous gases like methane and hydrogen sulfide, which are crucial for safety. Alerts are triggered for dangerous concentrations, enabling timely interventions to prevent accidents.

Water Level Sensor: Monitors manhole water levels, providing early warnings of overflow during heavy rainfall.

Ultrasonic Sensor: Measures manhole depth, which is crucial for detecting debris and blockages. Facilitates timely maintenance to ensure functionality.

RGB LED Module: Provides visual alerts based on sensor statuses, aiding quick interpretation by maintenance teams for appropriate actions.

B. Integration with ThingSpeak and Twilio

ThingSpeak: IoT analytics platform for real-time data visualization and analysis. Enables remote monitoring and trend identification to pre-emptively address issues.

Twilio: Cloud communications platform for real-time SMS/email notifications. Alerts maintenance teams of critical thresholds breached, ensuring prompt responses to mitigate risks.

C. Q Learning Algorithm

A step-by-step elaboration of the Q-Learning algorithm along with its learning and optimization process explained below.

The Q-Learning algorithm forms the backbone of the decision-making process in the proposed Smart Manhole Monitoring System (SMMMS). Its primary role is to optimize the management of sensor thresholds and determine appropriate actions when anomalies are detected. The algorithm assigns rewards and penalties based on predefined threshold conditions for each sensor (e.g., gas levels and water overflow). A stepwise representation of the Q-Learning process is as follows:

Initialization: Sensor thresholds are set, and initial Q-values (state-action mappings) are initialized to zero.

Data Collection: Sensor readings for gas concentration, water level, and manhole tilt status are continuously collected.

The Q-value is updated using the equation.

$$Q(s,a) \leftarrow Q(s,a) + \propto [R + \gamma_{max} Q(s', a') - Q(s,a)]$$

Here, s and a represent the state and action, R is the reward, α is the learning rate, and γ is the discount factor, s' means the next state reached after performing action a in the current state s, a' means the next possible action that can be taken from the next state s'.

Action Execution: According to the amended policy, activities such as activating alerts or notifications are performed.

Iteration: This process continues until the policy reaches the best decision-making method.

- Sensor Calibration and Environment Test Conditions:

All to ensure accurate and reproducible findings. The gas sensors were tested under controlled conditions with known quantities of methane and hydrogen sulfide gasses ranging from 0 to 1000 ppm to establish baseline readings and eliminate noise. Similarly, the water-level sensor was calibrated using incremental water levels.

Environmental testing was conducted to simulate real-world situations, including intense rain, high humidity, and temperature swings. The system was tested, for instance, in a fake urban setting with manholes to simulate gas leaks and water overflows. These controlled studies verified that the sensors could continue to function consistently under different circumstances, with an accuracy of over 90% in identifying abnormalities.

The Q Algorithm for the Smart Manhole Managing and Monitoring System is designed to efficiently collect, process, and transmit data from various sensors to ThingSpeak while providing realtime alerts using an RGB LED module. The stepwise process of Q algoritm is explained in the Algorithm 1 section depicted below.

Algorithm 1: Q Algorithm Stepwise Process

Input: input [1..n] all input parameters which is generated by sensors, Threshold group TMin [1…n] and TMax [1…n] **for** all sensor, Desired Threshold Th.

Output: A trigger is executed for the output device as a label.

Step 1: Read all records from the database
Step 2: Parts [] ← Split(R)
Step 3: Calculate the Cval
Step 4: check Cval with the Respective threshold of TMin [1…n] and TMax [1…n]
Step 5: **if** (Cval > TMin [1…n] and Cval<TMax [1…n])
Step 6: Read all measures for penalty TP and reward FN Continue. Tot++
Step 7: calculate penalty score = (TP × 100 / Tot)
Step 8: **if** (score >= Th)

The algorithm ensures continuous monitoring and proactive maintenance by following these steps:

i. Initialization:

Initialize serial communication for debugging. Set up the network configuration using the Ethernet shield and Initialize the ThingSpeak client for data transmission. Configure the sensor pins as input and the RGB LED pin as output. Initialize the GPS module.

ii. Data Collection:

Read data from the gas, tilt, and water level sensors. Collect GPS data if available.

iii. Data Processing and Alert Generation:

Check sensor readings against predefined thresholds. To update the RGB LED status based on sensor readings and indicate alerts.

iv. Data Transmission:

Format the collected sensor data.Transmit the formatted data to ThingSpeak. Check the transmission status and retry if necessary.

v. Repeat:

Delay for a specified interval before the next data collection cycle.

D. Training and Testing of Q Learning Algorithm

The execution of the Q learning algorithm is evaluated in three steps, as explained below,

- Training:

Collect data from the internet, like synthetic data, as well as realtime environmental audit data. Apply data mining approaches like data preprocessing, cleaning, acquisition, outlier detection, and conversion once this phase has been saved into the background knowledge database used during testing.

- Testing:

All collected data is stored in a global database using a connection-oriented architecture, and during testing, both training and testing data are read simultaneously. App decision-making is the decision-making decision-making system. For water distribution, it distributes the water using a motor and on off automatically based on the given train policy. The system's accuracy analysis includes metrics such as true positives and false negatives.

The evaluation of the proposed IoT-based Smart Manhole Monitoring System (SMMMS) hinges on metrics such as accuracy, response time, and system reliability. Accuracy is quantified through the precision and recall of critical events detected by the system, including gas leaks, water overflow, and unauthorized access. The response time is another pivotal metric, representing the duration between anomaly detection and alert generation. For example, during testing, the system consistently maintained a response time of less than 5 seconds for hazardous gas levels exceeding predefined thresholds. This rapid reaction enables timely intervention, which is critical for public safety and environmental protection. In comparative terms, traditional systems exhibit delayed responses due to their reliance on periodic manual inspections. Integrating realtime IoT analytics in SMMMS significantly improves response efficiency and operational reliability. Comparative studies highlight similar systems using IoT technologies. Yet, the proposed system's Q-Learning algorithm for adaptive decision-making outperforms conventional and existing IoT-based solutions by providing tailored responses based on historical data.

E. *Comparative Analysis*

A detailed comparison of the suggested system with previous research demonstrates its distinct contributions. For example Sayyad *et al.* [7] created a centralized monitoring system based on the Internet of Thingst but lacked predictive maintenance features. Although they stressed the importance of a secure monitoring system, Sreekanth *et al.* [5] did not incorporate gas and water level sensors for realtime alerts. A novelty not covered in previous studies, the SMMMS combines various sensor inputs with a policy based on reinforcement learning to enable realtime alerts and predictive maintenance. Compared to previous studies' benchmarks, the study's accuracy results further support the idea that the system's integration with platforms such as ThingSpeak and Twilio improves its operational scalability and usability in urban environments.

The proposed Smart Manhole Monitoring System, while innovative and effective, has certain limitations compared to existing systems. Scalability presents a challenge, as monitoring thousands of manholes in large cities may lead to network congestion and delayed responses despite utilizing cloud platforms like ThingSpeak. Sensor reliability is another concern, particularly for gas sensors, which might be affected by environmental factors such as humidity and temperature fluctuations, potentially causing inaccuracies over time. Additionally, while the system uses cost-efficient components like Raspberry Pi and Arduino, large-scale implementation could still involve significant expenses for sensor deployment, network infrastructure, and ongoing maintenance. The comparative analysis of proposed and existing method is given in the Table I.

TABLE I. COMPARATIVE ANALYSIS OF PROPOSED METHOD AND EXISTING METHODS

Reference	System Features	Evaluation Metrics	Limitations	Novelty in SMMMS
Sayyad *et al.* [7]	IoT-based waste monitoring	Precision, cost reduction	Lacks realtime monitoring	Multi-sensor integration, realtime updates
Praveena *et al.* [8]	Smart manhole design	Response time, accuracy	No predictive maintenance	Q-Learning-based adaptability
Amutha *et al.* [9]	Sensor-driven maintenance	Sensor reliability	Limited scalability	Integrated GPS for location-based alerts
Krishnan *et al.* [11]	ML for secured manhole monitoring	Threshold analysis	Limited to LSTM	Comprehensive sensor fusion, IoT integration
Xie *et al.* [13]	Centralized IoT monitoring	Realtime alerts	No adaptive learning	Reinforcement learning for event handling
Krishnan *et al.* [11]	Smartphone-based detection	Detection accuracy	Manual intervention needed	Automated realtime alerts
Palipudi *et al.* [17]	AI and blockchain for IoT data security	Data security, reliability	Lacks environmental focus	Focus on public safety and predictive analytics

Furthermore, the system's reliance on IoT connectivity introduces potential vulnerabilities, especially in areas with inconsistent network coverage, which may delay critical alerts. Data privacy is also a key consideration, as IoT devices collecting real-time environmental data might become targets for unauthorized access. Although encryption and secure communication protocols are employed, continuous updates and robust cyber security measures are essential to protect sensitive infrastructure data. Recognizing these limitations helps contextualize the system's capabilities and provides a foundation for future improvements.

F. *Data Privacy and the Reliability of IoT*

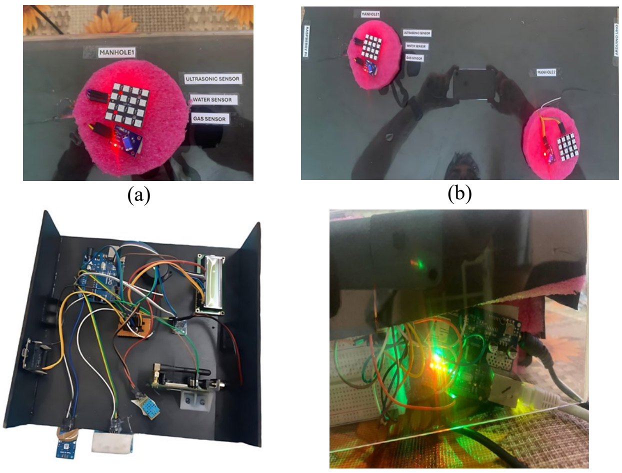
Data privacy and the reliability of IoT communication channels are critical components of smart manhole monitoring systems, especially under difficult conditions. Data breaches and unauthorized entrance are possible since IoT sensors installed in manholes collect data on gas and water levels and structural integrity. Data encryption, strong authentication, and adherence to regulations such as the General Data Protection Regulation (GDPR) are privacy measures used to protect vital infrastructure data. Table II shows the study of data privacy and data communication. The reliability of Internet of Things communication is endangered by adverse conditions such as signal interference, extreme weather, and physical impediments. Some strategies to lessen connectivity dependence include edge computing, signal amplification, and redundant networks like NB-IoT or LoRaWAN. Maintaining functionality is also aided by strong device design and efficient energy management. Combining secure protocols with event-driven alerts, which offer continuing monitoring and timely alerts even in challenging situations, enhanced reliability, and privacy.

TABLE II. STUDIES ON DATA PRIVACY AND IOT COMMUNICATION RELIABILITY

Reference	Focus Area	Findings	Suggestions for SMMMS
Amutha *et al.* [9]	Smart manhole maintenance	Communication delays impact performance	Implement predictive failure mitigation
Krishnan *et al.* [11]	Anomaly detection in IoT data	Improved threat detection in realtime	Add Machine Learning (ML)-based anomaly detection
Xie *et al.* [13]	IoT reliability during outages	Redundant channels improved resilience	Utilize LPWAN or hybrid communication
PackiaSlacer *et al.* [16]	IoT-based automation systems	Data caching improves system reliability	Integrate realtime data caching locally
Krishnan *et al.* [11]	Smartphone-based IoT systems	Limited to manual interventions	Add automated fallback mechanisms
Palipudi *et al.* [17]	Blockchain for IoT security	Enhanced data integrity and privacy	Incorporate blockchain for secure logging

IV. RESULTS AND DISCUSSION

The Smart Monitoring System uses an Arduino Uno as the central controller to monitor various environmental and safety parameters of manholes. The system integrates several sensors to detect gas levels, tilt status, water levels, and GPS location. Data is transmitted to ThingSpeak for realtime visualization and analysis, while realtime alerts are provided using an RGB LED module. Below is Fig. 2 shows the overall smart manhole system with Manhole 1 & 2:



(a) (b) (c) (d)

Fig. 2. The Manhole system. (a) top view of Manhole 1 (b) top view of Manhole 1 and Manhole 2 (c) top view of hardware (d) side view of hardware used.

A. *Gas Level Monitoring*

During testing, the gas sensor accurately detected dangerous gasses in the manhole environmentThroughout the testing phase, the sensor accurately and consistently measured gas levels. Fluctuations in gas concentrations were within expected limits, verifying the sensor's sensitivity and response. The RGB LED module was immediately triggered when gas levels exceeded a specified safety threshold, such as 500 units. This visual indication offered fast feedback on high gas levels. Concurrently, the system created an alert immediately relayed to the Thing Speak IoT platform. This realtime alarm mechanism allows timely reactions to critical circumstances, improving safety measures and allowing for proactive maintenance interventions.

As shown in Table III, during testing, the gas sensor accurately detected dangerous gasses in the manhole environment. Throughout the testing phase, the sensor accurately and consistently measured gas levels. Fluctuations in gas concentrations were within expected limits, verifying the sensor's sensitivity and response. The RGB LED module was immediately triggered when gas levels exceeded a specified safety threshold, such as 500 units. This visual indication offered fast feedback on high gas levels. Concurrently, the system created an alert immediately relayed to the Thing Speak IoT platform. This realtime alarm mechanism allows timely reactions to critical circumstances, improving safety measures and allowing for proactive maintenance interventions.

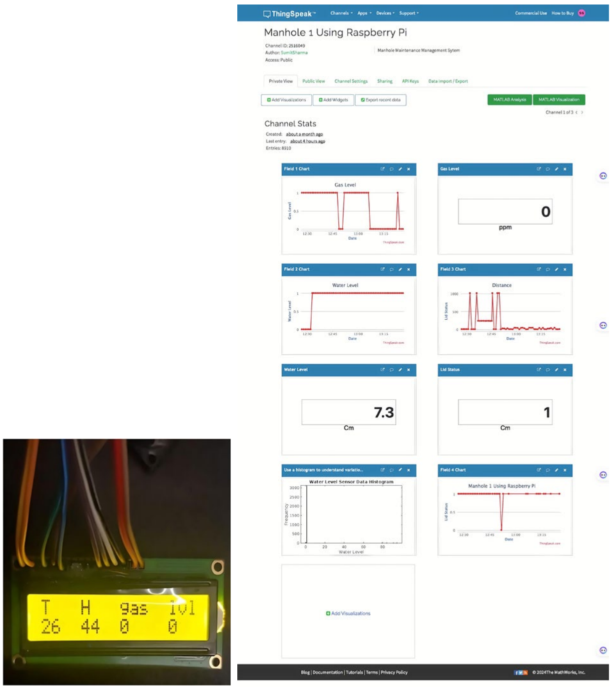
TABLE III. DATASETS FOR GAS CONCENTRATION

Sr.No.	GAS Level	Action to be Taken
1	$0 < \text{value} \leq 100$	NO SMS
2	$100 < \text{value} \leq 300$	NO SMS
3	$\text{Value} > 500$	Send SMS

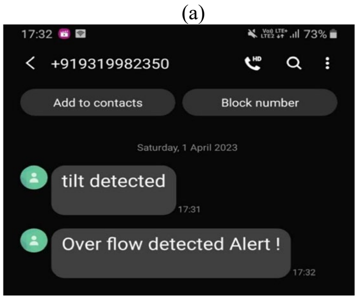
Practical Scenario: Gas Detection in a Manhole

- Visual alerts through the RGB LED module.
- Realtime notifications via Twilio to relevant authorities containing critical information like gas levels, GPS coordinates, and detection time.
- Activation of the Q-learning algorithm to prioritize actions based on pre-configured policies.

Fig. 3 shows output results of various sensors and output alert through sms. The described scenario demonstrates the system's ability to ensure timely interventions and mitigate risks effectively, showcasing its value in smart city infrastructure management.



(a)



(b)

Fig. 3. Output results. (a) output result graphs from Manhole 1 Rasberry Pi (b) tiltsensor output and alert mechanism through SMS.

B. Water Level Detection

The manhole's water levels were precisely tracked by the water level sensor. It successfully identified changes in water levels during testing, particularly in conditions with simulated intense rains. The system immediately sent out an alarm and turned on the RGB LED module when the water levels hit a critical point. This feature is essential for avoiding overflow and possible flooding, allowing maintenance crews to act quickly.

TABLE IV. DATASETS FOR WATER LEVEL

Sr.No.	The Water Level in %	Action to be Taken
1	Value = 0	NO SMS
2	0 < value ≤50	NO SMS
3	Value > 50	Send SMS

Table IV outlines the standard values used to track the water level and what should be done when it rises above the limits. NO SMS means sms not sent for the value equals to zero and if the value is greater than zero sms will be sent.

C. Realtime Alerts and Notifications

Inwith sensor readings, the RGB LED module successfully provided instantaneous visual warnings. This realtime alert system was essential in enabling workers on the scene to quickly recognize and address possible threats. Additionally, by integrating with Twilio, the system was able to notify maintenance staff in time-time realtime. These notifications guaranteed that important alerts were shared as soon as possible, allowing for quick and efficient fixes for any problems that were found.

Fig. 4 shows output result graphs from arduino uno. Table V shows the sensor outputs. It shows all entry id and gas levels accordingly.

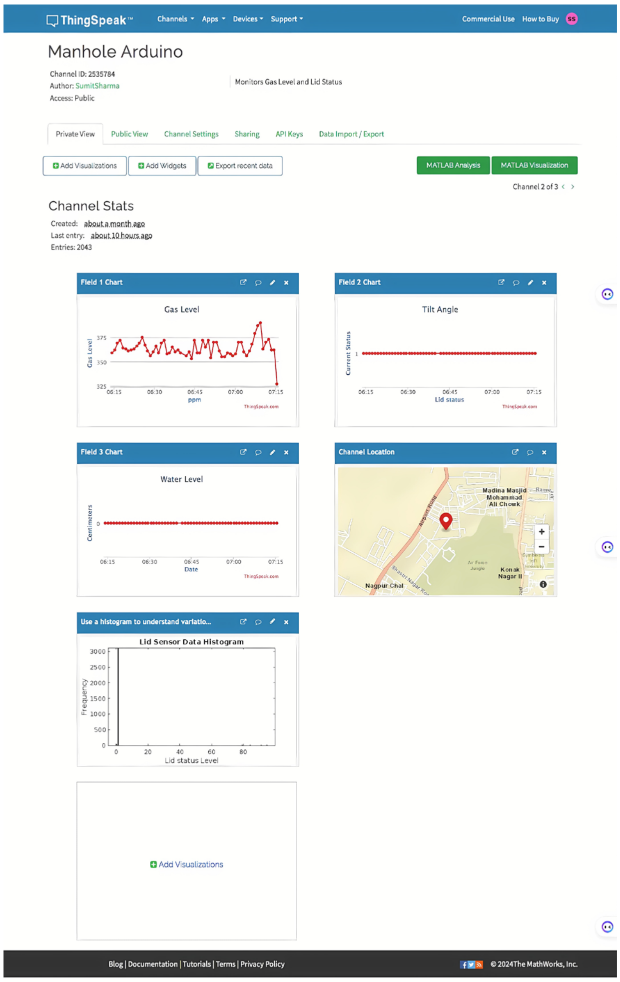


Fig. 4. Output result graphs from arduino uno.

Tables V and VI show sensor outputs. Table VII suggests the system was assessed using several tests and simulation results of sensors. The Q-learning policy system allocated rewards and punishments based on the minimum and maximum thresholds that were given to each sensor. The accuracy-based system performance evaluation is shown in Fig. 5.

TABLE V. SENSOR OUTPUT

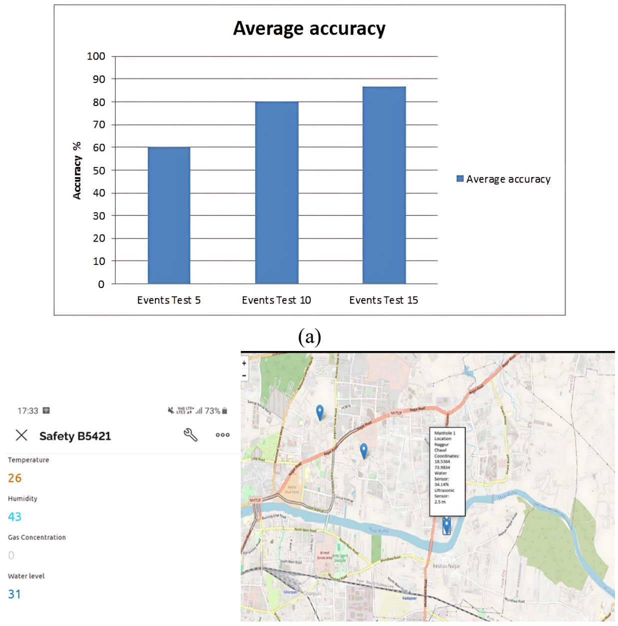
Date and Time(created_at)	Entry_id	Water Level Sensor	Gas Level	Depth	Lid Status
2024-06-02T21:35:14-04:00	2033	1	361	12.03	0 (Close)
2024-06-02T21:36:15-04:00	2034	1	368	11.24	0 (Close)
2024-06-02T21:37:16-04:00	2035	1	379	12.48	1 (Open)
2024-06-02T21:38:17-04:00	2036	1	387	13.89	1 (Open)
2024-06-02T21:39:18-04:00	2037	1	390	10.76	0 (Close)
2024-06-02T21:40:19-04:00	2038	1	363	10.55	1 (Open)
2024-06-02T21:41:21-04:00	2039	1	370	10.91	0 (Close)
2024-06-02T21:42:22-04:00	2040	1	373	17.44	0 (Close)
2024-06-02T21:43:23-04:00	2041	1	362	18.24	0 (Close)
2024-06-02T21:44:24-04:00	2042	1	362	18.48	1 (Open)
2024-06-02T21:45:25-04:00	2043	1	327	18.89	1 (Open)

TABLE VI. SIMULATION RESULTS OF SENSORS

Name of Place	Manhole Coordinator	Water sensor output	Ultrasonic Sensor
Nagpur Chawal	18.5384, 73.9383	34.13%	Lid close
Nagpur Chawal	18.5384, 73.9383	99.28%	Lid Open

TABLE VII. EVENT DETECTION

Events Total	Manhole Detection	Average accuracy (%)
5	3	60
10	8	80
15	13	86.66



(a)

(b) (c)

Fig. 5. Results. a) prediction of accuracy level for different sample events (b) real-time values over blynk IoT app (c) SMM output on GUI with all sensor output.

V. CONCLUSION

The smart manhole monitoring system uses IoT to monitor GPS location, water levels, and ultrasonic sensor The smart manhole monitoring system utilizes Raspberry Pi3b and various sensors to monitor manhole conditions. It integrates with Think Speak for data visualization and Twilio for instant notifications, ensuring swift responses. Its scalability and integration potential with other smart it systems make it a versatile solution for modern urban challenges, improving the overall quality of life. IoT-based manhole monitoring system advancements in environmental and public health management effectively control and report sewage overflow incidents.

Addressing hygiene challenges posed by harmful gases like CO, CH_4, and NH_3 in sewage systems. Integrated Wi-Fi allows local authorities to receive daily updates on sewage levels, ensuring timely responses. Challenges include sensor reliability under diverse environmental conditions and concerns regarding data security. Future enhancements could include integrating machine learning based on historical data for predictive maintenance, improving overall system efficiency and risk mitigation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

SA conducted the research and wrote the original draft; KV and AK reviewed and edited the manuscript; DAD acquired funding; FS provided resources; SS handled validation; VV supervised the work; all authors approved the final version.

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