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Smart Manhole Monitoring and Alert System for Urban Infrastructure

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ABSTRACT- *Water drainage systems underground have a significant contribution to make our urban sanitation and water management efficiency. Manholes provide access to underground sewer pipelines for inspection and maintenance purposes. In many urban areas, however, manhole monitoring is still conducted manually, which is very time-consuming and can put workers at risk from exposure to harmful gases, water overflow and unsafe conditions. In order to solve the above problems, this paper proposes an IoT-based Smart Manhole Monitoring and Alert System for monitoring underground drainage infrastructure in real-time. The proposed system is based on a compact DOT PCB platform which integrates multiple environmental sensors with an ESP32 microcontroller. The system automatically measures and monitors key parameters like water level, gas concentration, temperature, humidity and manhole unit tilt movement. All the sensor information is wirelessly sent to a monitoring dashboard in the cloud through GSM/Wi-Fi communications. The dashboard offers live sensor data, alerts and geographical information of the manhole system. The prototype developed was tested in varying environmental conditions, and showed good performance in terms of detecting abnormal cases and providing immediate warnings. The proposed solution saves the need for manual inspection, increases worker safety, allows remote monitoring of numerous manholes and offers an efficient solution for the management of underground infrastructure in smart cities.*

Keywords—*Internet of Things (IoT), Smart Manhole Monitoring, ESP32, Environmental Sensors, Gas Detection, Water Level Monitoring, Smart City Infrastructure, Remote Monitoring, GPS Tracking, Urban Drainage System.*

I. INTRODUCTION

In a modern city, the urban drainage system is a crucial part of the wastewater infrastructure that keeps the city clean and sanitary, and in good working order. Manholes are essential parts of such drainage systems because they allow access to underground pipelines of sewerage systems for their inspection, maintenance and repair. An appropriate manhole monitoring system should be used to avoid blockages of drainage, water overflow, build up of dangerous gases and damage to urban infrastructure. Many cities continue to carry out manhole inspection by hand. This traditional way of doing it uses lots of time, is not very efficient and can make workers get into unsafe situations like coming in contact with toxic gases, contaminated water and poor ventilation. Manual monitoring also makes continuous monitoring hard, resulting in issues being detected when they become significant. This can cause damage to the road, flooding in the city, traffic disruption and risk to public safety.

The Internet of Things (IoT) is rapidly evolving and intelligent monitoring can now be implemented to monitor underground infrastructure remotely across sensors and wireless communication. The IoT monitoring systems can collect data about the surroundings and send it in real-time to a remote monitoring platform. Various researchers have suggested using sensor-based systems to monitor parameters like water level, gas concentration and environmental conditions within manholes. Many of the systems that currently exist, however, have drawbacks such as complicated hardware architecture, no real-time visualization, poor remote access, and no real-time location tracking.

To address these challenges, a novel Smart Manhole Monitoring and Alert System using IoT technology is presented which incorporates environment sensing, wireless communication, GPS tracking and real-time visualization on a small-scale hardware platform. The proposed system consists of several sensors, ESP32 microcontroller and continuously measures the essential parameters like water level, gas concentration, temperature, humidity and tilt movements. The collected data is wirelessly sent to a monitoring dashboard in the cloud, allowing authorities to monitor a number of manholes and get instant notifications in abnormal situations. The proposed system has the advantages of improving the safety of underground infrastructure construction works, reducing manual inspection, enhancing monitoring efficiency and low cost, and can be used in underground infrastructure management of smart city.

II. LITERATURE REVIEW

Various researchers have been suggesting different methods of enhancing underground drainage system to improve monitoring and management of manholes. The traditional way of inspecting involves manual monitoring, in which the workers have to manually make their way into the manholes and check for faults or blockages in these sewer pipes. This, however, is an inefficient, time-consuming and exposes workers to hazards like toxic gases, polluted water, moisture, and poor ventilation. In order to address these issues, numerous researchers have been working on the concept of automated monitoring systems with the help of sensors and Internet of Things (IoT) technology.

A number of systems have been suggested that can continuously monitor environmental conditions inside manholes using water level sensors and gas sensors. These systems alert to unusual conditions, like water overflow and gas leaks, and warn. While they enhance monitoring efficiency and help maintain safety, most of them are intended for monitoring at a single location and wouldn't work well in monitoring a whole area with many manholes. There are also a few monitoring systems that utilize the Internet of Things (IoT) technology that have been created, where sensors are interfaced with microcontrollers, and the data received is sent to cloud-based monitoring platforms for remote monitoring. These systems offer live technology visualization via web dashboards or mobile apps, with less need for regular manual checks.

Most of the current solutions, however, rely on complex hardware configurations, several communication modules, and complex network topologies that make installation and maintenance costs and complexity high. The concept of smart city monitoring, which relies on wireless sensor networks, has been attracting attention in recent years for management of underground infrastructure. These systems can be used for monitoring several underground sites from a single location and give more access for municipal authorities. Although beneficial, many such systems are costly and require sophisticated infrastructure support making them less appropriate for cost effective implementation in the cities.

From the existing literature, it is clear that the use of IoT-based monitoring system can have a significant impact on the operation and security of underground drainage system. However, there remains a need for a low cost, compact, efficient solution that allows for integration of the environmental sensing, wireless communication, GPS tracking and real-time visualization of the data in a single platform. To overcome these drawbacks, a Smart Manhole Monitoring and Alert System based on IoT technology is proposed, which can be an economical and reliable solution for smart city applications.

III. METHODOLOGY

The proposed Smart Manhole Monitoring and Alert System is designed by integrating multiple environmental sensors, ESP32 microcontroller and wireless communication technology for real-time monitoring of underground infrastructure. All the essential electronic components are organized and efficient in this compact DOT PCB system platform with all the required parts. The ESP32 microcontroller is the base of the system. It continuously takes in data from the sensors, processes the data and reports the data measured by the sensor to the cloud-based monitoring platform via the Wi-Fi/GSM communication. The ESP32 is used due to its low power consumption, built-in wireless communication function, and processing power efficiency, which is beneficial for IoT applications.

Water level is monitored using an ultrasonic sensor inside of the manhole. The sensor functions by sending ultrasonic waves and the reflected echo signal is measured to determine the time needed for the return. The distance is calculated and the system is used to determine the water level in the drainage structure. When the water-level is above a pre-defined threshold value, the system automatically sends a notification of a flood alert on the monitoring dashboard. The system uses a gas sensor called MQ-135 to detect hazardous gases. This sensor can detect toxic gases like methane, carbon monoxide, ammonia and other toxic gases that can be found inside the manhole. The system will immediately provide a gas alert if the gas concentration is above the safe levels, to keep workers safe.

The DHT11 sensor is employed to measure the conditions of the ambient temperature and humidity in the manhole. A continuous monitoring program of these parameters can be used to detect anomalies in the environment that could impact underground drainage operations. The system includes an MPU6050 tilt sensor which is used to detect any physical movement or displacement of the manhole cover or monitoring unit. The sensor is able to detect any changes in orientation and alerts to any unusual movement or tampering. An NEO-6M GPS module is used to give accurate location tracking. Its GPS module tracks the manhole's location in real time, allowing the authorities to determine the precise location of the affected manhole in an emergency situation.

All the sensor data collected is sent to the ESP32 microcontroller which then transmits wirelessly to a cloud-based server. The real-time data is shown on a web dashboard and mobile monitoring app, which offers real-time sensor readings, alerts, system status and GPS-location-based tracking. This allows for multiple manholes to be monitored remotely, and will enable authorities to take immediate actions should they detect abnormal conditions.

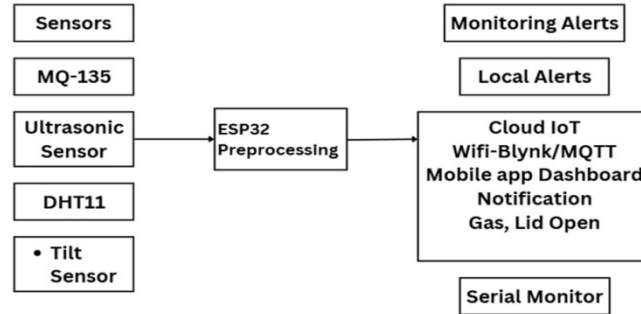


Fig1,BlockDiagram

IV. SYSTEM IMPLEMENTATION

The proposed Smart Manhole Monitoring and Alert System is realized via a number of environmental sensors, an ESP32 microcontroller, GSM/Wi-Fi communication and a mobile monitoring application. The hardware unit is put into the manhole and constantly monitors environmental conditions and relays real-time data to the monitoring agencies. The ESP32 microcontroller is the core of the system, controlling and processing all operations. It collects sensor data, analyses the data, compares it to preset thresholds and then communicates monitored data to the cloud-based dashboard and mobile app via wireless. The ultrasonic water level sensor is used to continuously monitor the water level in the manhole. If the water level rises above the normal level during heavy rainfall or drainage blockage (DB) condition. If the water level exceeds the water level set in advance, the ESP32 will notify in advance of flooding and send it to the mobile application. This will enable authorities to take preventive measures as soon as possible and in advance before flooding. The harmful gases like methane, ammonia, carbon monoxide and other toxic gases are inside the manhole that can be detected by the MQ-135 gas sensor. When the concentration of gas reaches a level above a safe level, a gas alert notification is produced immediately. This feature makes sanitation workers safer, and minimises risk of hazardous gases being inhaled by workers during the maintenance process.

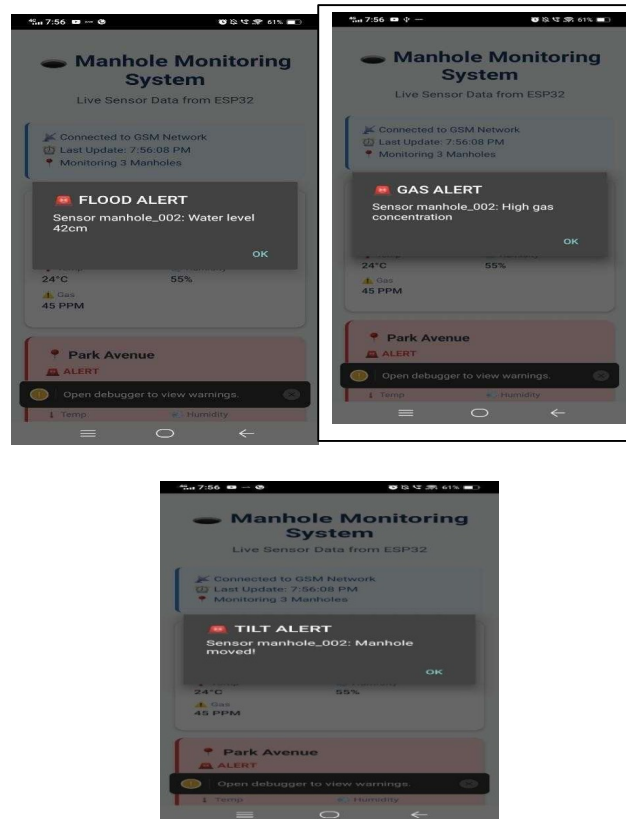


Fig.2.Flood, Gas & Tilt Alerts

The DHT11 sensor is used to measure the temperature and humidity in the drainage system. These parameters are useful in analysing the underground changes and also detecting abnormal operating conditions. The system is equipped with an MPU6050 tilt sensor that can track the position and movement of the manhole cover. The sensor detects the movement of the manhole cover when it is tilted, displaced or removed, which may be caused by theft, accidents, maintenance etc., and notifies with a tilt alert. This helps to reduce manhole openings and manhole damage on road surfaces causing accidents. The NEO-6M GPS module gives actual geographical location information of the monitoring system. The GPS coordinates are shown on the mobile dashboard, allowing for easy identification of the exact location of the manhole affected by the problem.

The processed results from all the sensors are sent to the mobile monitoring application via the ESP32 microcontroller with the help of GSM/Wi-Fi communication. The mobile app shows live sensor readings, system status, GPS location and alerts. The dashboard also indicates if the monitoring system is connected and how many manholes are being monitored. It instantly alerts to any abnormal condition like water overflow, toxic gas leakage, displacement of manhole cover etc. on the monitoring dashboard, when detected by the system. These alerts assist the monitoring authorities to know of the issue soon and act swiftly. The proposed system allows for continuous real-time monitoring of underground drainage infrastructure, and can greatly reduce the need for manual inspection. The use of wireless communication, environment sensing and the real-time alert generation enhances worker's safety, efficiency of monitoring and smart city infrastructure management.

V. RESULT AND DISCUSSION

The proposed Smart Manhole Monitoring and Alert System was implemented and tested in various environmental conditions to assess its functionality, reliability and real-time monitoring capabilities. This system was able to continuously monitor critical environmental conditions like water-level, gas concentration, temperature, humidity, tilt-movement and geographical location of the manhole. The variation of water level in the manhole was accurately detected by the ultrasonic sensor during testing. The mobile monitoring dashboard notifies the users of a flood alert whenever the water level is higher than the predefined threshold value. This functionality allows for early detection of drainage overflow in order to take action in advance of the flooding.

This MQ-135 gas sensor was able to detect harmful gases in the manhole. Any toxic gases present in the system, and if the concentration is beyond the safe level, the system would alert the user of the gas immediately. This is a very important safety feature as it reduces exposure to hazardous gases for maintenance personnel when inspecting and cleaning. DHT11 sensor was placed to continuously monitor temperature and humidity level of the drainage system. Environmental data gathered assisted in the detection of abnormal conditions in the atmosphere and adequate monitoring of underground infrastructure.

The MPU6050 movement or displacement sensor was able to detect any motion of the manhole cover or monitoring unit. If there are any abnormal tilts or movement, the system will send out a tilt alert message. This feature helps reduce the potential risk of an accident from open or displaced manhole covers, and enhances system security from tampering or theft. The NEO-6M GPS module gave the precise GPS position of the monitoring unit at all times. The GPS location data was made available on the monitoring dashboard that would help the authorities locate the specific manhole in emergency scenarios.

Table 2, System Performance Analysis

Parameter	Observed Performance
Water Level Detection Accuracy	95%
Gas Detection Response Time	3-5 seconds
GPS Location Accuracy	±5 meters
Sensor Data Update Interval	2 seconds
Alert Notification Time	Less than 5 seconds
GSM/Wi-Fi Communication Reliability	Stable
Temperature Sensor Accuracy	±2°C

HumiditySensorAccuracy	±5%
TiltDetectionResponse	Immediate
OverallSystemReliability	High



Fig5.Livereadingsof sensors

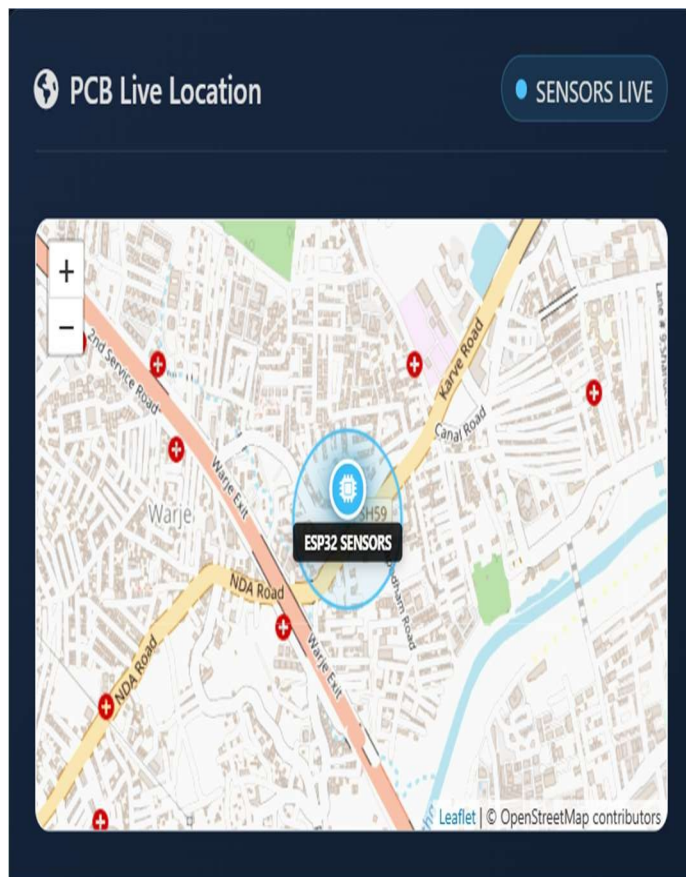


Fig 6. System Location Table1,ComparisonwithExistingSystems

Features	Existing Systems	Proposed System
Manual Inspection Required	Yes	No
Real-Time Monitoring	Limited	Yes
Water Level Detection	Available	Yes
Gas Leakage Detection	Limited	Yes
GPS Tracking	Not Available	Yes
Tilt/Tamper Detection	Not Available	Yes
Mobile Dashboard Monitoring	Partial	Yes
Instant Alert Generation	Limited	Yes
Multi-Parameter Monitoring	Partial	Yes
Remote Monitoring Capability	Limited	Yes
Cost Effectiveness	Moderate to High	Affordable

All the sensor data has been analysed by ESP32 microcontroller and the data has been sent to the mobile application via GSM/Wi-Fi communication with efficiency. The monitoring dashboard was continually updated with real-time sensor readings, alerts, system status, and GPS location. The sensor readings were taken at regular intervals, providing accurate and reliable monitoring. The developed system also had the ability to monitor several manholes at once using a single dashboard interface. This enables municipal officials to operate on the effective management of large underground drainage networks more efficiently, without doing regular manual checks.

The user-friendly mobile dashboard offered a view of live sensor data, system status, last sensor update time and alerts. Abnormal conditions including manhole cover displacement, gas leakage, and overflow of water were detected and the alerts were shown on the dashboard immediately and the manhole identification information was shown. After experimental analysis, it has been revealed that the proposed system is not only reliable but also stable in wireless communication and also has a swift response time. Real-time monitoring and automatic alert generation not only protect workers from danger but also decrease the need for manual inspections and boost the management efficiency of underground drainage systems in smart city settings.

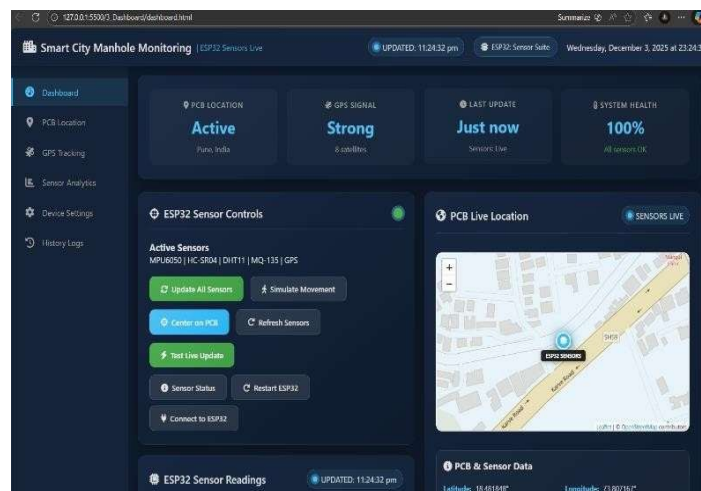


Fig7. Dashboard-live location of system

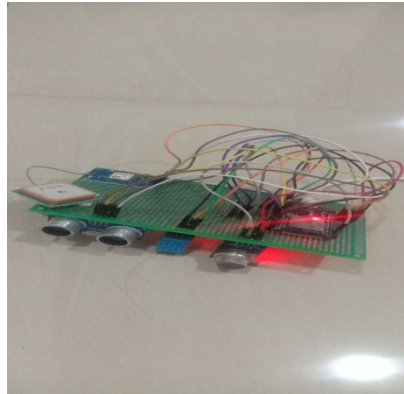


Fig8.FinalSystem

VI. CONCLUSION AND FUTURESCOPE

The proposed smart manhole monitoring and alerts system by IoT technology is an effective and reliable solution to enhance the safety and management of underground drainage systems. The system uses a variety of environmental sensors, all connected to an ESP32 microcontroller, which are installed on a small hardware platform to measure and record valuable data like water level, gas concentration, temperature, humidity, tilt motion and geographical location of the manhole in real-time. All sensor data collected is wirelessly sent to a monitoring dashboard accessible remotely and in real-time from the cloud, allowing municipal authorities to see them.

The developed system is able to detect the abnormal environmental conditions and provide instant alert notifications when hazardous conditions like water overflow, leakage of toxic gases or manhole cover displacement is detected. The experimental results show that the system proposed is working properly and stable real-time monitoring performance is maintained under various environment conditions. Automated monitoring and wireless communication greatly diminish reliance on manual inspection techniques, increase worker safety, cut down on maintenance delays and boost the efficiency of urban drainage management systems.

The proposed system is also cost-effective and scalable, which will be helpful for smart city infrastructure applications. GPS tracking and real-time dashboard monitoring enables multiple manholes to be managed at once, and can help respond swiftly in the event of an emergency. The system can be further improved by incorporating more sensors, such as vibration sensor, liquid flow sensor, and smoke detection sensor in future work to monitor the underground infrastructure to a greater extent. Machine learning algorithms can also be used to make predictive analysis of the machine and find out its possible failures before they happen so that preventive maintenance can be done.

The monitoring platform can be enhanced with integration of automatic alerts like SMS, email and mobile push notifications for instant response in emergency. The dashboard can also be enhanced with advanced data visualization and historical data analysis capabilities, for improved decision-making and maintenance planning. In addition, energy-efficient solutions like intelligent battery management methods and solar-powered systems can be deployed for the long-term and sustainably operated. The envisaged enhancements in the future would add intelligence, scalability, energy-efficiency and would be very well suited to future smart city infrastructure monitoring applications.

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