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Lora based Manhole Cover Status and Toxic Gas Monitoring with IoT Technologies

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Abstract—Currently smart city management is of critical importance in the urban infrastructure of growing countries. In this context, it is necessary to make the underground manholes and sewage systems smart and traceable. Open manhole covers pose security risks which may lead to various accidents and damages. Gas leaks, on the other hand, pose serious risks and endanger human health. In this study, a wireless device was developed to monitor the condition of manhole covers and track gas levels within them. This device, automatically monitors manhole gases, detects gas leaks, checks the status of the covers and through the Internet of Things (IoT) system it is connected to provides alarms to inform the authorities. The sensors used inside the device can detect the presence of toxic gases, thereby contributing to occupational health and environmental safety.

Keywords-manhole; iot; toxic gases; warning system; smart city

I. INTRODUCTION

The increasing global population and urbanization necessitate making infrastructures safer and more manageable. Smart city management employs digital technologies to enhance the quality of life in cities and sustainably manage infrastructure. This management goes beyond surface-level solutions such as traffic lights, meters, or irrigation systems; it also encompasses numerous components such as energy, communication, transportation, environment, and infrastructure security. Monitoring manholes, which are critical elements of infrastructure, is an integral part of the smart city ecosystem. Manhole covers pose significant security risks if stolen or left open. Moreover, the accumulation of harmful gases leaking from underground soil or pipelines alters the conditions within manholes, posing substantial health risks to personnel and citizens. The accumulation of hazardous gases inside manholes jeopardizes work processes and increases the risk of poisoning [1]. Manhole explosions, often caused by gas accumulation and negligence, are common problems in urban settings. According to a report in the press, the theft of a manhole cover highlights the need to monitor covers [2]. Furthermore, the risk of falling into open manholes or inhaling gases inside manholes, resulting in injuries or fatalities, is a significant concern. During operations in manholes, it is not possible to measure gas levels before opening a manhole with unknown internal conditions. This limitation introduces the risk of dangerous situations, such as gas explosions due to static electricity upon opening the cover [3]. Even in the absence of explosions or other hazards, personnel are still at risk of exposure to toxic gases, which poses serious health concerns. M. Venkata Sudhakar et al. have stated that without proper monitoring and recording of manholes, many people are required to conduct frequent inspections, which is both time-consuming and resource-intensive [4].

Smart city management applications aim to provide cleaner and better opportunities for society. Manual monitoring is often insufficient, leading to slower responses to problems or, in some cases, issues being overlooked entirely. To manage and resolve problems promptly, manholes, sewers, and drainage systems used in various fields need to be made smart and traceable [5]. Looking at similar studies, Chan H. Sree et al. proposed a manhole monitoring system based on a wireless sensor network [6]. Similarly, S. Salehin et al. implemented an automated manhole monitoring system that detects hazardous chemicals and gases inside manholes, senses the status of the manhole cover, warns nearby individuals, and informs authorities about the system's condition [7].

To address the aforementioned problems and risks, this study aims to monitor the status of manhole covers and gather information about the levels of specific gases within manholes to establish an early warning system. Therefore, the design of a wireless sensor network is proposed.

In this context, one of the potential solutions is a smart manhole monitoring system utilizing IoT technology. IoT is a smart network of interconnected physical devices equipped with sensors, electronic components, and software. By leveraging this technology, it is aimed to monitor gases within manholes or underground pipeline systems, and prevent the opening or theft of manhole covers. The data collected from the relevant sensors installed inside the manhole are transmitted to a central system via a network. This system can automatically trigger alarms based on the status of the manhole cover and make environmental conditions traceable, thus simplifying issue resolution [8].

The hardware managing the process at the endpoint is the 'Smart Manhole Monitoring Device,' equipped with a high-performance and energy-efficient processor. It detects conditions such as temperature rise, gas density caused by toxic gases, and open manhole covers through sensors embedded within. This device optimizes the operation, ensuring that sensor data is processed quickly and accurately, and subsequently transmitted to the IoT network. Thus, a more reliable, efficient, and cost-effective solution is provided compared to manual monitoring methods.

II. METHODOLOGY

A manhole monitoring system is proposed, consisting of communication gateway devices operating on a LoRa communication infrastructure at endpoints and smart manhole monitoring device hardware. This system also integrates with smart manhole monitoring software at the central unit, offering comprehensive monitoring of each manhole based on mapped location data [9]. The primary functions of the system include monitoring the status of manhole covers, measuring toxic gas levels, and sending alert signals in cases requiring security alarms. The software infrastructure is developed to support different operating modes, with each system function managed as outlined below:

A. Manhole Cover Status Monitoring

One of the system's primary functions is monitoring the status of manhole covers using a limit switch that is activated when the cover is opened or closed. The device processes data promptly and transmits the status of the cover to the central unit without delay. Additionally, when the cover is opened, the measurement frequency increases, enabling more frequent updates to the central monitoring unit. Conversely, when the cover is closed, the measurement frequency is reduced, ensuring more efficient energy usage.

B. Toxic Gas Monitoring

The presence of potentially hazardous gases inside the manhole is continuously monitored using specialized gas sensors. The device processes data received from embedded sensors, and transmits it to the central unit. When the central unit detects gas concentrations exceeding a defined safety threshold, the system activates alarm processes, providing real-time information for toxic gas detection.

C. Operating Modes

The system operates in various modes. When the cover is opened, the device switches to a higher measurement frequency, enabling quicker detection of potential security threats. When the cover is closed, the measurement frequency is reduced, optimizing power consumption. In both cases, the system regularly transmits necessary information about the manhole status to the central monitoring unit.

D. Alarm and Alert System

When the cover is open or hazardous gas levels are detected, the system automatically enters alarm mode. The device transmits data to the central unit through a LoRa communication gateway. Communication between the transmitter inside the manhole and the external LoRa gateway device is achieved using LoRa technology. The LoRa gateway device relays the received data to the central monitoring system via the internet. The central monitoring system provides remote access to data such as the status of manhole covers and toxic gas detection. In alarm situations, alerts are sent to authorities via SMS or email, and the manhole status is updated in the system.

E. Efficient Battery Management

Efficient battery usage is a critical factor in extending the operational lifespan of portable devices. For devices with limited battery capacity, optimizing power consumption directly impacts battery life. The smart manhole monitoring device is equipped with a 12000mAh battery pack. Calculations regarding power consumption and battery life are conducted to determine how usage levels change and how to optimize the device's operational duration. If the device is set to regularly enter sleep mode and sensors are activated only twice daily, the battery life can extend to approximately 2.5 years. This duration may vary depending on the activity levels of the processor and sensors and their wake-up frequency. Effective battery management ensures uninterrupted device operation for extended periods. In summary, the system depicted in Figure 1 monitors the status of manhole covers and gas levels while offering a flexible software structure that ensures low power consumption and high reliability. Various operating modes allow for energy savings without compromising safety measures. The real-time status of each manhole can be easily tracked through mapped locations, and potential risks can be identified in advance [10],[11].

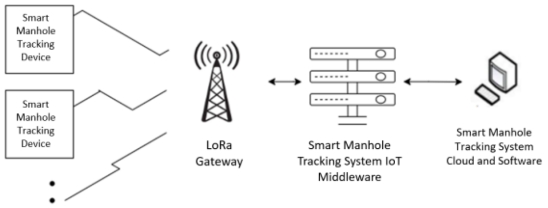

Figure 1. The status of manhole covers and gas levels

III. SENSOR SELECTION

The selection of sensors for the smart manhole monitoring device is based on the following criteria:

- Market Availability
- Cost
- Power Consumption Level
- Operating Principle
- Data Source Availability

These criteria are established to ensure the efficiency and reliability of the sensors [12]. Each sensor exhibits different technical parameters, such as power consumption levels and measurement principles. The suitability of a specific sensor cannot be immediately determined solely by its technical specifications. The selection process considers situations that may cause explosions and gases that are most harmful to human health. Hazardous gases commonly accumulating in manhole environments pose significant health risks and may sometimes result in fatalities. Gases such as carbon monoxide (CO), hydrogen sulfide (H_2S), methane (CH_4), and oxygen (O_2) frequently reach dangerous levels in manhole air. This situation endangers both workers and people in the surrounding area. Particularly, carbon monoxide and hydrogen sulfide, being odorless and colorless, can poison individuals without their awareness. Methane is an explosive gas, while reduced oxygen levels can lead to asphyxiation due to oxygen deficiency. Early detection of these gases is critical to minimize risks and ensure safety around manholes [13],[14].

- Hydrogen Sulfide (H_2S): This hazardous gas, often characterized by a foul odor, can form in sewer systems, swamps, and fertilizers. It occurs in anaerobic environments where organic matter is decomposed. For example, residual contaminated water in sewer pipes can react to produce hydrogen sulfide [15]. A detection threshold of 50 ppm is chosen in this study to meet safety requirements and monitor the gas at levels that may pose a hazard even at low concentrations.
- Carbon Monoxide (CO): This gas is produced by the incomplete combustion of organic matter when oxygen supply is limited. Unlike complete combustion, which generates stable products like carbon dioxide (CO_2), incomplete combustion results in carbon monoxide. Concentrations exceeding 40 ppm are considered highly hazardous [16],[17]. The detection range is set up to 5000 ppm.
- Methane (CH_4): As a major component of natural gas, methane forms during the anaerobic decomposition of organic matter. While used as an energy source, its greenhouse effect poses environmental issues. Concentrations of 10,000 ppm in confined spaces can create highly explosive conditions [18]. The detection range for methane is set between 1–10,000 ppm.
- Oxygen (O_2): Alarm thresholds for oxygen levels are generally set at 23.5% and 19.5%. Under normal atmospheric conditions, oxygen levels in manholes are approximately 20–21% by volume. However, certain factors in manholes may cause fluctuations. The selected sensor can detect oxygen levels in the range of 0–25% [19]. Manhole covers are constructed from various materials such as metal and composite, and they can be designed as directionless or hinged [20],[21]. Due to this diversity, it is determined that using a limit switch is the most suitable method to detect whether a cover is open or closed. As a passive component, the limit switch reliably detects the position of the cover without requiring power. Consequently, the cover status sensor must have at least an IP68 protection rating, ensuring durability against harsh weather conditions and external factors. As shown in Figure 2, this sensor must function reliably under challenging conditions and independently of the orientation of the manhole cover.

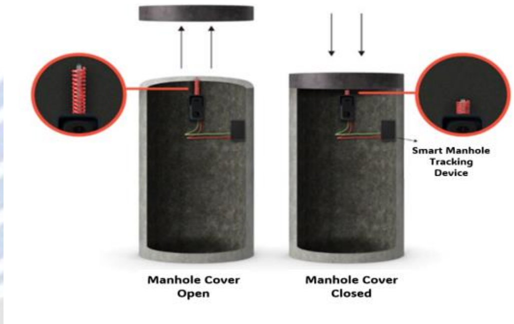

Figure 2. Sensor function reliably

IV. DESIGN

The smart manhole monitoring device consists of two physical units and four logical layers.

A. Physical Units:

1. Smart Manhole Monitoring Device Main Unit
   a) The main component of the device, housing embedded sensors, a power source, a main processor, and communication circuits.
   b) Includes suitable input/output interfaces for connecting limit switches.

2. Manhole Cover Status Detection Limit Switch
   a) A secondary component positioned close to the cover, operating on a mechanical principle to withstand impacts during the opening and closing process.
   b) Connected to the main unit via a cable.

B. Logical Layers:

a) Communication Layer
b) Sensor Layer
c) Power Management Layer
d) Processor Layer

A. Communication Layer

The communication layer primarily consists of components such as LoRa modules and antennas that enable the use of LoRa communication technology. LoRa technology represents a cornerstone of modern communication systems, introducing numerous innovative features in hardware design. Optimized for low power consumption, this communication layer ensures long battery life, facilitating more efficient energy use. Its design for reliable data transmission over long distances provides significant advantages, particularly in rural and challenging environmental conditions. Moreover, the robust structure of this architecture resists harsh weather and physical impacts, thereby increasing its applicability in various use cases.

B. Sensor Layer

The sensor layer contains sensors and sub-modules specifically designed to measure the types of gases targeted by the Smart Manhole Monitoring Device. These sub-modules are categorized into four distinct groups based on the gases being measured. Additionally, this layer includes the limit switch connections intended for monitoring the status of the manhole cover.

C. Power Management Layer

The power management layer is responsible for providing and managing the power supply necessary for the proper operation of the other layers under suitable conditions. Consequently, it is directly connected to all layers. Fundamentally, this layer offers the hardware infrastructure and software algorithms required for the device to operate under optimal power conditions with maximum efficiency.

D. Processor Layer

The processor layer encompasses the main algorithms that manage measurement, status changes, and communication processes specific to the device, as well as their associated peripherals. This layer also runs power management algorithms. It continuously communicates with the communication and sensor layers to facilitate the collection of sensor measurements and their transmission to the communication layer. Figure 3 clearly illustrates the connections and interactions between the layers.

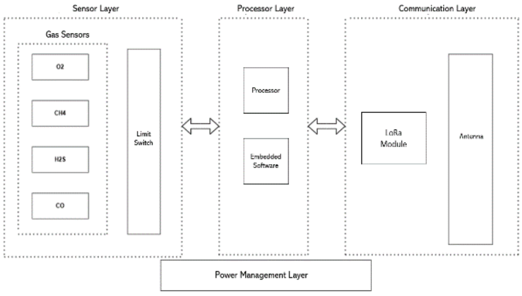

Figure 3. The connections and interactions between the layers

Algorithm Summary for the Processor Layer

To ensure efficient power management, the main processor can enter sleep mode. The processor wakes up either when a status change in the limit switch is detected or through a timer. When the device is periodically activated, it verifies the wake-up method. If it is triggered by the limit switch, the device confirms the status change and transmits the updated cover status. If the wake-up is timer-based, the device checks the status of the sensors. If the sensors are off, it activates them, allows them to adjust to the environmental conditions for a certain period, and then sets the timer to return to a short sleep mode. Upon the next timer-based activation, the device collects sensor data, including the cover status if the sensors are already active. After gathering data, it deactivates the sensors and transmits the collected data to the communication layer. The device updates its operating mode based on whether the cover is open or closed. Depending on the operating mode and the current status, the device sets the timer for the specified interval and returns to sleep mode. The process flowchart for this algorithm is presented in Figure 4.

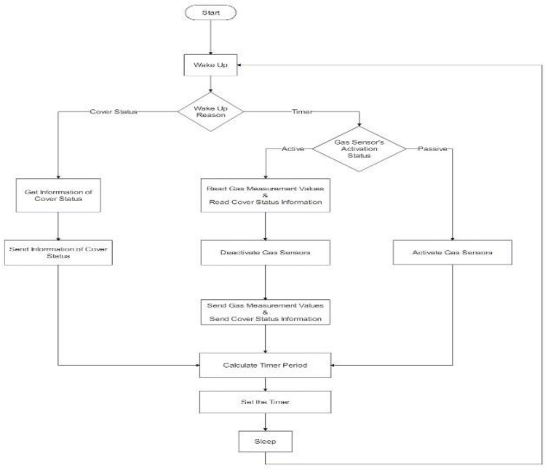

Figure 4.Process flowchart

V. MONITORING

The data detected and transmitted by the Smart Manhole Monitoring Device, such as gas values and cover status, are recorded, processed, and evaluated by the central software of the Smart Manhole Monitoring System to generate necessary alarms and alerts. Additionally, the central software provides visualization and reporting capabilities for historical data measured by the Smart Manhole Monitoring Device. Examples of data recorded by the central software, such as gas values and cover status, are presented in Figures 5, 6.

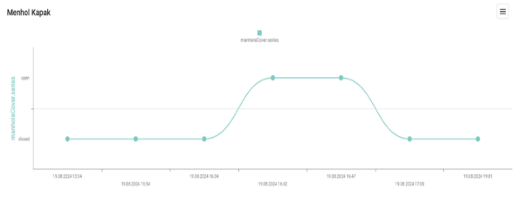

Figure 5. Data recorded by the central software- Manhole Cover

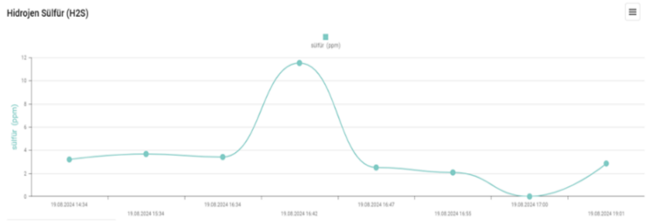

Figure 6. Data recorded by the central software-H2S

VI. CONCLUSION

This study focuses on the development of manhole monitoring systems, which are a crucial component of smart city management. With the advancement of IoT technologies, it has become possible to monitor manholes and sewage systems more effectively, enabling quicker identification of health and safety threats. Issues such as the theft of manhole covers, gas leaks, and uncovered manholes pose significant dangers to urban infrastructure, potentially leading to accidents. The developed Smart Manhole Monitoring System continuously monitors the status of manhole covers through its Smart Manhole Monitoring Device and Central Monitoring Software, promptly detecting potential hazards and notifying the relevant authorities. The proposed system's communication method could be enhanced in future studies by incorporating alternative communication technologies such as NB-IoT alongside LoRa communication. This would allow the system to be deployed in regions with varying infrastructure. Additionally, expanding the variety of sensors to detect different hazardous situations could be another approach for future developments, though such expansions should be considered considering the increased energy requirements. Future work could also focus on selecting more efficient sensors to further reduce the device's power requirements. Simplifying the current monitoring process by reducing sensor diversity and interpreting hazardous conditions within manholes through a minimal number of sensors—rather than reporting gas values—could also be explored as an alternative method.

In conclusion, the adoption of smart manhole monitoring systems not only enhances the security of urban infrastructure but also ensures its long-term sustainability. The widespread implementation of such systems would help prevent accidents and health risks, contributing to safer and smarter cities. The ongoing development and expansion of these technologies represent a significant step forward in smart city management.

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