International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

IoT based sewage tunnel safety monitoring alert system

Angamuthu G [1,*] and Marikkannan M [2]

[1] *Department of Computer Science and Engineering, Government College of Engineering, Erode, India.*
[2] *Department of CSE, Government College of Engineering, Erode, India.*

International Journal of Science and Research Archive, 2025, 15(03), 008–016

Publication history: Received on 20 April 2025; revised on 28 May 2025; accepted on 31 May 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.3.1669

Abstract

Internet of Things (IoT) has emerged over the past few years as one of the fastest growing technologies. In today's technological world, Internet of Things figures prominently in technology discussions due to its rapid growth. The IoT refers to the network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, and network connectivity, allowing them to collect and exchange data and it enables these devices to interact with each other to provide hassle free environment to the people and their Home, Industries Etc., In that Scenario, this technology going to ensure the Sewage Tunnel Safety Monitoring Alert System for workers. It senses the harmful Gases and Smoke from the closed and fully or semi opened tunnels. This concept explains how The IoT prevents from harmful effects. It investigates the resource allocation of a Reconfigurable Intelligent Surface (RIS) aided Joint Communication and Sensing (JCAS) system in a tunnel sewage scenario. In the JCAS system, an RIS is implemented at the corner of the zig-zag tunnels to improve the complicated wireless environment. Furthermore, a data centre is placed on the ground to analyse the obtained data and route the communication data over the network. Long Range Wide Area Network (LoRa WAN) perform in this Tunnel Safety Monitoring and Alert System.

Keywords: Tunnel Safety; Reconfigurable Intelligent Surface (RIS); Joint Communication and Sensing (JCAS); LoRaWAN; IoTSGD; CSGD

1. Introduction

Internet of Things works the network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, and network connectivity, allowing them to collect and exchange data. The IoT enables these devices to interact with each other and with the environment to enables the creation of smart systems and services. IoT systems are typically composed of several components, including IoT devices, communication networks, gateways, and cloud-based data processing and storage systems. IoT devices use sensors and other technologies to collect data, and then send that data to the cloud for analysis and storage. The cloud also provides a centralized platform for managing and controlling IoT devices and networks. IoT development involves a wide range of technologies, including wireless communication protocols, cloud computing, big data analytics, machine learning, and security technologies. According to the definition of IoT, It is the way to interconnect with the help of internet devices that can be embedded to implement the functionality in everyday objects by enabling them to send and receive data. Today data is everything and everywhere. Hence, IoT can also be defined as the analysis of the data that generates a meaningful action, triggered subsequently after the interchange of data. IoT can be used to build applications for agriculture, assets tracking, energy sector, safety and security sector, defence, embedded applications, education, waste management, healthcare product, telemedicine, Smart city applications etc.,

* Corresponding author: Angamuthu G

2. Related Study

Sewage Safety monitoring and alerts of the tunnel environment needs a high sampling density of data, which may need to deploy many conventional sensors to different places and upload data on right time. As a matter of fact, it tends to use wires to bridge sensing points to gather data at processing servers. But, a common drawback of wired networks is less scalable because sensors must be deployed as the tunnel advances. To overcome this problem, Wireless Sensor Networks (WSNs) are scalable for tunnel environments, and multihop routing is necessary for WSNs because direct wireless transmission is unfeasible in winding tunnels [1].

As a consequence, the IoT gateway that once had a specific function more towards sensor networks can now provide information on the flow of data that passes through it in both directions, acting as a translator. This allows two different protocols to communicate and route data to the Internet [7]. A Reconfigurable Intelligent Surface (RIS) is a smart, programmable surface composed of many passive elements that can reflect and manipulate wireless signals to improve communication performance. In IoT, RIS enhances connectivity by directing signals around obstacles, improving coverage, and reducing energy consumption without active transmission. Its key features include low power usage, software-controlled reconfiguration, improved signal quality in challenging environments, and scalability for dense IoT deployments. Joint Communication and Sensing (JCAS) is a technology that integrates wireless communication and environmental sensing into a single system using shared hardware and spectrum. In IoT, JCAS enables devices to not only exchange data but also sense their surroundings (e.g., motion, location, or obstacles) through the same radio signals. Key features include efficient spectrum usage, reduced hardware complexity, real-time environment awareness, and enhanced performance for applications like smart transportation, surveillance, and industrial automation. A lightweight key synchronization update algorithm, which is then used as a building block in our proposed lightweight secure communication protocol. The security of the protocol is analysed to show that it can resist common attacks, such as replay attacks, and man-in-the-middle attacks [6].

2.1. IoT in Industries

In addition to that Industrial IoT (IIoT) also plays a vital role in Spread Spectrum Multiple Access (SSMA) that IIoT is the industrial application of IoT. IIoT is a network of interconnected smart industrial objects embedded with electronics, sensors, actuators, and these interconnected things can communicate with each other.

2.2. IoT in Mining

MIoT is an important branch of IIoT, mainly referring to a network that comprises a group of interconnected sensors and actuators at mine sites. Sensors are used for data collection, and actuators are responsible for system adjustment and warning of abnormal conditions when they obtained value exceeds the prelimited value. In other words, MIoT can help real-time monitoring of mines, predicting potential accidents, optimizing the mining process, and managing personnel and equipment. In contrast to underground IoT in other industries such oil and agriculture where sensors are buried and communicate through the soil, IoT systems designed for underground mines enable IoT devices to be placed in open underground spaces and communicate through the air. Although MIoT devices are located deep underground, communication methods in surface and underground mines are similar, mainly achieved through cable based or radio frequency (RF) communication technologies [2].

2.3. IoT in Wearables Devices

This is a common prevention technique to all the places where the workers are in need of safety concern. The risks associated with underground mining include suffocation, gas injury, roof collapse, and gas burst. The IoT and communication technologies have made it feasible to create Personal Protective Equipment (PPE) models and equipment with cutting edge capabilities, such as environmental sensing, monitoring, and risk identification. In the proposed idea, a framework is designed using STM32 technology that consists of one transmitter module embedded into the helmet and a receiver module kept outside the mining area called the control module. The helmet transmitter comprises five sensors, namely, temperature, humidity, gas pressure, MEMS accelerometer, and heart rate sensor, to monitor the circumstances in the coal mine and miners' health conditions. There is also a built-in camera module to communicate the gesture conditions of mining workers to the control unit [3].

2.4. IoT in Fire Sensing

Fire detection systems are widely used in these environments, and they have resource constrained environments so a lightweight machine learning model is designed that will execute on low-power edge devices. Real-time data stream pre-processing algorithms deployed that minimize the computational complexity and energy consumption by processing data locally and only transmitting the essential information to the cloud. Also for there are remote industrial sites that don't have a connection to the cloud so edge computing solves these challenges. Federated Processing involves the pre-processing of sensor data and training of machine learning models occurs across multiple edge devices/servers in each site without transferring raw data to a central location or cloud. After making final predictions, model updates from each local device are sent to a central server, which aggregates these updates to improve a global model in the cloud. Implementing firefighting predictive systems at oil and gas industries will come with some challenges such as inaccurate information because of sensor faults due to the surrounding conditions. The automation of multi-sensor data fusion for different types of sensors faces major difficulties with synchronization and quality issues. More processing power is required in the edge layer to execute the models in real-time which is a major setback of edge computing. Transmission of data is difficult and so is system maintenance due to low connectivity in inaccessible or remote areas of oil and gas industries. Furthermore, real-world scenarios can outperform machine learning models that lack proper data that is free of noise so those forms of information limit the models' accuracy [4].

2.5. IoT in Healthcare Monitoring

The recent development of Information and Communications Technologies (ICT), designed for the Internet of Things (IoT) framework, has led to an increased interest in the study of new smart, portable, and interconnected devices in different applications. Electrochemical analyses and, in particular, bio sensing applications are not an exception. Traditionally, the identification of clinically relevant biomarkers for disease diagnosis and follow-up is carried out with bench-top instrumentation [8].

The one methodology outlined utilizes advanced AI-driven optimization techniques beyond theoretical analysis, directly enhancing low-energy IoT protocols in healthcare settings. For instance, RL dynamically optimizes signal strength under varying conditions, while ML models predict and refine energy consumption. These approaches highlight our contribution to improving protocol performance rather than surveying existing solutions. Energy consumption is critical for IoT devices in healthcare, where efficient protocols ensure prolonged battery life and operational continuity. To optimize energy use, we employed ML models, including gradient boosting and LSTM networks, to predict power consumption based on historical and real-time data.

The energy optimization equation is

$$P_{opt} = \min \left(I\,(t) \cdot V(t) \cdot f\,(Ut)\right)$$

T belongs to T

where:

- Popt is the optimized power consumption.
- I (t) and V(t) represent the current and voltage at time t.
- f (Ut) is the predicted usage factor derived from our machine learning models.
- T is the monitoring period [14].

2.6. IoT in Road Safety

It enables an end-to-end non-intrusive IoT-based automated framework to monitor driver behaviours, designed specifically for logistic and public transport applications. It consists of an embedded system, edge computing and cloud computing modules, and a mobile phone application, in an attempt to provide a holistic unified solution for drowsiness detection, monitoring, as well as evaluation of drivers. Drowsiness detection is based on detecting sleeping, yawning, and distraction behaviours using an image processing-based technique.

To minimize the effects of latency, throughput, and packet losses, edge computing is performed using commercial off-the-shelf embedded boards. Moreover, a cloud-hosted real-time database for remote monitoring on interactive Android mobile application has been set up, where admin can add multiple drivers to get drowsiness notifications along with other useful related information for driver evaluation [14].

Vehicle-to-vehicle (V2V) communication enables autonomous vehicles to exchange critical data, such as real-time information on precise location, speed, intended path, and security data. This creates situational awareness among autonomous vehicles allowing them to adapt to dynamic traffic conditions. V2V communication enables multiple autonomous vehicle applications such as lane changes, braking man-oeuvres, and speed adaptation based on road conditions. With coordinated communication, road congestion and bottlenecks at intersections can be avoided.

Furthermore, V2V also facilitates driving methods such as platooning, which reduces aerodynamic drag and improves fuel efficiency [9].

2.7. IoT in Agriculture

Agricultural IoT technology is a new type of agriculture that combines the IoT with agricultural production, and is a new trend in global agricultural development. For example, The purpose of an intelligent orchard is to keep track of environmental temperature and humidity, light intensity, soil humidity, and other factors that affect fruit tree growth, and to realize the monitoring, collection, transmission, and regulation of data.

So, LoRa is a low power long-distance communication technology that belongs to the Low Power Wide Area Network (LPWAN). LoRa is widely used in medical treatment, environment, military affairs, precision agriculture, etc., and its application fields are constantly expanded by research and technological progress [11].

3. Types of Protocols Used in IoT

IoT communication protocols are essential for enabling data exchange between devices, and choosing the right protocol depends on key factors such as range, data rate, latency, energy efficiency, and cost.

3.1. Message Queuing Telemetry Transport (MQTT)

MQTT is a lightweight, open-source protocol using publish or subscribe model, ideal for low bandwidth, high latency environments such as sensor networks and smart homes[10].

3.2. Constrained Application Protocol (CoAP)

CoAP follows a RESTful model and is designed for efficient, reliable data transfer in resource constrained environments, making it suitable for cloud connected IoT systems.

3.3. Bluetooth or Bluetooth Low Energy (BLE)

BLE offers short range and energy efficient communication, widely used in wearables, smart home, and healthcare devices. For long-range applications [13].

3.4. LoRa / LoRaWAN

LoRaWAN provide low-power, wide-area communication and is suited to smart city infrastructure, agriculture, and industrial monitoring. E. Zigbee

It supports low-power mesh networking, ideal for home and industrial automation, while Z-Wave is another mesh protocol commonly found in smart home systems.

3.5. Wi-Fi (IEEE 802.11)

It offers high data rates and extended range, making it appropriate for high-bandwidth applications like internet-connected devices. Additional protocols include NB-IoT, designed for low-power, wide-area connections.

3.6. 6LoWPAN

This protocol supports IPv6 communication over low-power networks; DDS, a real-time publish-subscribe protocol used in robotics and automation; XMPP, an open-source protocol for device-server communication

3.7. Hypertext Transfer Protocol (HTTP)

This protocol is a standard web protocol also used for accessing web services in IoT.

3.8. Lightweight Machine to Machine (LwM2M)

It is majorly used for efficient machine-to-machine communication in constrained environments. Selecting the appropriate protocol involves balancing the specific needs of the application, ensuring efficient performance, reliability, and scalability in diverse IoT scenarios. The Table 1. describes the comparative analysis of different parameter with different protocols in order to improve the performance of system.

Table 1 Comparative Analysis of Protocols

Protocol	Scalability	Data Rate	Power Efficiency	Best For
MQTT	High	Medium	High	General Purpose Scalable IoT
DDS	High	High	Medium	Real Time Industrial, Robotics
LoRaWAN	Very High	Low	Very High	Rural, Long-Range Areas
NB-IoT	Very High	Medium	High	Wide Area

4. Sensor and Devices

4.1. Gas Sensors

MQ811: Co_2 Sensor, MQ135: NH_3 Sensor, MQ4: CH_4 sensor. MQ7: Carbon Monoxide sensor. MQ136: H_2S Sensor.

Those sensors are used for detecting the presence of hazardous gases in sewage. The sensor produces a wide range of values which are emitted from sewage to the controlling kit. The calibration of these sensors is done by defining resistor networks to make them usable for industrial and domestic utilization [15]. The smoke detectors are designed to detect fire when it is still soldering or in the early stages of flame. They function on either ionization or photoelectric principle with both having advantages in certain applications [5].

4.2. Ultrasonic Sensor

The Arduino Ultrasonic Sensor is used to sense the presence of any object and predict the distance of the object in appropriate units which is inches in this case. Therefore, we can define the Arduino Ultrasonic Sensor as a device that uses the ultrasonic sensing technique to estimate the distance of an object. Arduino is used for creating this sensor since it needs to be programmed to detect the reflected rays from objects and display the distance in the desired format.

4.3. Arduino UNO

Arduino UNO is a low-cost, flexible, and easy-to-use programmable open-source micro controller board that can be integrated into a variety of electronic projects. This board can be interfaced with other Arduino boards, Arduino shields, Raspberry Pi boards and can control relays, LEDs, servos, and motors as an output. Arduino UNO features Adding Wireless Connectivity (AVR) microcontroller Atmega328, 6 analogue input pins, and 14 digital I/O pins out of which 6 are used as PWM output.

4.4. NodeMCU

NodeMCU is an open-source firmware for which open-source prototyping board designs are available. The name "NodeMCU" combines "node" and “Micro Controller Unit” (MCU). Strictly speaking, the term "NodeMCU" refers to the firmware rather than the associated development kits.

4.5. Gsm Module

Global System for Mobile communication modules is essential for connecting IoT devices to cellular networks, enabling data transmission and communication. They facilitate the integration of sensors, microcontrollers, and other IoT components with the internet, allowing for remote monitoring, control, and data exchange. GSM modules are widely used in various IoT applications due to its simplicity, cost-effectiveness, and wide network coverage.

4.6. Water Level Sensor

One of the functions of level sensors is to determine the maximum allowable water flow level of certain substances. These substances may be in the form of liquids, slurries, granules, or powders. The level of a body of water such as a river, lake, or container can also be measured using these sensors. Water level indication circuits are widely used in liquid storage systems across various sectors, including chemical plants, electrical substations, and industrial facilities. Among the many potential applications of this simple system are rainfall detection, leak identification, and sump pit monitoring.

4.7. Buzzer

A mechanical, electro-mechanical, as well as piezoelectric buzzer or beeper is an auditory signalling device. Alarms, timers, trains, and user input confirmation are common uses for buzzers and beepers.

5. System Architecture

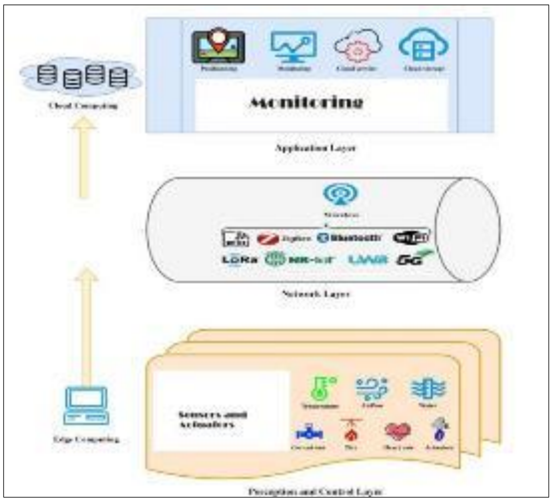

Figure 1 System Architecture

5.1. Block Diagram

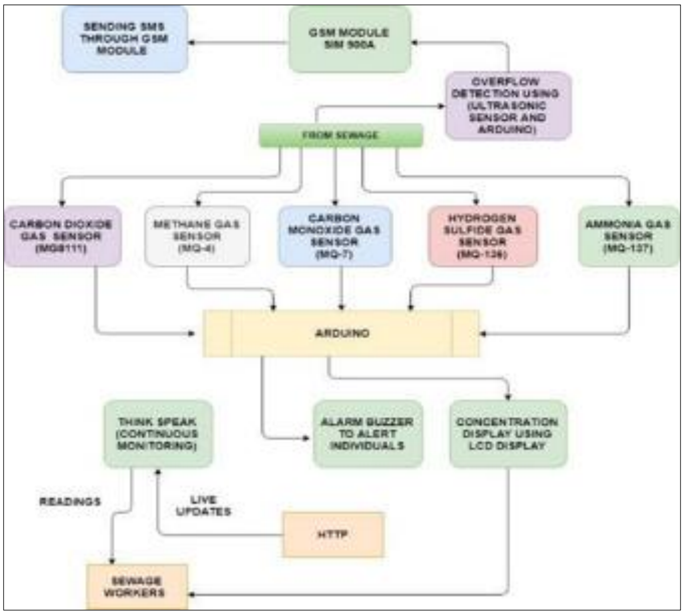

Figure 2 Structural Representation of System

The Figure 2 describes how layers are controls the flow of communication via the network and Figure 1 shows how the sensors and devices are transmits signals to concern modules to ensures the safety and monitoring of the system.

5.2. Perception and Control Layer

Actual function of it is the foundational layer where sensors and actuators collect real-time environmental data. Components include sensors for gas and dust, temperature, airflow, water level, fire, and heart rate. Main role of this layer captures raw data and responds to physical changes, initiating safety alerts in hazardous sewage environments.

5.3. Network Layer

This Layer will take Responsibility for transmitting data from the perception layer to the upper layers. More over Wireless Technologies Uses some communication protocols such as RFID, ZigBee, Bluetooth, Wi-Fi, LoRa, NB-IoT, UWB, and 5G.ete., Main Role Ensures fast and reliable wireless communication across all system components, especially in remote or hard-to-reach sewage areas.

5.4. Application Layer

An application Layer Processes and interprets data for decision-making and alerting. It provides the features such as Offers monitoring dashboards, position tracking, cloud services, and storage.In addition to this delivers intelligent insights and notifications to operators or emergency responders via cloud-based interfaces, enhancing real-time safety management. Edge computing performs local, low-latency data processing close to the sensors, while cloud computing handles large-scale analytics, long-term storage, and centralized monitoring.

6. Challenges in Implementation

While IoT has great potential for improving real-time monitoring and safety in hazardous environments like Tunnels, several challenges must be addressed for effective implementation—many of which are also relevant to sewage safety systems. In this Real time implementation, slow adoption of IoT, driven by high costs, long operation life spans, and reluctance to disrupt processes, mirrors similar challenges in sewage infrastructure. Customization and lack of standardized solutions increase complexity. Data sharing is limited due to confidentiality concerns, making it difficult to access comprehensive datasets for predictive modelling.

6.1. Hardware Considerations for Sewage Systems

Sensors in harsh environments such as high humidity, corrosive gases in sewage systems must be intrinsically safe and resilient. Power supply is a major concern battery replacement is difficult and dangerous in confined spaces. Energy harvesting, particularly from vibrations or airflow, offers a promising solution for powering wireless sensor nodes autonomously. Piezoelectric energy harvesters have proven capable of generating enough power to transmit data periodically using low-power protocols like ZigBee or BLE. Hardware considerations for sewage systems include robust sensors for flow, pressure, and contamination detection, durable enclosures to withstand harsh environmental conditions, and reliable power sources such as solar or backup batteries. Additionally, communication modules (e.g., LoRa, NB-IoT) and edge computing units are essential for real-time data processing and remote monitoring.

6.2. Communication Challenges Adapted for Sewage Systems

Underground communication is difficult due to signal attenuation and interference. Technologies like LoRa, 5G, and millimetre wave can provide reliable long-range connectivity in sewage tunnels. Visible Light Communication (VLC) may also be an alternative where radio signals fail, such as during high moisture conditions. For robust operation, the network must be scalable and self-healing to account for node failure or environmental changes.

6.3. Data Management for Sewage Monitoring

Integrating large volumes of time-series data from various sensors can be challenging due to data silos and incompatible formats. A unified data structure and real-time analytics framework (edge, fog, or cloud-based) are necessary to ensure reliable alerts and predictive maintenance. Standardized workflows for data cleaning, exchange, and processing will enable faster response to hazards such as gas build dup or structural failure

7. Result and Discussions

The previous work provided a variety of gas sensors, such as the smoke detector and the gas detector, to detect the presence of harmful compounds in trash, in addition to moisture and temperature detectors. For the purpose of controlling the current configuration from separate node locations, one receiver end is provided. The gadget supplies of data, beginning with the sewage and ending with the control unit. Quantifying these sensors lends credence to the idea of sensor connections, which opens the door for their implementation in both business and residential settings. Based on a predetermined condition, the throughput is sent to the cloud using the Node MCU WiFi interfaced IoT module. Things Speak IoT is the foundation of this project.

In order to detect hazardous gases in sewage environments. The system enables remote monitoring of in-sewer gas levels, humidity, and temperature through a cloud-based platform, allowing for real-time detection of obstructions and gas buildup. Traditional manual sampling methods are being replaced with this automated solution, which enhances safety for workers exposed to toxic gases like sulfur dioxide, ammonium chloride, nitrogen oxides, and carbon monoxide. The study targets locations such as drainage systems, public housing, and industrial areas. The new IoT-based Sewage Gas Detection (IoTSGD) system shows improved accuracy over the Conventional Sewage Gas Detection (CSGD) method.

This paper concludes LoRaWAN is highly suitable for a sewage tunnel monitoring and alerting system because it provides long-range, low-power wireless communication that can operate effectively in underground or obstructed environments where traditional signals struggle. Its ability to transmit data over several kilometres, even in Non-Line of Sight (NLoS) conditions, makes it ideal for reaching sensors placed deep within tunnels [12].

Additionally, LoRaWAN supports battery-powered sensors that can last for years without maintenance, which is essential in hard to access sewage systems. Its reliable, low bandwidth communication is perfect for transmitting periodic environmental data such as levels, water levels, flow rates and sending real-time alerts in case of anomalies or hazards

8. Conclusion

To developing a comprehensive IoT-based sewage monitoring system involves overcoming issues of hardware resilience, power supply, wireless communication, data integration, and interoperability—challenges also faced in underground mining but with direct relevance to improving Alert and safety in sewage environments. The purpose of sewage treatment is to prevent the potentially harmful release of volatile substances into the surrounding atmosphere. This process frequently produces dangerous gases as a result of natural decomposition. Recent news reports indicate that a significant number of sewage workers have tragically lost their lives on the job due to exposure to highly toxic gases. Inhalation of these gases can cause serious health complications. The proposed system, which includes additional sensors for detecting other harmful gases such as sulfur dioxide, could have a profound impact on the lives of sewage workers thanks to its advanced IoT-based technology. This layout has the potential to benefit society in a significant way.

Future enhancement will be succeeded by using LoRaWAN Protocol to achieve a greater number of devices connected through wireless network but it has some hurdles such as slow data transfer rate, limited payload, and potential for spectrum interference

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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