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Original Research Article

Development of LoRaWAN-Based IoT Monitoring Device for Pressure Rate Profiling in Water Pipelines

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Abstract

Water Pipeline systems are critical infrastructure for the delivery of safe and reliable water to communities. However, these systems are vulnerable to leaks, bursts, and other failures that can lead to water loss, property damage, and disruptions in service. One key factor in the health and longevity of water pipeline systems is the maintenance of proper pressure levels. Monitoring pressure in water pipelines is essential for ensuring that the system is functioning properly, and for identifying potential issues before they become major problems. The development of IoT technology has opened new possibilities for monitoring water pipeline pressure. IoT devices can be designed to collect and transmit pressure data wirelessly, eliminating the need for manual data collection and allowing for real-time monitoring and early warning systems. This study aims to develop an IoT monitoring device for pressure rate profiling in water pipeline systems. The device utilized pressure sensor and GSM module to collect and transmit pressure data in real-time to a cloud-based data management system. Through laboratory experimentation, the developed monitoring system in this study was able to both detect and localize leakages with the possibility of monitoring the leakage over a mobile application. The device also exhibits an average pressure variation of 7.7 KPA which indicates a high consistency.

Keywords: Water Pipeline systems, water loss, property damage, IoT technology.

INTRODUCTION

Water is essential to sustaining human life. However, a significant amount of this resources is being wasted in distribution networks before reaching homes and industrial properties. Most water pipes are buried under the ground, and they tend to deteriorate due to factors like material type, climate, human activities, age, pressure zone and other intrinsic factors (Latif *et al.*, 2022). Monitoring the pressure in water pipeline network is crucial to ensure the consistent flow of water and to prevent any damage to the pipeline The effect of a pipeline leak increase with the leak's size, hence the need for early detection of leaks. Therefore, a leak system should be in place to monitor the pipeline operations and take preventive measures to decrease the causal effects of the leak (Korlapati *et al.*, 2022). There are several leak detection methods in use to detect and locate leaks. Some of these methods include flow rate monitoring, pressure point analysis, negative pressure wave, distributed fiber sensing, acoustic sensing, real-time transient modeling, model simulation, Lidar systems and infrared cameras (Bai *et al.*, 2004). These methods have their limitations which includes unauthorized access, manipulation of data, time consumption and vulnerability to damage. Most leak detection system rely on the use of the Internet of Things (IoT) (Agbolade *et al.*, 2023). IoT has the potential to revolutionize the way water pipelines are monitored. By integrating sensors and communication modules, IoT devices can provide real-time monitoring and data analysis, enabling early detection of potential problems and improved response time (Pérez-Padillo *et al.*, 2020). IoT can also be used to mitigate some of the challenges of previous leakage monitoring systems if well applied. This study proposes a compact, low-cost, and easy to use monitoring device for pressure rate profiling in water pipelines. The device measures pressure rate using pressure sensors and transmits data to a cloud-based platform for analysis enabling real-time monitoring, early detection of potential problems, and improved response times. The study focuses on development of the IoT monitoring system for leakage detection in pipeline to ensure minimal loss and wastage of water resources.

LITERTAURE REVIEW

Water pipeline systems are crucial components of modern infrastructure, providing essential resources for various sectors. However, their hidden nature and susceptibility to deterioration pose challenges for effective monitoring and maintenance (Oladele *et al.*, 2023). This section reviews the existing literature on water pipeline monitoring, pressure profiling, and the integration of IoT technology. One of the most important metrics for leakage detection is pipeline pressure (Agbolade et. al. 2023). Pressure from Equation (1) is defined as the force exerted per unit area and is typically measured in units such as Pascals (Pa), pounds per square inch (psi), or bars. In the context of water pipelines, pressure is an important parameter that can indicate the health and performance of the system.

$$Pressure = Force / Area \quad (1)$$

Force in Equation (1) is the amount of force exerted on a surface, and Area is the size of the surface that the force is acting upon. In the case of water pipelines, pressure can be calculated based on the flow rate and diameter of the pipe using the Bernoulli's equation in Equation (2)

$$P = \frac{\rho v^2}{2} + H + E + F \qquad (2)$$

Where P is the pressure, ρ is the density of the fluid, v is the velocity of the fluid, H is the pressure head which is the pressure at the surface of the water, E is the elevation head which represents the vertical distance between the surface and the point where pressure is being measured and F the friction head which is the energy loss due to friction between the water and the pipe walls. Pipeline monitoring systems in recent times lean heavily on IoT and has benefited immensely from rapid advancement in different IoT technology. The Internet of Things (IoT) in this context refers to a network of interconnected devices, sensors, and software applications that can communicate with each other over the internet (Dahunsi *et al.*, 2021). IoT technologies have equally been widely used in various fields, including healthcare, manufacturing, transportation, and environmental monitoring (Abdelhafidh *et al.*, 2018). IoT has become a promising technology in pipeline monitoring, particularly in the water industry. In a study by Atitallah *et al.*, (2021), IoT-based pipeline monitoring using wireless sensor networks (WSNs) was proposed. The study utilized IoT-based sensors to collect data on water quality and pressure. This study highlights the potential of using IoT technology in monitoring water pipelines.

Water Pipeline Monitoriing

Water pipeline monitoring involves the continuous measurement and analysis of pipeline performance to ensure that it is operating at an optimal level. Several methods have been developed for pipeline monitoring, including the use of pressure sensors, flow meters, and acoustic sensors (Karray et al., 2016). Pressure sensors have been found to be particularly effective in monitoring pipeline performance, as they can provide accurate and reliable data on the pressure within the pipeline. Pressure sensors are devices that can detect changes in pressure and convert them into an electrical signal. They can be used to monitor the pressure within a water pipeline and provide data on the flow rate, blockages, and leaks within the system. Different types of pressure sensors have been developed, including strain gauges, capacitive sensors, and piezoelectric sensors (Chen & Yan, 2020). Piezoelectric sensors have also been found to be effective in pipeline monitoring, as they can detect small changes in pressure and provide accurate data on pipeline performance (Owojaiye & Sun, 2013). Aside measuring pressure and other physical parameters that can characterize leakage in a pipeline, leak detection systems just like all IoT applications also require a communication link between the sensors and a backend server. Popular communication protocol include WiFi, Bluetooth, Zigbee, LoRa (Agbolade et al., 2023; Agbolade et al., 2022), and cellular networks (Agbolade & Sunmola, 2021) among several others. A study by Lee et al. (2017) uses the ZigBee technology for IoT-based bridge safety monitoring system. It monitors the conditions of a bridge and its environment, including the waters levels nearby, pipelines, air, and other safety conditions in real time. Wireless sensor networks (WSNs) are networks of interconnected sensors that can communicate with each other wirelessly. WSNs have been widely used in pipeline monitoring, as they can provide real-time data on pipeline performance and facilitate remote monitoring of pipeline systems. A study by (Muthukumar et al., 2023), an IoT-based system was proposed for pipeline monitoring using WSNs. The study employed a distributed WSN-based system to collect data on the conductivity, pressure, and flow rate of water in pipelines. The data was transmitted wirelessly to a cloud-based server for further analysis.

Challenges in Iot Pipeline Monitoring

Despite the progress made in the application of IoT technology in pipeline monitoring, there are still gaps that need to be addressed. One of the main challenges is the issue of data security and privacy. With the high volume of data being collected and transmitted, there is a risk of unauthorized access and manipulation of data. The development of secure communication protocols and data encryption techniques is crucial in addressing this challenge. Another gap is the lack of standardization in IoT-based pipeline monitoring. With different technologies being used, it is difficult to compare the results obtained from different studies. Standardization of IoT-based pipeline monitoring will enable the results obtained to be more easily compared and evaluated. Water pipeline monitoring is critical for ensuring the safety, efficiency, and sustainability of water supply systems. According to previous research, pressure is one of the key parameters that can be used to monitor the condition of water pipelines (Abdulshaheed et al., 2017). Several studies have shown that pressure changes can indicate the presence of leaks or other issues in the pipeline system. However, traditional pressure monitoring methods are often inefficient and require manual measurements, making them impractical for large-scale pipeline systems. This has led to the development of IoT-based monitoring systems that can provide real-time pressure data and detect anomalies in the pipeline system (Joseph et al., 2022). These systems typically use sensors, communication modules, and cloud-based platforms for data analysis and visualization.

While IoT-based monitoring systems have shown promising results in previous studies, there is still a need for further research to optimize the design and implementation of these systems for water pipeline monitoring (Muthukumar *et al.*, 2023). Water pipelines are critical infrastructure that delivers clean water to communities. However, these pipelines are vulnerable to various forms of damage, including leaks, corrosion, and water hammer, which can cause significant economic, environmental, and health impacts (Haimes *et al.*, 1998). Traditional monitoring methods, such as visual inspections and manual measurements, are costly, time-consuming, and can be ineffective in detecting potential failures. Therefore, there is a growing interest in leveraging the Internet of Things (IoT) technology to develop more efficient and reliable pipeline monitoring solutions. In a similar vein, (Pérez-Pérez *et al.*, 2021) proposed using artificial neural network techniques (Sunmola & Agbolade, 2021) to detect and locate water leaks in pipelines and online measurements of pressure and flow rate. But there was uncertainty and some of the parameters vary with time. IoT-based pipeline monitoring systems typically consist of various sensors, communication modules, and cloud-based data analysis platforms for example, pressure sensors can be used to monitor pressure changes in the pipeline, while flow meters can track water flow rates. Additionally, acoustic sensors can detect leaks and cracks in the pipeline walls, while temperature and humidity sensors can monitor environmental conditions that can affect pipeline integrity. Communication modules, such as cellular or satellite networks, can transmit the data collected by these sensors to cloud-based platforms for real-time analysis and visualization.

Overall, the literature suggests that the development of IoT-based monitoring systems for water pipeline networks has the potential to significantly improve the efficiency and reliability of water pipeline management. The integration of multiple sensors, communication modules, and cloud-based data analysis tools provides a comprehensive monitoring system that can detect and diagnose pipeline faults in real-time, enabling water utilities and governments to effectively manage their water resources. However, there is still a need for further research to optimize the design and performance of these systems, and to develop user-friendly interfaces and training materials for their effective use. By leveraging various sensors, communication modules, and cloud-based data analysis platforms, these systems can detect potential pipeline failures in advance, reducing the risk of water supply disruptions and improving overall system efficiency.

METHODOLOGY

Understanding how fluid forces operate is necessary for designing the pipes in a real water network system. In order to construct a water network, the amount of the resultant force and its center of pressure must be evaluated. To depict water usage as a function of time, a model was built using regular functions.

System Architecture

The system's overall architecture includes numerous monitoring hubs at different locations on a pipeline. The monitoring hubs assess the pressure rate and sends data to the receiver hub. The receiver hub then compares the data to check for leaks before sending the data to the cloud (firebase) for storage. Each monitoring point is a self-contained system that can work independently off the other monitoring hubs. To enhance efficiency, the receiver hub and monitoring hubs are powered separately. The flow chart for the project is provided Fig. 1.

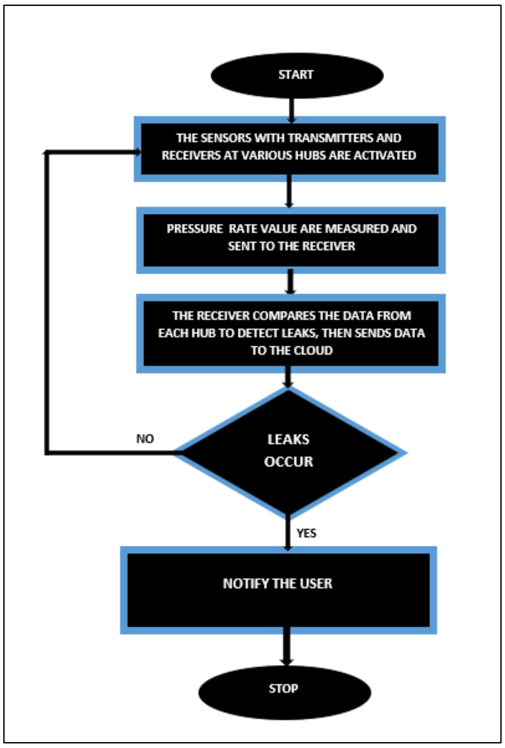

Figure 1: Project Flowchart

Hardware Components

The entire monitoring system is powered with an ESP32 Microcontroller. The ESP32 microcontroller plays a central role in data processing and communication within the monitoring hubs and the receiver hub. Communication between the transmitter and receiver was done through LoRaWAN while the receiver uses cellular network to transmit data to the cloud for storage and further analysis. The Pressure Sensors integrated into the monitoring hubs, allow precise measurement of pressure rates along the pipeline with the entire system powered by 12V power supply. A Buck Converter included in the power section helps to step down voltage from the 12V batteries to provide the 5V necessary to power the ESP32 microcontrollers. The receiver system also employs the ESP32 microcontroller. It communicates with the monitoring hubs via the SX1276 LoRa module that operates the LoRaWAN protocol. The ESP32 collects data from each hub, compares data, sends leakage notifications to the mobile application, and then uploads data to an online server (FIREBASE) via the GSM MODULE (sim800). The receiver connection is as shown in Fig. 2.

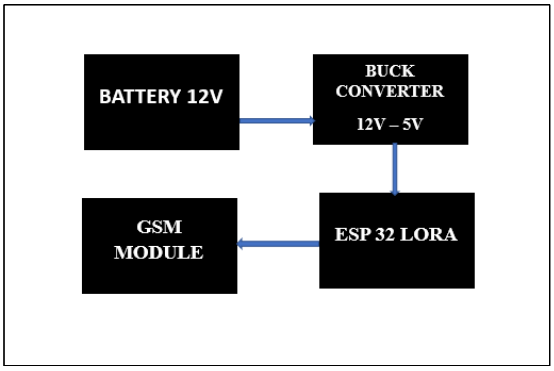

Figure 2: Block diagram of the Receiver System

To ensure easy integration, the TTGO LoRa module was employed. The TTGO LoRa module is a low-power, wireless communication module that combines the power of the ESP32 microcontroller with the long-range and low-power capabilities of LoRa technology. It is an excellent solution for applications that require long-range communication, such as remote monitoring, asset tracking, and industrial automation. The module features a powerful 240 MHz dual-core processor, integrated Wi-Fi and Bluetooth, and supports a range of communication protocols such as LoRaWAN, BLE, and MQTT making it a versatile platform for developing IoT applications. The TTGO LoRa module provides long-range communication capability, which allows it to transmit data over distances of several kilometers with low power consumption. This makes it ideal for applications that require low power consumption, such as remote sensors that are powered by batteries and need to last for months or even years. The GSM module was connected to the ESP using serial UART on the ESP 32 as shown in Fig. 3. A sim card is inserted in the GSM module for cellular connectivity. The internet shield was configured using AT command and data sent over a cellular network in real time. The receiver is capable of sending notifications to a mobile application in real time when leakages are detected. To program the microcontroller to be able to interact with modules, sensors, displays, and the FIREBASE server, the Arduino Integrated Development Environment (IDE) is being used. Finally, both the hardware and software were integrated to create IoT monitoring. The monitoring hubs are strategically situated along the pipeline as shown in Fig. 4.

RESULTS AND DISCUSSION

The system underwent final rounds of testing to guarantee proper and efficient performance. The system functioned as expected, and all joints and connections were securely fastened. The sensors, modules, and display all function flawlessly and upload correctly and on time. The receiver hub receives data from each monitoring hub as HUB A, HUB B, HUB C, and HUB D. It compares the pressure value for all the hubs. If the pressure for HUB A > HUB B, the system sends a leakage between point A and point B notification to the mobile phone application. If the pressure for HUB B > HUB C, the system sends a leakage between point B and point C notification to the mobile phone application. If the pressure for HUB C > HUB D, the system sends a leakage between point C and point D notification to the mobile phone application.

Figure 3: Device in development

Figure 4: Device installation along pipeline

The system also accurately logs the data collected by the receiver hub to an online server for backup, which can be reviewed later and used for research purposes. The system performs optimally, and it is efficient in its power consumption. The pressure rate data collected from the four nodes readings is presented in the Tab. 1 to 6.

Table 1: Pressure rate data from the four-node network under normal flow

NODE 1	NODE 2	NODE 3	NODE 4
100.1	57.01	40.41	35.25
105.4	56.64	33.94	37.11
98.27	56.03	45.53	33.08
100.02	59.81	41.63	34.79
103.5	54.57	39.92	31.25
101.5	57.5	39.95	37.84
102.7	56.52	37.35	36.5
104.2	57.25	37.11	31.01
102.7	60.18	41.75	35.77
103.7	54.44	32.1	34.55

Table 2: Pressure rate data from the four-node network under normal flow

NODE 1	NODE 2	NODE 3	NODE 4
135.63	80.08	63.35	47
128	80.81	62.61	49.44
129.8	79.71	60.55	52.61
126.1	81.67	61.4	51.39
123.2	82.4	62.26	49.8
129	82.4	61.16	51.39
121.8	78.25	60.91	52.86
130.8	85.94	61.4	53.83
127.5	81.42	60.67	52.61
126.7	87.65	63.6	48.83

Table 3: Pressure rate data from the four-node network under normal flow

NODE 1	NODE 2	NODE 3	NODE 4
128.9	77.88	62.26	52.37
128.84	88.99	63.23	49.07
126.9	83.98	64.45	52
126.7	80.93	63.98	48.34
128.6	76.96	58.47	52.37
126.7	77.76	61.89	53.47
127.44	80.32	60.55	49.19
127.8	83.74	57.5	50.78
128.9	81.79	60.3	52.73
129.8	77.76	61.28	52.73

Table 4: Pressure rate data from the four-node network with leak at valve one, valve two and three closed.

NODE 1	NODE 2	NODE 3	NODE 4
113	68.73	45.17	42.36
113	71.66	48.1	33.08
112.7	70.43	47.61	41.14
115.2	68.24	45.65	41.5
108.1	65.06	47.12	43.21
113.2	66.53	48.1	41.26
119.5	66.16	50.05	39.79
112.4	67.5	46.75	35.77
112.7	67.26	49.19	37.6
109.9	66.04	44.92	38.7

Table 5: Pressure rate data from the four-node network with leak at valve two, valve one and three closed.

NODE 1	NODE 2	NODE 3	NODE 4
112.9	64.82	47.61	44.07
118.9	66.77	44.92	45.65
114.64	64.7	48.6	44.92
112.4	66.53	45.76	44.92
108	67.02	48.95	41.14
113	72.75	47.61	42.48
112.1	66.53	49.19	41.75
111.33	64.7	49.32	42.48
112.4	66.16	45.41	41.75
114.5	67.38	46.88	43.7

Table 6: Pressure rate data from the four-node network with leak at valve three, valve one and two closed

NODE 1	NODE 2	NODE 3	NODE 4
84.84	41.99	35.39	31.25
75.32	43.95	35.35	29.3
86.5	42.75	35.4	33.2
85.94	47	39.18	29.05
82.89	39.92	36.99	29.42
85.33	42.48	34.79	29.91
77.88	42.85	36.25	28.69
80.44	41.02	31.98	29.3
78.74	39.92	31.25	29.3
83.13	44.07	33.65	31.37

The results presented in Table 1 to 6 shows the device is capable of high consistency with data shown an average pressure variation of 7.7 kPa. The pressure rate data effectively demonstrates the ability to detect leaks in the pipeline system. In all leak scenarios, the data reflects significant deviations from normal pressure levels, indicating the presence of leaks. This highlights the importance of continuous pressure monitoring for leak detection and early intervention. The data further highlights the dynamic nature of the water pipeline system, with pressure readings fluctuating over time. This variability underscores the need for continuous monitoring to adapt to changing conditions and maintain efficient water distribution. Through the design and development of the hardware and software components of the monitoring device, as well as testing and validation of the device's accuracy and reliability in a laboratory setting and, in the field, we have achieved our objectives. The device proved to be capable of providing accurate and reliable pressure data in real-time and has the potential to significantly improve water pipeline management systems by enabling real-time monitoring and early warning systems, reducing maintenance costs, and enhancing the sustainability of water systems. Overall, this project has contributed to the growing body of research on the use of IoT technology in water infrastructure management and has demonstrated the potential for IoT devices to enhance the efficiency and sustainability of water systems. The results of this project can serve as a basis for further research and development in the field and can be used to inform decision-making by water utility companies and policymakers. Ultimately, the adoption of IoT devices for pressure monitoring in water pipelines can have a positive impact on both the environment and the economy by reducing waste and improving the efficiency of water systems.

CONCLUSION

In this work, a LoRaWAN leakage detection system was developed to monitor leakages on water pipeline. The developed leakage detection system relied on pressure variation along the pipeline network. The design includes a pressure sensor for measurement and a LoRaWAN based communication protocol to transmit pressure data from the transmitter to the receiver. The receive employs the use of a cellular protocol in addition to LoRaWAN to transmit the data to a server. The developed system exhibits a high level of consistency with an average of 7.7 kPa variation across all nodes.

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