IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 4, June 2024

An Analysis of the Detection of Water Leakage in Pipes Through the Use of Sensors

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Abstract: *This paper suggests a novel approach to leak detection and location that is based on sensors. Wireless Sensor Networks (WSN) have been primarily employed in military applications due to their reliability and efficacy. In numerous civilian applications, including leakage detection, it is now regarded as the first-hand method. Different kinds of applications necessitate consideration of a variety of technical issues, such as power consumption. WSN has recently become a viable solution for water leakage. Pipelines are utilized to transport water from water sources such as lakes and rivers to urban areas. Non-Revenue Water (NRW) is the quantity of water that has been produced and subsequently lost prior to reaching the consumer. It may be the result of defective meters, illicit connections, and leakage. The primary objective of this paper is to create a leak and water monitoring system that utilizes the concept of IoT. This system will include a flow sensor that can be used to detect leaks and solenoid valves that are placed in various pipeline sections to obstruct the flow of water until the defective part of the pipeline is repaired. It is important to note that water leakage is a global issue that has already escalated to a critical issue in numerous regions. In addition, the relevant authorities will be wirelessly informed of the breach once it has occurred.*

Keywords: Sensor Technology, Leakage Detection, Pipeline Monitoring, Data Analysis

I. INTRODUCTION

Water management is a critical aspect of society. International attention is generally given to leakage due to its significant impact on water scarcity. This not only results in revenue losses but also has an impact on the national reserves. In developing countries such as India, the domestic sector experiences a loss of water of approximately 30 to 40% of the total flow in the distribution system due to leakage. By employing a water monitoring system, we can prevent water wastage, reduce power consumption, and readily preserve water for the next generation.

The transportation of essential materials, including water, oil, and gas, is the responsibility of water pipeline breach detection systems. Major financial losses and potential environmental damage are the result of any conduit breach. Contaminants may be introduced into water systems through leaks in water pipelines, which can result in a decrease in water quality and a risk to the health of water users.

The majority of water pipelines are concealed beneath the ground, which complicates the identification of leakage. For this reason, water leakage is typically identified when water is expelled from the earth as a result of immense conduit breaches. Historically, leakage detection has been predicated on the assumption that all breaches are visible and ascend to the surface. The primary cause of leaks is the general aging and, as a result, breakable water distribution infrastructure. The identification of leakages is not readily apparent due to the fact that pipelines are not directly visible or accessible. Water agencies are compelled to extract additional water from lakes and streams in order to compensate for losses in the water supply system, which places additional strain on aquatic ecosystems. The water utility is required to implement corrective measures to reduce water loss in the water distribution system upon the detection of a breach. These losses are mitigated by the precise identification and repair of faulty water pipelines within a supply system. The reliability of the water supply network is compromised by leaks. This could result in households and businesses relocating, identifying alternative sources of potable water, or seeking other costly measures to safeguard themselves from the potential risks of unreliable water supplies.

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II. RELATED WORK

The soil type, density, profundity, and surface coverage also influence the detection of pipeline leaks. The detection accuracy is significantly influenced by the interference of frequency, which is caused by water pressure, conduit material, and diameter.

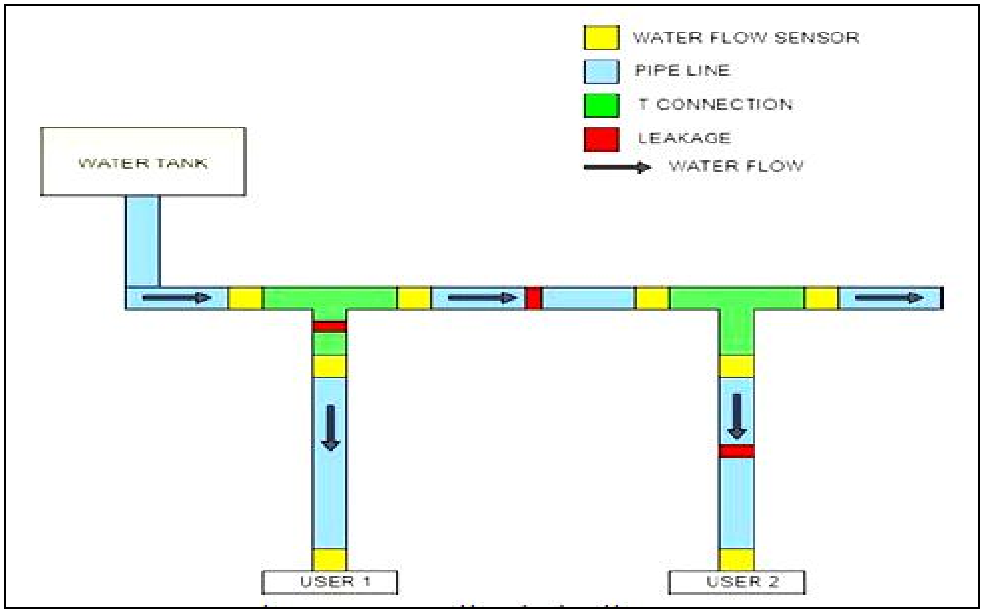

Fig. 1. Generalized pipeline structure

As illustrated in Figure 1, a pipeline structure is composed of numerous branches and nodes. This structure can be deconstructed into its elemental components, which include three nodes and two branches. A microcontroller is positioned at the intersection of two or more sub-pipes, where it receives data from the sensor located at each adjacent sub-pipe. The water flow rate is measured at the inlet and outlet of a conduit using a water flow rate sensor in the structure. These flow sensors are subsequently connected to a microcontroller unit. The sensor does not impede the passage of water; rather, it accumulates data regarding the flow rate. A solenoid valve is an electromechanical device that is employed to regulate the passage of liquid. The valve is operated by the solenoid coil in a manner that is akin to that of a human. The valve is opened to the necessary extent when a specific quantity of liquid is required, and it is completely closed when the flow is not required. The relay module will be used to interface with the solenoid valve and connect it to the microcontroller. The microcontroller devices establish wireless communication with one another. The flow rates measured by two controllers would be significantly different when a breach is present in a conduit. This has the potential to identify breaches.

Pressure management, active leak control, speed and quality restorations, and maintenance and regeneration of the pipeline are the four fundamental activities that contribute to the reduction of leakage. The maintenance team's periodic inspections, which are the basis for traditional detection methods, have numerous drawbacks, including:

Necessitates substantial human effort.

Does not offer real-time pipeline monitoring.

Induce a significantly greater economic loss.

Contribute to environmental pollution.

The underground wired network for communication is extremely expensive and is subject to damage. Conversely, wireless networks are considerably more efficient and resilient. It also offers simplicity and adaptability in system deployment; however, underground wireless communications have not yet been developed and implemented. Nevertheless, wired base communication can be employed to transmit information over a long distance in order to reach remote administration nodes.

When the system is in the "On" state, the discharge rate is consistently monitored by the microcontroller. The microcontroller detects a leakage whenever the flow rate difference between two consecutive sensors exceeds a calibrated threshold value, as illustrated in the figure. The Wi-Fi module also logs the flow rate difference into the cloud. An alert or notification is issued and a message is transmitted to the appropriate authorities whenever a leakage is identified.

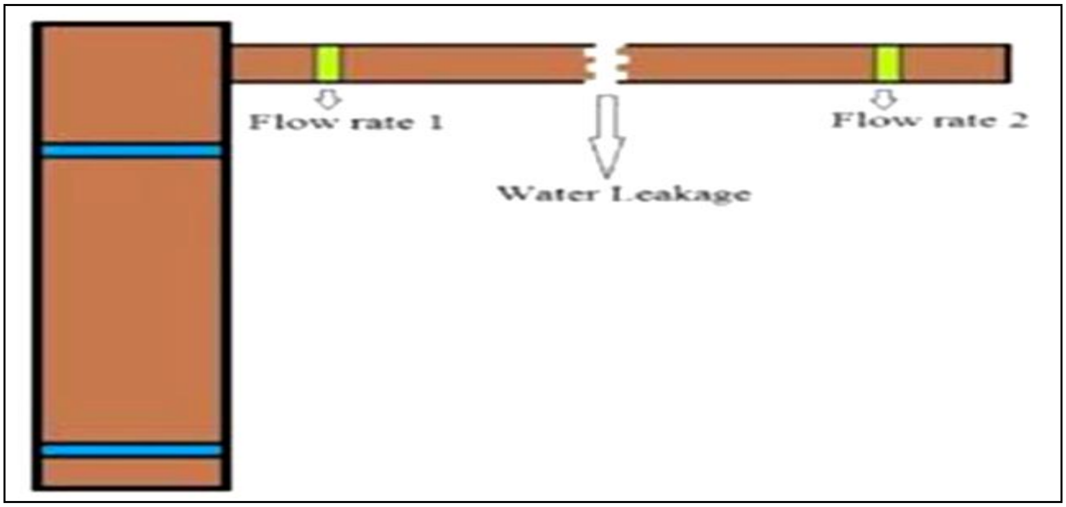

Fig. 2. Flow rate

III. LITERATURE SURVEY

Deepiga and Sivasankari [1] have developed water monitoring systems, including water contamination monitoring, water conduit leakage sensing monitoring, and tank water level sensing monitoring. The microcontroller-based water level monitoring system is employed to notify the agent of the water level in the tank. The pressure is determined by utilizing force-sensitive resistors (FSRs) that are produced by a breach in water conduits. An increase in the LED meter and a gushing sound of water in the conduit, which can be heard in the headpiece, will constitute the indication.

The wireless leakage detection system proposed by Adsul and Kumar [2] is a non-destructive technique (NDT) system that is portable and utilizes a variety of sensors and a microcontroller. Using sensors and an Arduino microcontroller, the system detects parameters such as humidity, temperature, pressure, sound detection, and gas detection in the vicinity of leakage areas.

Jayalakshmi and Gomathi [3] have suggested the development and implementation of a wireless sensor-based water leakage monitoring and detection system. The purpose of an improved system is to identify potential subterranean water leaks in residential water pipelines that are monitored by a personal computer.

Daadoo and Daraghmi [4] have concentrated on the implementation of wireless sensor networks for the purpose of detecting leaks in underground water pipelines in order to address the issue of water dispersion. The authors have developed a wireless network system that employs mobile wireless sensors to streamline the leakage identification process and address the issue.

Myles [5] has elucidated the theoretical foundation and practical application of a fiber optic-based technology that employs Brillouin acoustic scattering to identify minute temperature fluctuations within the cable. The method's background physics will be delineated in the paper, which will also present the results of a case study that was conducted to detect leaks in a saline conduit.

Sithole et al. [6] have introduced a low-cost, practicable Smart Water Meter device (SWMD) that is capable of identifying potential leaks. The quantity of water consumed by a consumer has been measured using flow meter sensors.

Medina et al. [7] have developed a method for the detection of leaks in water supply systems that is based on signal analysis. The paper illustrates the process of extracting features from pressure signals and their subsequent application to the detection of changes associated with the initiation of a breach. Example: Signals were acquired from an experimental laboratory circuit, and features were extracted from the temporal domain and transformed signals.

The control of water leakage in water distribution networks is a critical issue for all utilities involved in the provision of potable water, as demonstrated by Martini et al. [8]. The endeavor pertains to the identification of water breaches through the utilization of vibration monitoring techniques. The purpose of this paper is to create a system that automatically detects ruptured breaches in service pipelines in an early stage.

Choi et al. [9] have introduced a novel method for the detection and localization of leaks that is based on vibration sensors and generalized cross correlation techniques. The paper elucidates the theoretical variance of the time difference estimation error by means of summation in the discrete frequency domain. It also identifies the optimal regularization factor that reduces the theoretical variance in practical water pipe channels.

The service described by Kei [10] involves the installation of sensors at arbitrary intervals on water pipes to capture vibrations caused by water leaks. The data is then transmitted to a cloud computer via wireless networks or public switched telephone networks, and the leak location is identified with high precision based on the results of the data analysis.

Oliver and Scott [11] have introduced a sensor network design method that generates principles that are comprehensible to humans for the purpose of detecting leaks. Furthermore, it identifies the optimal locations for flow sensors within a specific network and operating scenario. Under real-world conditions of uncertain measurements, the method is shown to produce predictions that are acceptable in terms of predictive accuracy.

Nakhkash and Mohammad [12] have explored the potential of electromagnetic simulations to detect breaches in buried water pipelines using Ground Penetrating Radar (GPR). the ground configurations and the Finite Difference Time Domain (FDTD) model of a GPR system are described. The GPR data is reported in the publication, along with the response signatures and features that result from the soil-water mélange. These results validate the efficacy of GPR for water leak detection and aid in the identification of water leakage.

Siong and Chen [13] have created an automatic water pipeline leak detection device that perpetually monitors the pipelines to minimize the need for human resource involvement. The device not only decreases the time required to analyze the collected information but also the number of human resources required. The device enables leak detection personnel to remotely listen to the noises of any pipeline leaks by concentrating their attention on the suspicious area. The system design enables the leak detection staff to readily differentiate between the genuine leakage and the false alarm. The severity of the breach and its precise location will be ascertained by leak detection personnel in the event of a leak.

Araujo et al [14] have developed a model to assist decision-making systems in the quantification, location, and opening adjustment of control valves in a network system. The primary objective is to reduce pressures and, as a result, leakage levels. The objective of the research is to develop a solution that enables the simultaneous optimization of the number of valves and their location, as well as the adjustment of valve opening for prolonged simulations, in accordance with the system's characteristics. The hydraulic network analysis is conducted using the Environmental Protection Agency Network (EPANET) model, and two operational models are constructed using the genetic algorithm optimization method for pressure control and leakage reduction. This is necessary because a leak is a pressure-dependent function. A global evaluation of the system for various scenarios is required, as the method has ensured an adequate technique performance in these two modules.

Lin et al [15] have created a wireless sensor network that is primarily intended for military applications. Nevertheless, numerous civilian applications, including inventory management, product quality monitoring, and disaster zone monitoring, have emerged in recent years. For various applications, it is necessary to consider a variety of technical issues, including power consumption, radio propagation models, routing protocols, and sensors. The paper suggests a specific application for wireless sensor networks, which is a water distribution network monitoring system. It also suggests a potential communication model for the water distribution monitoring network and delineates a channel measurement approach for the purpose of determining an appropriate path-loss model. The flat earth two-ray model has been employed to verify the precision of the proposed measurement approach.

Haqshenas [16] has suggested a method for the acoustical monitoring of breaches in buried water distribution pipelines. The fundamental principle is that the acoustic commotion produced by water pouring from a breach in a pressurized conduit provides information regarding the existence of a leak and, ideally, its location. Acoustic methods for leak detection are primarily based on correlation analysis, which involves the installation of a sensing device on each side of a leak. the arrival time difference is a measure of the leak position, and the two received acoustic signals are correlated. It has the potential to offer metallic pipelines with an exceptionally high level of precision, theoretically. The primary disadvantage is the absence of generality. When applied to plastic pipelines, correlation techniques fail to produce a precise prediction almost invariably. The research involves the application and assessment of the pulse-echo method for the purpose of identifying breaches. For numerous years, the methodology has been implemented in the diagnosis of electrical lines. The primary idea is to transmit a predetermined surge and analyze the resulting signal to identify any indications of leakage. One anticipates the presence of a Doppler shift in the modulated signal wave as a result of dynamic disturbances in the water conduit in the vicinity of the leakage point, which are caused by evacuating water. The report commences with an introduction that provides a comprehensive overview of the leak detection issue. The theory section of the paper continues with an explanation of a model for the prediction of the sound field as a consequence of the reflection of a reference acoustic wave from a moving reflector. The experimental component entails the application of the technique to an urban water pipeline system and the subsequent outcomes of the measurements. The subsequent signal processing section delves into the analysis of data and the final results.

IV. CONCLUSION

Worldwide, water leakage is an extremely distressing issue that necessitates immediate attention. Otherwise, it will result in substantial economic and raw material losses. Four wireless sensor network (WSN) technologies were introduced in this paper for the purpose of detecting breaches. Additionally, the proposed method has the potential to assist in the creation of an automatic leakage management solution that gathers leakage data, generates alarms regarding the likelihood of leaks, and provides information regarding the precise locations of leaks. The survey clearly demonstrates that the current leakage detection methods have varying accuracies, deployment costs, and applicable environments. However, it is a common practice and is advised to combine multiple leakage detection methods to create a hybrid system. The review presented indicates that the existing methods are capable of detecting explosion type leakages to a certain extent.

Nevertheless, their application in the detection of background type leakage is ambiguous. Background leakage is frequently concealed and challenging to identify in a large-scale infrastructure network, such as water distribution networks (WDN), in contrast to sudden pipe bursts, which have been the subject of extensive research. Consequently, the current leakage detection techniques, which employ signal processing/analysis to detect leaks in large-scale water distribution networks, are ineffective in detecting background leakage in a WDN and do not meet the need for leak detection. This form of discharge is responsible for a greater proportion of water loss, necessitating additional research efforts.

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