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Nonlinear Augmented Reality Enabled Smart Water Leakage Identification And Infrastructure Management Of Pipeline System

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Abstract:
A great deal of water could be saved by implementing automatic leak detection all over the world. In developed nations, pipe induced vibrations or sounds are used in acoustic devices for detecting leaks while in developing countries it's majorly through visible physicality on floors usually resulting to wastage of a lot of water as they are not notified until something goes wrong there. Pipe leaks due to various reasons such as worn-out, natural disasters and improper installation can be rectified with the solution that detects and locates damages within the earliest times possible. A affordable way out would be having an embedded system with flow sensors at several points along the pipeline being used as means of identifying leaking waters at minimum cost. Detected faults could be sent wirelessly to appropriate departments via cloud-based information storage. This concept also involves incorporating AR technology into our designed system since underground sewage systems are not easy to locate in most cases. The AR interface displays the underground sewage pipeline blueprint, allowing users to visualize pipe locations without technical expertise. Moreover, the system identifies leaks and potential pipeline issues within the AR environment, providing real-time insights for prompt resolution. Efficient water resource management is a key global goal due to increasing water demand. Automation in such systems reduces errors, enhances efficiency, and bridges the supply-demand gap..

Keywords: Water Leakage, IoT, Augmented Reality, Cloud Server, Water Flow Sensor, Smart Monitoring System.

Introduction

Water conservation is a critical objective for countries worldwide, and effective water management in townships is essential. Many densely populated cities face challenges due to poor water resource management, including issues such as pipe spillage, excessive water usage, and water contamination, leading to inefficient water utilization. Furthermore, pipe leaks can cause flooding in streets, disrupting public transportation systems. Extensive literature surveys have highlighted the significance of addressing these challenges. One approach involves the development of microcontrollers and monitoring devices for detecting water leakages. An innovative solution is the integration of Internet of Things (IoT) and Augmented Reality (AR) technologies into water monitoring systems. These systems incorporate flow sensors to measure flow rates and generate alerts when leaks are detected, with AR technology pinpointing the leak's location. An effective water leakage detection system can be constructed using smart devices like NodeMCU, Arduino, Water Flow sensors, and Wi-Fi technologies. However, existing research work primarily focuses on detecting leaks and providing alerts to users, followed by AR visualization of the leaks. To enhance these systems, three crucial factors should be

considered:
a) Leakage Detection: Implement robust mechanisms for timely and accurate detection of water leakages within the infrastructure. (b) Flow Rate Monitoring and Water Volume Usage: Continuously monitor flow rates and water usage to identify patterns and optimize consumption. (c) Visualizing Leaks in AR: Enhance user experience by integrating AR technology not only for leak detection but also for visualizing the leaks in real-time, providing actionable insights for efficient maintenance and repair operations. By addressing these factors comprehensively, water management systems can significantly improve efficiency, reduce water wastage, and mitigate the impacts of water-related issues in populated areas.

Literature Review

Mukul Kul Shrestha's [1] study on the assessment of the city water supply's effectiveness in India may be accompanied by a literature review that examines various aspects of water supply management. It can also review research on water demand management, water conservation strategies, and innovations that increase water supply infrastructures' effectiveness.

Furthermore, the study can examine the existing literature on planning framework, legislation and governance structure of city water supply system in India. This comprehensive study will provide a solid basis for assessing the efficiency of city water supply systems and identifying areas for improvement in the Indian urban context.

The Indian government's Central Water Commission resides within the Ministry of Water Resources [2] published guidelines in November 2014 intended to increase the effectiveness of water consumption in home, industrial, and irrigation sectors. with a focus on increasing the effectiveness of water use, the paper may include approaches to water resource conservation in agriculture, residential and industrial sectors. This resource can provide valuable insights into best practices and technologies to improve water management efficiency, which are essential for water management in India.

In their study, Adam Openshaw and Kalvin Vu [3] focus on Flow rate sensors is used in agricultural leak detection to find irrigation system faults. This research likely explores the use of flow rate sensors to detect anomalies in water flow patterns, which could indicate leaks or breaks in the system. By leveraging these sensors, Openshaw and Vu likely suggest a technique to improve sprinkler equipment' efficiency by promptly identifying and addressing leaks, thereby reducing water wastage and ensuring optimal irrigation practices. This resource is valuable for understanding the application of sensor technology in improving irrigation system reliability and sustainability.

Teddy Ariyatham's [4] thesis likely focuses on water leak detection, possibly within the context of urban water distribution systems or similar infrastructures. This research likely investigates various methods and technologies for finding and recognizing water infrastructure breaches, such as acoustic methods, pressure-based systems, or advanced sensor networks. Ariyatham's work is likely to contribute to the field's understanding of effective leak detection strategies, potentially emphasizing the importance of early detection to prevent water loss and infrastructure damage. This resource is likely to be valuable for gaining insights into current practices and technologies used in water leak detection and management.

Riya Sood, Manjeet Kaur and Hemant Lenka [5] in their paper describe the design and development of possibly automatic flow meters, which can be used in various applications such as industrial water management, commercial and residential settings Occurrence, error reduction and possibly the study explores the technical details, operating principles, and potential benefits of automatic flow meters, highlighting the potential for water systems to move effective to facilitate accurate payments. This resource can be valuable in understanding technological advances in flow measurement and its implications for water management efficiency.

T.S. In their review, Deepiga and A. Shiva Sankari [6] present a study on possibly intelligent water monitoring system that uses wireless sensor network to monitor water consumption in home or office environment is capable of thinking The study discusses the use of wireless sensor networks for possibly transmitting data and developing a user-friendly interface for acquiring and interpreting observational data This study presents a cost-effective solution learn and work well for to monitor water use in domestic and commercial situations it can help.

Suresh, Balaji, Jeffrey Anto, and Zenith [7] are investigating the use of the Raspberry Pi, a popular microcontroller platform, to develop and control flow control systems. The analysis likely covers the technical aspects of the system such as the sensor interface, data processing, and control algorithms. In addition, research is likely to examine the accuracy and overall efficiency of the system, reliability, and cost-effectiveness. This feature is perhaps the most valuable in terms of understanding the Raspberry Pi's potential for developing innovative solutions for flow monitoring and control. Perhaps in his study, A. M. Sadeghion et al, Nicole Metze, D. N. Chapman, and C.J. Anthony [8] explore the concept of "intelligent pipelines," pipelines focused on using intelligent networks of wireless sensors to find water leaks. This research may investigate the integration of advanced sensor technologies such as acoustic sensors or pressure sensors in wireless networks to monitor the ongoing condition of pipelines. This resource can be valuable in understanding the development of smart water management systems and their application in maintenance projects.

In their study, B. V. Hieu et al. (2011) [9] focused on cordless Acoustical signal transfer for underground pipe leak identification in actual time. Their research, published in the KSCE Journal of Civil Engineering, highlights the importance of wireless technology for early leak detection. By transmitting cable acoustic signals, they aimed to provide a real-time monitoring system that could help detect rapid leaks, prevent damage and conserve liquid water in this study improves water efficiency in underground pipelines, due to leakage supports the aspect of infrastructure by providing a promising strategy for reducing losses.

According to A. M. Sadeghion et al. (2014) [10] introduced the concept of "smart pipes" by focusing on the use of intelligent wireless network of sensors for water infrastructure detecting leaks. Their work, published in the Journal of Sensors and Actuator Networks, highlights the need for advanced technologies to address leak problems. The study proposes an innovative approach to use wireless sensors embedded in the pipeline infrastructure for leak monitoring and detection. Using smart wireless sensor networks, the system aims to provide real-time information about pipeline conditions, enabling timely interventions to prevent water loss and infrastructure disruption. This research contributes significantly to the field by providing practical and efficient solutions. It is also important to ensure sustainability.

In their study, Gao Wai (2005) [11] discussed the choice of vibration/sound sensors for pipe leak detection. Their study highlights the importance of sensor selection in the presence of water a leak detection, especially in plastic pipes where traditional methods may be ineffective -Evaluating Sensor Technologies. Discovering the best sensors to detect leaks in pipes made of plastic is the goal of this research. The findings contribute to valuable insights into the selection of sensor technologies for leak detection applications, provides guidance for optimal sensor performance, leaks in plastic pipes and improves the efficiency of detection systems.

Jheng Liu and Yehuda Klenar (2012) [12] have analyzed the technology of the technology, as in the IEEE Sensors Journal, the various engineers have not designed health systems. In reviewing methods of inspection, and indifference policy, reviewing the newly condemned, Investigation provides a comprehensive overview of the current state of pipe inspection technology. This work is invaluable to researchers and professionals in the infrastructure industry and provides insight into the latter's engineering and development to ensure the integrity and functionality of pipelines used in water distribution systems.

Jayalakshmi M and Gomathi V (2015) [13] by using the mechanism of soil intermediate softing and networking protection and importance of lease of aggregated soil. Viel seminar networks for continuous observation of the flood network, providing real-time information about flood potential. By providing monitoring and detection capabilities, the system aims to reduce water loss and prevent infrastructure degradation. Research helps the field operate by providing practical and reliable solutions to improve the efficiency of systems for distributing water and ensure the efficient use of water resources.

Riya Sood and more. (2013) [14] focused on the design and development of passive flow meters, as published in International Computer Science and Engineering. Their research emphasizes the accuracy and efficiency of flow measurements, especially in the context of water conservation and management. The study proposes a new automatic flow measurement system that aims to provide more accurate flow rate measurements. This function contributes to the efficiency of the water distribution system through automated planning, which enables efficient monitoring and control of the available water. This function is essential for efficiency in water management increasing and ensuring adequate management of water supply.

Dalius Misiunas and others. (2005) [15] investigated pipeline rupture detection using stress transient analysis. Their research highlights the importance of early detection and mitigation of pipeline breaks to prevent water loss and reduce damage to infrastructure by providing ultimate pressure monitoring to manage sudden changes in pressure due to pipeline breaks and other helpful information for the field, provides a valuable means of improving the efficiency and water distribution systems' dependability.

A. M. Obeid et al. (2016) [16] reviewed in detail methods and techniques for monitoring pipelines based on wireless sensor networks, as published in IET Science, Measurement & Technology. Their study highlights the importance of wireless sensor networks for water emphasis on maintenance of pipelines. The objectives of the study are to review and provide insights into effective systems for the maintenance of pipelines. The findings contribute valuable knowledge in the field, offering direction for the development and deployment of water infrastructure tracking systems based on wireless sensor networks. This work is important for improving water management systems and facilitate an efficient and sustainable water distribution system.

Demma A. and others. (2003) [17] investigated fundamental diffraction mode reflection from cracks and grooves in pipelines. Their research focuses on detecting and characterizing defects in pipes using acoustic signals, e.g. cracks and grooves, leading to leaks and structural failure. By studying the fundamental diffraction mode images, the research aims to develop a non-destructive test method to detect and measure the internal composition of defects in pipe.

Methodology

The design and operation of the smart water leak detecting system are covered in this section.

Flow Sensor Placement:

This system becomes operational once water is authorized for diverse industrial and domestic applications by water board authorities. As shown in Figures 1 and 2, flow monitoring sensors are positioned strategically at frequent times along the primary pipeline and its branches. This setup enables the precise identification of leaks at specific branches. Water flows through all pipelines, passing through various flow rate measurement sensors before reaching its destination.

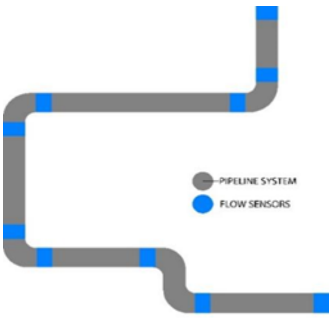

Figure 1: Water flow sensor placement

Figure 2: Real-time Water flow sensor placement

Flow rate and Volume measuring methods:

This system becomes A microcontroller is connected to each flow rate measuring sensor in a certain area, as shown in Figure 3. Multiple sensors are connected to the network, allowing for the monitoring and management of water access across the entire area. Each flow rate sensor transmits the water volume passing through it to the microcontroller. The microcontroller gathers data from the sensors and transmits the values to the Cloud via Wi-Fi connected to the internet. This data logging process records flow rate measurements into a sensor cloud, enabling their utilization for future purposes. Flow rate can be calculated inferentially using several strategies such as [8] In their study, D. N. Chapman, C. J. Anthony, Nicole M, and M. Sadeghioon likely delve into the concept of "Smart Pipes," focusing on the implementation of smart wireless networks of sensors for detecting leaks in pipelines. This research probably explores the Utilization of modern sensor technologies, such as acoustic sensors or pressure sensors, integrated into a wireless network to continuously monitor the condition of water pipelines. The study likely discusses the design, deployment, and performance evaluation of the Smart Pipes

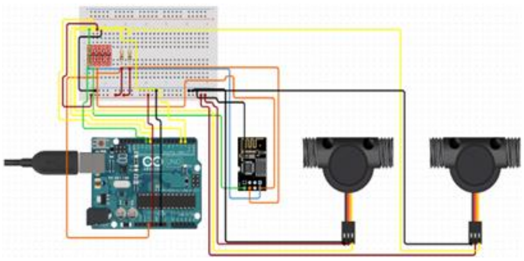

Figure 3: Flow sensor connection to microcontroller

System, highlighting its potential to increase the identification of leaks in water delivery networks' effectiveness and dependability. This resource is likely to be valuable for understanding the cutting-edge in water control mechanism and their applications in infrastructure maintenance, in kinetic energy or speed. Using the water's change in velocity, we were able to calculate the water's flow rate. Velocity is determined by the pressure applied to the pipelines. Because the pipe's sectional dimension is known and constant, the average velocity may be used to calculate the flow rate. In such cases, Z=V x A, where Z is the rate of flow/total flow of water throughout the pipe, X is the avg. velocity of the flow, and Y is the cross-sectional area of the pipe, is the basis relationship for calculating the liquid's flow rate.

- P.frequency (Hz) = 4.5Z, where Z represents rate of flow in Litres/min.
- Rate of Flow (litres per hour) = (P.frequency x 60 minutes) / 4.5Z.

Method for Detecting Leaks

When the system is active, the microcontroller continuously monitors the flow rate. The leak detection algorithm operates by identifying a leak whenever the difference in the rate of flow between two consecutive sensors in sequence exceeds a predefined threshold value. Figure 4 illustrates the scenario of a leakage in the system. Through the wireless network module, the flow rate differential data is also sent to the cloud. A warning or notification is generated upon leak detection, and a message is forwarded to the appropriate authorities for prompt action.

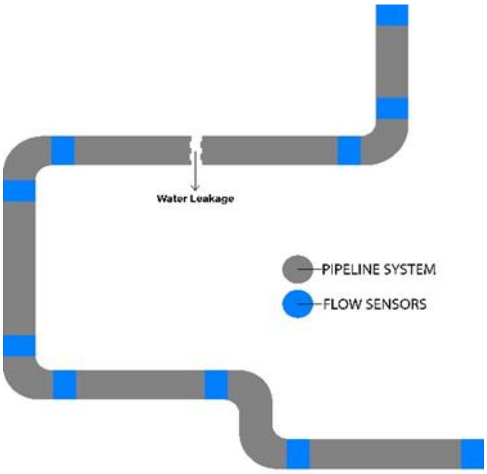

Figure 4: Leakage Scenario

Locating leakage and visualizing leaks in AR:
When installing sensors in the pipeline each sensor receives an identification number. This data, combined with where the sensor placed is used to generate a 3D representation of the pipeline. If there is a leak, the system checks the flow rate, between sensors. If it identifies a leak between sensors their unique IDs are recorded, which helps pinpoint where the leak is located.
Users can use their smartphones equipped with VR or AR features to view the 3D pipeline model. This allows them to keep an eye, on flows and volumes in time and spot any leaks promptly.

In addition, the system is efficiently managed and maintained using unique IDs assigned to sensors. They make it possible to quickly pinpoint which sensors are involved in leak detection and thus simplify troubleshooting operation. Therefore, it improves operational efficiency and reduces cost.

Figure 5: Real-time AR

In the above Figure 5 real-time data from the water flow sensors is displayed in augmented reality (AR).

Still, the 3D model of the pipeline developed from sensor data gives a complete visible picture of the whole structure. The users can click through it using their virtual reality or augmented reality devices to understand its physical layout as well as flow patterns for leaks prevention purposes.

Such an immersive experience assists in deciding on appropriate preventive techniques against future leaks or

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optimizing performance of the system.

In the Figure 6 pipeline layout is described, water flow sensors are fixed at both ends. When viewed in AR, the entire pipeline structure is displayed, showcasing the water flow rates from all connected sensors. If all sensor flow rates are equal, it indicates no leaks in the pipeline.
The flow rate sensors are strategically positioned. In Figure 7 - Leaks are visually pinpointed, highlighting the specific area of the leak.
The branch pipeline with a leak exhibits lower water flow rates compared to the desired flow.

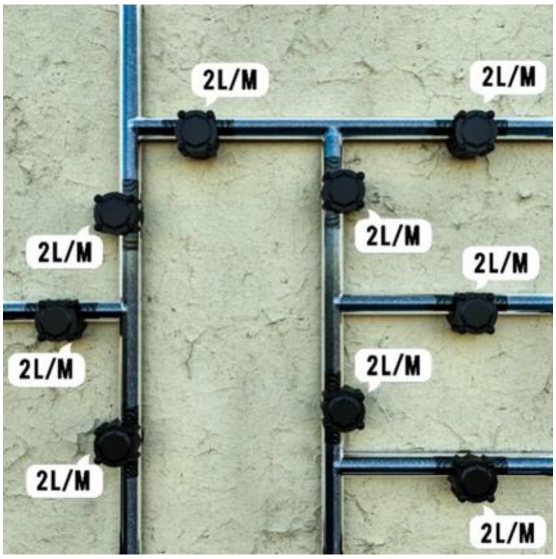

Figure 6: Showing normal flow rate of the pipelines

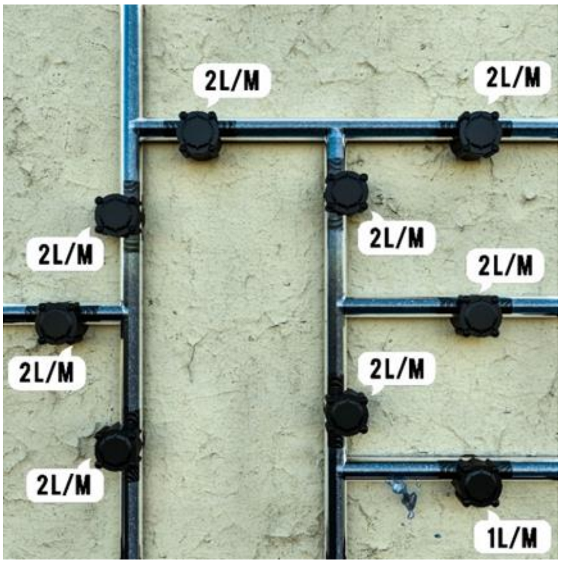

Figure 7: Showing leakage by flow rate of the pipelines

Result and Discussion

We created a prototype by connecting two flow rate sensors in line along a water pipes. Testing this prototype under several water flow conditions produced satisfactory results. To let water move through the pipelines, the water flow controller is initially turned on. The flow rate difference between sequential sensors is determined by the microcontroller using a water leakage detection algorithm after it has periodically collected flow rate data from both sensors. The purpose of logging this difference data into the cloud is to initiate leakage detection. Upon detecting a leak, notifications are promptly sent to the relevant authorities for the repair of damaged pipelines. Furthermore, the AR interface visualizes the detected leaks within the pipeline, providing a user-friendly way to identify and address issues.

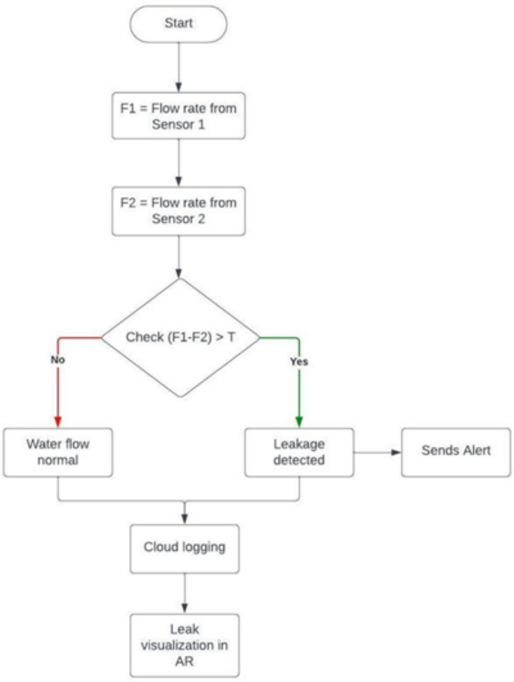

Figure 8: Flowchart for the process control

In the above mentioned figure 8, the overall process of data flow from the flow sensors was mentioned. The water leakage detection system can be integrated into existing plumbing by installing flow rate sensors along the water flow path. These sensors don't impede water flow; instead, they gather flow rate data.

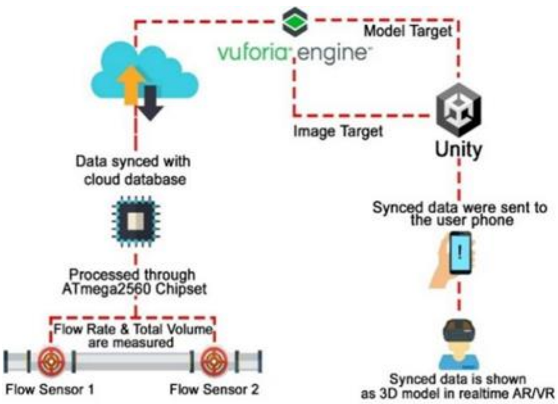

Figure 9: Architecture Diagram

The system for the leakage identification is shown in Figure 9.

Flow Sensors

These sensors are installed in the pipeline to measure the water flow transmitting analog signals that indicate the flow rate.

Microcontroller

The microcontroller receives the analog signals, from the water flow sensors converting them into data that represents the water flow rate within the pipeline. Additionally, this microcontroller processes the data related to water flow.

Cloud Connectivity

Connecting via Wi Fi the microcontroller establishes a link with the cloud to transmit processed water flow data for storage, analysis and remote access.

SMS Alert System

In case of any irregularities relevant users or maintenance personnel receive notifications via SMS on their devices. This immediate alert system ensures responses to any issues concerning water flow.

Vuforia and Unity Integration

By utilizing Vuforia Engine to train a target model or image integrated into a Unity application users can scan a target image (potentially depicting a representation of the pipeline) to overlay a predefined pipeline model in augmented reality (AR). This feature enables users to visualize and engage with real time pipeline models, for maintenance and troubleshooting tasks.

Figure 10 (a):Comparison between two consecutive sensors.

Figure 10 (b): Normal condition

Figure 10 (a) shows the graph that represents the data gathered from two sequential sensors over a given interval. The flow rate condition under typical conditions is depicted on the graph in Figure 10 (b). The rate of flow is nil when there is no water flow, and it gradually rises and stays constant when water flow is provided.

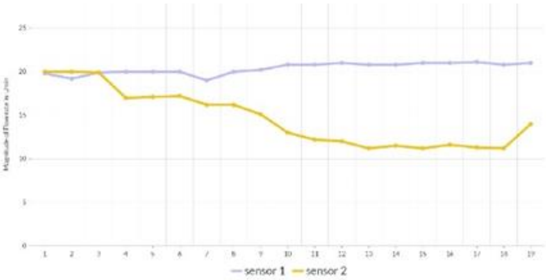

Figure 11 (a): Water leakage condition

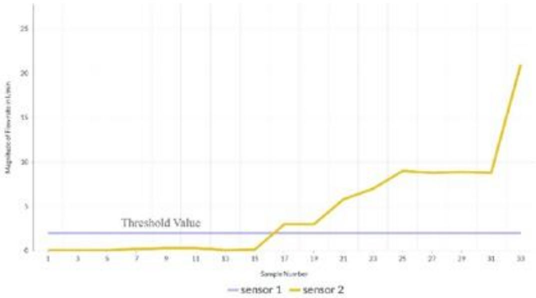

Figure 11 (b): Rate of change Flow Rate between Two consecutive sensors

As seen in Figure 11 (a), the flow rate in a specific node alters when there is a leak. The water supply is cut off (as indicated in Figure 11 (b)) after a predefined threshold value is crossed by the flow rate differential between the two sensors in that node.

Experiments have shown that water flow sensors are useful at tracking and detecting leaks in pipeline control systems. This strategy benefits both home and commercial cities with multiple water pipelines and significant leak rates. Currently, only water distribution professionals can discover leaks. As a result, using this technique, the problem can be fixed quickly.

- Automatic leaks and burst detection in water distribution pipelines
- Cost-effective manufacturing, installation, and maintenance
- Quick acquisition of data
- Automatic leak detection without human intervention.
- Water leak identification in instant
- Enhanced monitoring of the location
- Affordable installation costs

Table1: Water Flow through Flow Sensor (Normal State) (Threshold value = 1.5)

Flow Sensors (1.2)	**Threshold Difference**	**Leak Status**
2, 2	0	
4, 3.5	0.5	
6, 5.3	0.7	Nil
8, 7.1	0.9	
10, 9	1	

Table2: Water Flow through Flow Sensor (Broken State) (Threshold value = 1.5)

Flow Sensors (1.2)	Threshold Difference	Leak Status
2, 0.45	1.55	
4, 2.28	1.72	
6, 3.38	2.62	Detected
8, 5.06	2.94	
10, 5.58	4.42	

In table 1 and table 2, Water flow through the flow sensor with threshold value and leak status is mentioned

Conclusion

In summary it's crucial to prioritize water conservation and management, in communities. Dealing with issues like water resource management, such as leaks, overuse and contamination requires solutions. Incorporating microcontrollers, IoT, AR technology and smart devices like NodeMCU and Arduino presents promising opportunities for creating leak detection systems. These systems focus on detecting leaks monitoring flow rates tracking water usage levels and visualizing leaks using AR technology to improve water management practices. Detecting leaks promptly while providing real time visualization and data insights enables authorities and users to take steps to optimize water consumption and reduce water waste. Ultimately employing technologies alongside strategies is vital for sustainable water management in communities. Ensuring a steady and effective water supply while safeguarding this valuable resource, for future generations.

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