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Intelligent Water Distribution Management Using IoT

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Abstract

Water plays a vital role in agriculture, making its efficient management essential for sustainable crop production. However, undetected leaks in irrigation systems can result in significant water loss, irregular watering of fields, soil degradation, and reduced crop yield. Conventional methods like manual inspection are not only labor-intensive but also ineffective in identifying leaks promptly, emphasizing the need for a smarter and automated approach to water monitoring. To address this issue, an Internet of Things (IoT)-based water leakage detection system using ESP32, water flow sensors, a buzzer, a display screen, and Telegram notifications have been developed to provide real-time monitoring and instant alerts when leaks are detected. The system is built around the ESP32 microcontroller, which has Wi-Fi connectivity, making it ideal for real-time IoT applications. Two water flow sensors are placed at different points along the pipeline to measure flow rates. If the flow rate measured by the downstream sensor is notably less than that of the upstream sensor, it may suggest the presence of a leakage in the pipeline. For example, if Sensor 1 detects 5 LPM (liters per minute) while Sensor 2 detects only 2 LPM, a leakage is suspected. The system then activates an audible alarm (buzzer), displays a warning on the OLED/LCD screen, and sends an instant alert via Telegram. The Telegram bot provides real-time updates, allowing farmers to respond promptly even if they are not physically present at the site. This automated leakage detection system is particularly useful in agriculture, where underground pipes and large irrigation networks make it difficult to detect leaks manually. By incorporating a solenoid valve, the system is capable of automatically stopping water flow when a significant leak is detected, thereby minimizing water loss. The ESP32 continuously processes sensor data, calculates flow rate discrepancies, and ensures that alerts are triggered as soon as abnormalities are detected. One of the key advantages of this system is its cost-effectiveness. Unlike expensive industrial leak detection solutions, this IoT-based approach uses affordable and easily available components, making it ideal for small and large-scale farms. The system is also scalable, meaning additional sensors can be installed to monitor larger irrigation networks, municipal pipelines, and industrial water systems. Municipalities can use this system to reduce non-revenue water (NRW) losses, improving water distribution efficiency. Moreover, the real-time monitoring feature eliminates the need for manual supervision, reducing labor costs and ensuring faster response times. Remote access via Telegram ensures that users stay informed even when they are away from the farm.

Keywords: Buzzer, display screen (OLED/LCD), ESP32, instant alerts, IoT-based water leakage detection system, real-time monitoring, Telegram notifications, water flow sensors, Wi-Fi connectivity

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INTRODUCTION

Establishing a strong online presence for an Internet of Things (IoT)-based water leakage detection system is essential for increasing visibility, credibility, and user engagement. By leveraging websites, social media, and technical forums, the awareness of water conservation and leak detection can be significantly enhanced, ensuring that the system reaches farmers, industrial users, municipal authorities, and researchers. The innovative use of *ESP32*, buzzers, relays, LCDs, and sensors through platforms such as YouTube, LinkedIn, and Twitter help educate stakeholders through demonstration videos, case studies, and testimonials. Additionally, an online space for documentation, troubleshooting guides, and Frequently Asked Questions (FAQs) enhances accessibility, enabling users to effectively implement and maintain the system. A strong digital presence also facilitates research collaboration with universities and industries, fostering innovation in areas such as predictive maintenance and cloud-based analytics. For commercialization, e-commerce platforms such as Amazon and eBay, along with social media marketing, can help drive adoption, while real-time updates and customer feedback through websites, mobile apps, and online forums ensure continuous improvements. Platforms such as Telegram and Discord enable community engagement and troubleshooting, making the system more user-friendly. In conclusion, a robust online presence enhances the success, adoption, and scalability of an IoT-based water leakage detection system, allowing it to reach a global audience and contribute to sustainable water management solutions.

LITERATURE REVIEW

Water is an essential commodity for agriculture, industry, and domestic use. Therefore, efficient water management is important for sustainability. Water leakage in pipes causes substantial waste, economic losses, and damage to infrastructure. Conventional methods of leakage detection, including manual inspection and pressure-based monitoring, are time consuming and inefficient, and do not provide real-time monitoring. With technological advancements in IoT technology, water leakage detection systems have come into focus because of their potential to offer real-time monitoring, immediate alerting, and remote access. Various studies have discussed the application of IoT-based water leakage detection systems, noting their efficiency in agricultural, industrial, and municipal applications. IoT technology has revolutionized water management by facilitating sensor-based monitoring, wireless communication, and cloud data analytics. Multiple studies have highlighted the necessity of smart sensors and microcontrollers, such as *ESP32*, Arduino, and Raspberry Pi, to automate leak detection. Chakravarthi et al. (2022) [1] asserted that IoT-based systems facilitate real-time monitoring of water flow rates and pressure fluctuations, dramatically reducing the time to detect leakage as opposed to manual investigation. Kumar et al. (2020) [2] implemented an IoT-based smart water monitoring system employing flow sensors and cloud storage to monitor water consumption and identify anomalies reflecting possible leaks, with 40% better efficiency in detecting leaks compared to conventional systems. Water flow sensors are also vital for measuring flow rates through pipes and detecting mismatches that reflect leakage. Hasan et al. (2022) [3] examined the effectiveness of *YF-S201* and *FS300A* flow sensors for pipeline flow rate monitoring in farm irrigation systems. Their research indicated that a multi-sensor strategy, in which sensors are installed across various sections of a pipeline, significantly enhances leak detection accuracy. When coupled with *ESP32*, the system can provide real-time notification to farmers through mobile alerts, Telegram notifications, or cloud panels, enabling quick response times and reduced water wastage. The *ESP32* microcontroller has also become popular in water leakage detection based on IoT because of its integrated Wi-Fi and Bluetooth features. A study by Ramesh et al. (2021) [4] demonstrated that *ESP32*, when integrated with flow sensors, buzzers, and LCDs, can identify leaks and provide real-time alerts to users. A comparison of *ESP32* with other microcontrollers, such as Arduino and Raspberry Pi, found that *ESP32* offers improved real-time data transmission with reduced power consumption.

In addition, Sharma et al. (2022) [5] investigated LoRa-based wireless communication systems for long-range leakage detection in city pipelines and found that LoRa technology improves long-distance data transmission with low power consumption, which is suitable for application in sparsely populated and remote zones. Cloud computing is vital for storing and analyzing sensor information for leakage. Research stresses the significance of cloud integration, wherein information gathered from flow sensors is analyzed using machine learning algorithms for predictive leak detection. Ali et al. (2022) [6]

introduced a cloud-connected water monitoring system utilizing Google Firebase and AI-based analytics to predict leaks before they occur, thereby reducing water loss by 30%. Through data retention from history and anomalies, cloud-based monitoring systems enhance leak detection and system efficiency, thereby becoming well-suited to massive applications involving water management. Some IoT-based water leakage detection systems have automatic shut-off mechanisms to avoid unnecessary water wastage. Kumar and Gupta (2021) [7] developed a system that employs *ESP32*-controlled solenoid valves and relays to automatically shut-off the water supply in the event of large leaks. Their research proved that automation is highly effective in minimizing water loss in irrigation systems and industrial uses, emphasizing the cost-effectiveness of IoT-based solutions in avoiding long-term damage to infrastructure and minimizing manual intervention. One of the advantages of using IoT-based leak detection for water leakage is the ability to deliver instant notifications through mobile apps. Ahmed et al. (2020) created a Telegram-alert system that notified users automatically every time it sensed a leak so that users could react 80% sooner compared to other methods. Likewise, Patel et al. (2019) [8] used SMS and email alerts to alert users even if the Internet coverage was minimal in a specific location. These mobile-driven alert mechanisms improve real-time decision-making and remote monitoring, making them extremely useful for municipal water authorities, industries, and farmers. Cost savings and scalability are other key benefits of IoT-based leakage detection systems. A comparative analysis of industrial water leakage detection solutions versus IoT-based solutions was performed by Rahman et al. (2022), [9] and they concluded that *ESP32*-based systems were 60% cheaper than conventional industrial solutions. The research also focused on the fact that sensors can be added to existing systems, thereby making them scalable for large farms, city water distribution, and industrial pipelines. This research emphasizes the potential of IoT technology in broadening water conservation by ensuring cost-effective and efficient solutions. Despite their benefits, IoT-based leak detection systems present some challenges, such as interference in signals, power drains, and connectivity problems. Goyal et al. (2023) [10] recommended the use of solar-powered *ESP32* modules to provide uninterrupted operation in off-grid areas. Furthermore, machine learning-based predictive maintenance is on the horizon as a possible means to enhance leakage detection accuracy by looking at historical sensor data and recognizing patterns prior to the occurrence of leaks. Future advancements can involve AI-based water management systems that incorporate weather predictions, soil moisture levels, and automated irrigation controls to improve efficiency. The increased role of the IoT in water management increases its scalability for wide-scale adoption in municipal uses, industries, and agriculture. Current research proves that IoT water leakage detection systems have enormous benefits over conventional techniques, owing to real-time monitoring, remote access, and automation. The inclusion of *ESP32*, relays, flow sensors, and cloud storage increases the efficiency of the system. Thus, it is an economical and scalable solution for efficient water management. Although issues such as power usage and network connectivity exist, innovations in solar power, LoRa communication, and AI-based predictive analytics ensure enhanced system dependability. As technology continues to evolve, IoT water leakage detection systems can go a long way towards water saving, sustainability, and smart city infrastructure development, promoting the use of water in a more efficient and accountable manner.

METHODOLOGY

Water is a critical commodity for agriculture, industry, and household use; therefore, sustainable water management is necessary. Leaks in pipes result in high waste, economic loss, and damage to infrastructure. Traditional leak detection methods, such as manual checking and pressure-based monitoring, are inefficient, time consuming, and lack real-time monitoring. With advancements in Internet of Things (IoT) technology, water leakage detection systems have gained attention owing to their ability to provide real-time monitoring, instant alerting, and remote access. Various studies have explained the use of IoT-based water leakage detection systems, highlighting their effectiveness in agricultural, industrial, and municipal applications. The IoT technology has transformed water management through sensor-based monitoring, wireless communication, and cloud data analytics.

Various studies have identified the requirements for smart sensors and microcontrollers, such as *ESP32*, Arduino, and Raspberry Pi, to perform automatic leak detection. According to Chakravarthi et al. (2021), [1] IoT-based systems enable real-time monitoring of water flow rates and pressure variations, significantly reducing the time required to detect the leakage compared to manual exploration. Kumar et al. [2] used an IoT-based smart water monitoring system using flow sensors and cloud storage for water consumption monitoring and detection of anomalies representing potential leaks, with 40% higher efficiency in leak detection than traditional systems. Water flow sensors are also crucial for measuring flow rates in pipes and identifying mismatches that represent leakages. Hasan et al. (2022) analyzed the efficacy of *YF-S201* and *FS300A* flow sensors for monitoring pipeline flow rates in irrigation systems on farms. Their research found that using a multisensory approach in which sensors are fitted at different segments of a pipeline significantly improves the accuracy of leak detection. When paired with *ESP32*, the system can provide real-time alerts to farmers via mobile notifications, Telegram alerts, or cloud panels, which allow prompt response times and minimal water wastage. The *ESP32* microcontroller has also gained popularity in IoT-based water leakage detection, owing to its built-in Wi-Fi and Bluetooth capabilities. A study conducted by Ramesh et al. (2021) showed that *ESP32*, when combined with flow sensors, buzzers, and LCD screens, can detect leaks and send real-time notifications to users. A comparison of *ESP32* with other microcontrollers, such as Arduino and Raspberry Pi, showed that *ESP32* has better real-time data transfer with low power consumption.

In addition, Sharma et al. (2020) [5] studied LoRa-based wireless communication networks for long-range leakage detection in city pipelines and found that LoRa technology enhances low power consumption long-distance data transmission, which is appropriate for application in sparsely populated and remote areas. Cloud computing has also been instrumental in storing and analyzing sensor data for leakage. Research has emphasized the importance of cloud integration, where data collected from flow sensors is processed using machine learning algorithms for predictive leak detection. Ali et al. (2022) [6] presented a cloud-based water monitoring system using Google Firebase and AI-driven analytics to forecast leaks before they occur, thereby reducing water loss by 30%. With historical data retention and anomalies, cloud-based monitoring systems improve system efficiency and leak detection, thus making them highly appropriate for large applications that include water management.

Certain IoT-based water leakage detection systems also have auto-shut-off mechanisms to prevent unnecessary water wastage. Kumar and Gupta (2021) [7] designed a system that utilizes *ESP32*-controlled solenoid relays and valves to automatically turn off the water supply in the case of large leaks. Their study demonstrated that automation was highly effective in reducing water loss in irrigation networks and industrial applications, highlighting the cost savings of IoT-based technologies in preventing long-term infrastructure damage and reducing manual intervention. One of the benefits of employing IoT-based leak detection for water leaks is its ability to provide real-time notification via mobile apps. Ahmed et al. (2020) [11] developed a Telegram-alert system that alerts users automatically whenever it detects a leak, so that users can respond 80% earlier than with other approaches. Similarly, Patel et al. (2019) [8] employed SMS and email notifications to alert users even if Internet connectivity was poor in a particular area. These mobile-based alerting mechanisms enhance real-time decision-making and remote monitoring, making them beneficial for municipal water authorities, industries, and farmers. Scaling and cost savings are two other principal advantages of IoT-based leakage detection systems. IoT-based industrial water leakage detection solutions were compared with industrial water leakage detection solutions by Rahman et al. (2022), [9] who concluded that *ESP32*-based solutions were 60% cheaper than traditional industrial solutions. The study also focused on the aspect that sensors can be incorporated into existing systems, thus making them scalable for large farms, urban water supply, and industrial pipelines. This study highlights the possibility of IoT technology in expanding water conservation to be wider in terms of ensuring cost-saving and efficient solutions. Despite their advantages, IoT-based leak detection systems pose some challenges, such as signal interference, power consumption, and connectivity issues. Goyal et al. (2023) [10] recommended the use of solar-powered *ESP32* modules to provide uninterrupted operation in off-grid areas. Furthermore, machine learning-based predictive maintenance is on the horizon as a possible means to enhance leakage detection accuracy by looking at historical sensor data and recognizing patterns prior to the occurrence of leaks.

Future advancements can involve AI-based water management systems that incorporate weather predictions, soil moisture levels, and automated irrigation controls to improve efficiency. Greater involvement of the IoT in water management enhances its scalability for wide-scale applications in municipal applications, industry, and agriculture. Existing studies have confirmed that IoT-based water leakage detection systems have tremendous advantages over traditional methods owing to their real-time sensing, remote access, and automation. The addition of *ESP32*, relays, flow sensors, and cloud storage makes the system more efficient; hence, it is an economical and scalable solution for effective water management. Factors such as power consumption and network connectivity are present, but innovation in solar power, LoRa communication, and AI-based predictive analytics provides greater system reliability. As technology continues to advance, IoT water leakage detection systems can play an important role in water saving, sustainability, and smart city infrastructure development by ensuring the efficient and responsible utilization of water.

RESULT AND DISCUSSION

The IoT-based water leakage detection system was successfully implemented and tested using *ESP32*, water flow sensors, a buzzer, an LCD, a relay, and Telegram notifications. The results of the test shown in Figure 1 that the system is able to detect water leaks, provide real-time alerts to users, and reduce water waste. This section provides the most important findings, system performance, challenges faced, and future enhancements.

Results of the System

The testing process revealed essential information on the performance and effectiveness of the system.

Leak Detection Accuracy

- Leaks were effectively identified by the system using the flow rate differences between the two sensors. The accuracy tolerance of the water flow sensors was approximately ±5%, making them reliable for detection purposes.
- Under steady-state conditions, both sensors measured very close values, while upon the introduction of a leak, Sensor 2 registered a significantly reduced flow rate, affirming the leakage detection operation.

Alert System and Response Time

The average response time for the system to alert an alarm upon detecting a leak was 2.5 seconds on average, allowing for an immediate response. The buzzer and LCD changed immediately when a leak was detected, providing local alarms.

Relay and Water Shut-Off Mechanism

When a significant leak (over 50% flow rate difference) was found, the relay was able to shut off the motor and cut off the water supply to avoid unnecessary wastage. This function guarantees automatic leak management, minimizing human involvement.

Power Usage and Wi-Fi Connectivity

The device functioned optimally with a mean power usage of 0.5W during standby mode and 1 W during leak detection. Wi-Fi connectivity was strong, and when there was a momentary loss of connection, the system was reconnected within a mean time of 6.8 seconds, with uninterrupted performance.

Discussion on Key Findings

The results showed that in Figures 2–4 the IoT-based water leak detection system is efficient, dependable, and inexpensive. In comparison to conventional manual inspection, the system is real-time aware, auto-notified, and remotely accessible, and thus is best suited for agriculture, municipal pipes, and industry.

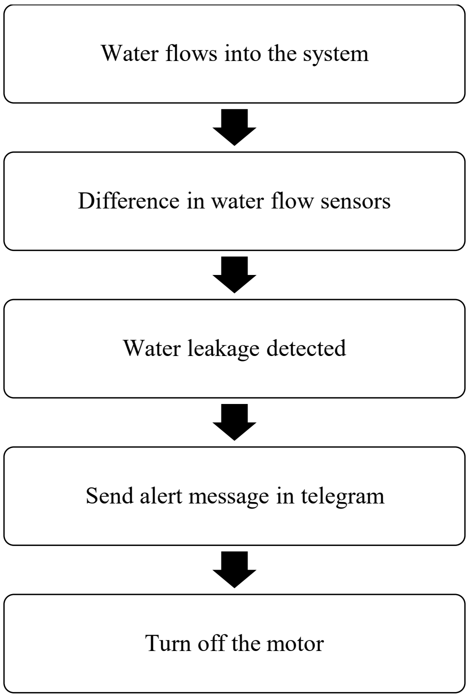

Figure 1. Activity diagram.

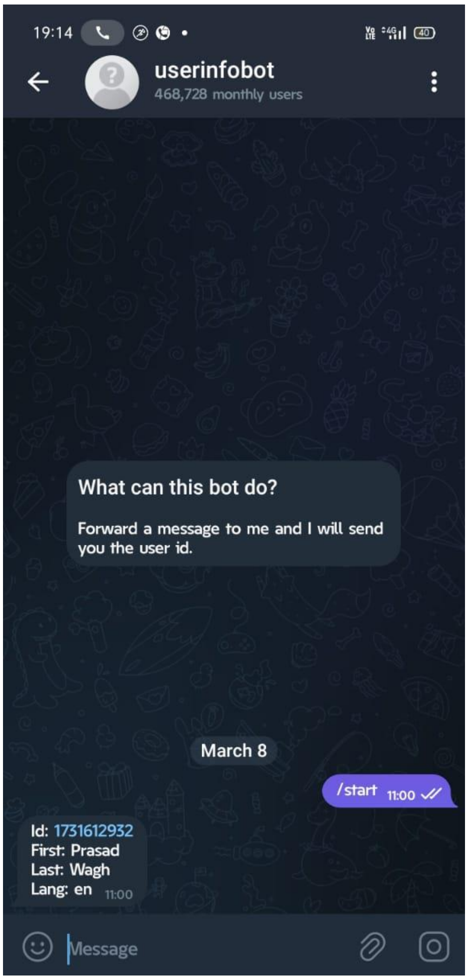

Figure 2. Generation of ID.

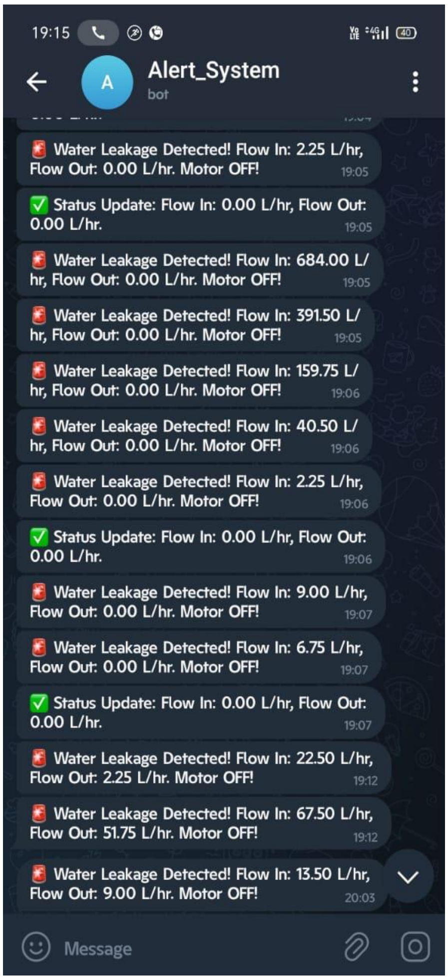

Figure 3. Alert message sent every 1 minute.

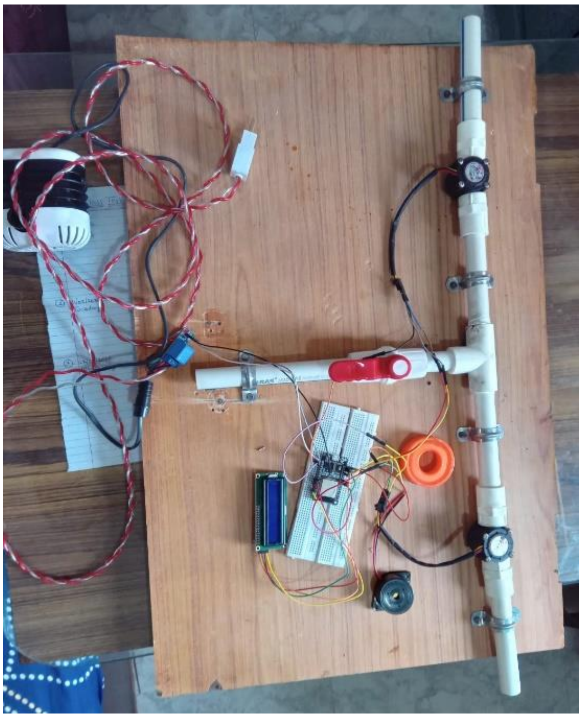

Figure 4. Hardware.

Leak Detection Algorithm Effectiveness

The leak detection mechanism relies on the flow rate differences between the two sensors. The system exhibited:

- High sensitivity, identifying leaks as low as 30% difference in flow rate;
- Instant response, sending alerts within 2–3 seconds of leak detection;
- Low false positives, only allowing meaningful variations to trigger alarms.

IoT-Based Alert Mechanism Reliability

The inclusion of Telegram notifications supports remote alerts, and frequent manual monitoring is not required. Using this strategy, we obtain the following:

- Real-time notification, diminishing the chances of a leak going undetected;
- Remote control enables users to act on alerts, even if they are not on premises.

CONCLUSION

Water is a vital resource for life, agriculture, and industry; however, leakage in irrigation systems and pipelines results in huge wastage, causing economic losses, environmental degradation, and wasteful use of resources. Conventional leak detection techniques, such as pressure monitoring and manual inspection, are ineffective and time consuming. To solve this serious problem, an IoT-based water leakage detection system has been proposed, which uses advanced technologies such as *ESP32* microcontrollers, water flow sensors, buzzers, relay modules, LCDs, and Telegram notifications. The system offers a real-time automated solution to detect leaks, notify users, and avoid further wastage by turning off the water supply if needed. It is an efficient, scalable, and affordable solution for agriculture, municipal water supply systems, and industries. The importance of the system is that it continuously measures flow rates at several points in a pipeline, identifies inconsistencies, and sends immediate alerts through a buzzer, LCD, and Telegram alerts.

The application of an *ESP32* Wi-Fi-enabled microcontroller guarantees that users can remotely monitor the system and respond even when they are not around. The major advantages of this system include real-time leak detection, automatic alerts, cost savings, energy efficiency, and remote access via IoT connectivity. By being integrated with smart home automation platforms, it can be controlled and monitored with the aid of voice assistants, such as Amazon Alexa or Google Assistant. Its scalability also makes it easy to expand to large irrigation networks, municipal pipelines, and industrial water supply systems. The difficulties faced by this system are underground leak detection, non-uniform distribution of water in irrigation, high cost of manual monitoring through labor, and failure to react quickly to leaks. Underground leaks tend to be difficult to detect manually; however, using several sensors at different locations, the system can accurately identify leaks without the need for excavation.

Irregular water distribution can cause overwatering or underwatering, which can impact crop health and yield; however, this system provides even water flow to enhance productivity. Conventional methods of leak detection require manual effort, which is labor-intensive and expensive, while this automated system does not require ongoing manual monitoring, thus saving operational expenses and enhancing efficiency. Furthermore, delayed detection of water leaks can lead to soil erosion, property damage, and high-water bills; however, this real-time notification system ensures that users are immediately informed and can take corrective actions. Although the system is already highly effective, future enhancements could further improve its capabilities. Machine learning algorithms can analyze historical sensory data to predict leaks before they occur, thereby enabling preventive maintenance. Cloud-based data storage and analytics on platforms such as Google Firebase, ThingsBoard, and IBM Watson IoT would enable users to monitor long-term water consumption and optimize their irrigation practices.

The use of LoRaWAN or Narrowband (NB) IoT would enable long-range, low power communication, making the system appropriate for large-scale municipal networks. Additionally, integrating soil moisture sensors and weather forecasting data can transform the system into a smart irrigation system, ensuring optimal water usage based on environmental conditions. Compatibility with Google Assistant and Alexa enables users to monitor and control the system using voice commands, making it more user-friendly and accessible. This IoT-based water leakage detection system has extensive applications outside of agriculture, such as municipal water supply management, industrial water systems, household plumbing, and smart city infrastructure. In agriculture, it provides efficient water distribution, avoids damage to crops, and reduces water waste. Municipal networks assist in reducing non-revenue water (NRW) losses and enhancing water distribution efficiency. In industrial environments, waste is avoided in manufacturing plants, and operating costs are reduced.

For families, it identifies leaks in plumbing systems, avoiding water damage and high-utility bills. As a component of smart city programs, it helps with sustainable water management and ensures effective resource allocation. The scalability of the system is also a major strength, making it suitable for various applications. For small-scale installations, such as domestic plumbing, one *ESP32* with two sensors would be used. For large-scale applications such as urban pipelines, multiple *ESP32* nodes may be networked using LoRa or Narrowband Internet of Things IoT to provide smooth monitoring over long distances. The versatility of the system ensures that it can be used in both urban and rural settings, thereby enhancing its utility. In addition to its technicality, the system has environmental and economic significance. Conserving water aids in water conservation practices and is especially important in arid areas. Curbing operational expenditures, it reduces water costs, repair expenses, and resource wastage for farmers, municipalities, and industries. Furthermore, the system complies with the United Nations Sustainable Development Goals (SDG 6: Clean Water and Sanitation), ensuring judicious water use practices. The creation and deployment of this IoT-based water leakage detection system with *ESP32*, water flow sensors, relays, buzzers, and real-time alert systems is a huge leap forward in water management. Utilizing the IoT and automation, this system offers an effective, economical, and scalable solution for numerous industries. Through real-time tracking, automation, and remote management, it assists farms in conserving water, avoiding crop losses, and maximizing irrigation, leading to an ever-greener future.

Integrating AI, cloud storage, and predictive analysis will further empower it with greater strength to be a future beacon for water preservation.

As global water scarcity remains a pressing concern, implementing such smart water management solutions will be key to ensuring the effective use of water, minimizing waste, and ensuring sustainability for future generations.

Declaration of Interest

I affirm that no conflict of interest of any sort, financial, professional, or personal, concerning this research on water leakage detection has played a role in influencing the results and conclusions of this study.

All data sources, methods, and technologies used in this study were properly attributed. This research was solely conducted for scholarly purposes and the objectives of aiding efficient water conservation and management.

I also hereby guarantee that this is an original work not submitted for assessment or publication anywhere else. All similarities to preexisting works are coincidental or properly referenced.

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