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FlowTrace: Advanced Leak Response Framework

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Abstract: Water leakage is a major problem in urban water distribution networks and domestic supply systems. It leads to significant resource waste, damage to infrastructure, and substantial economic loss. Although several IoT and ML-based systems have developed over the past ten years for leak detection and system improvement, many current methods do not provide real-time control, early fault prediction, or user-friendly consumption insights. This paper presents the latest IoT- enabled leak detection system that focuses on sensor deployment methods, data collection techniques, and efficient communication over the network. To address the identified research gaps, we propose FlowTrace, an innovative and intelligent IoT frame work that integrates four core solutions i.e., automatic shut-off control, water usage tracking, leak severity classification, and pressure drop-based early detection.

Keywords: IoT, Smart water management, Leak detection, Flow sensors, Pressure sensors, Solenoid valve, Automatic shut- off, Water usage tracking, Leak severity classification, Early leak detection, Machine Learning.

I. INTRODUCTION

Water is one of the most essential yet limited natural resources needed for life and growth. According to the United Nations World Water Development Report 2023, over 30% of the world's water supply is lost each year due to leaks in various pipelines and distribution networks. Thus resulting in significant financial and environmental losses. Traditional leak detection often relies on manual inspection or visual observation. This approach is time-consuming, labour intensive, and is often ineffective at identifying minor or hidden leaks, especially in complex network systems. The Internet of Things (IoT) has changed how we manage water at a lower cost by allowing for real-time sensing, data transmission, and automatic decision-making. IoT-based systems can continuously monitor flow rates, pressure, moisture, and other parameters. They securely send the collected data to cloud platforms for analysis and visualization. When paired with Machine Learning algorithms, these systems can become predictive, helping to identify unusual water usage patterns and detect any early signs of potential leaks before major bursts occur. However, many existing IoT and ML-based leak detection frameworks are reactive. They identify leaks only after significant water losses or damages have happened. There is a major concern for systems that can detect leaks, prevent damage, classify severity, and offer valuable insights to users.

To fill these gaps, this paper introduces FlowTrace, an innovative and cost-effective IoT framework that combines four essential functions into one system:

1) Automatic shut-off control for preventing active leaks.
2) Water usage tracking for monitoring and analysis.
3) Leak severity classification for alerts based on severity.
4) Pressure drop-based early detection for finding any hidden leaks.

FlowTrace uses real-time sensing, data processing, and actuation through a microcontroller-based design, which improves accuracy, efficiency and responsiveness in managing water leaks. Additionally, it also enhances traditional detection systems with user-focused analytics that track the water consumption and sends early maintenance alerts to the user. This paper also assesses conventional and recent IoT- based methods to identify the research gaps and design flaws in current frameworks.

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From this evaluation, FlowTrace emerges as a proactive, intelligent, and user-friendly solution that combines detection, prevention, and monitoring into a single IoT framework for sustainable water management.

II. LITERATURE REVIEW

Several studies have looked into IoT and ML technologies for smart water leakage detection and monitoring. For instance, a hybrid IoT and ML model that uses ultrasonic sensors to identify normal and leak conditions was proposed in 2021. However, with its high detection accuracy, it requires a lot of computation and lacks preventive control [1]. Similarly, in 2020, a wireless network of flow and pressure sensors was proposed for locating leaks in municipal pipelines. While this method improves detection accuracy, it is more expensive to design and is a better fit for industrial environments rather than home use [2]. A review published in 2022 highlighted the transition from manual inspection methods to automated IoT-based systems that use wireless communication standards like Zigbee and LoRa. However, the review pointed out that challenges such as poor power efficiency, high maintenance costs, and limited intelligence still exist [6]. Another recent study in 2024 examined LoRa WAN-based remote monitoring for large- scale networks; it found that this approach reduces power consumption and increases communication range. However, it has some drawbacks, particularly latency issues from relying on the cloud that reduce real-time performance [3]. Table I represents the comparison of IoT and ML-based systems for water leakage detection. While the previous works indicated a meaningful level of detection accuracy, there was no automation for prevention, and no analytics for user-level. The proposed system FlowTrace would address these issues with real-time control, early detection, and intelligent data monitoring procedures.

Table I. Comparative Analysis

System	Communication	Key Feature	Limitation
IoT + ML Ultrasonic System	Wi-Fi	High accuracy ML classification	Lacks real-time shut-off
IoT Localization System	Mesh	Leak Localization	High energy cost
Review on Technologies	-	Predictive overview	No implementation
LoRa WAN Detection	LoRaWAN	Long-range monitoring	No user analytics
FlowTrace	Wi-Fi/LoRa	Detection+ Prevention + Analytics	Prototype stage

A consistent issue across these studies is that most systems are still reactive, meaning they detect leaks only after water leak has happened. Very few systems offer proactive prevention, user-level analytics, or automatically controlled mechanisms. To address these gaps, the FlowTrace framework proposes a simple and low-cost IoT solution that combines automatic shut-off control with monitoring water usage, classifying leaks everity, and early detection based on pressure drop. This approach aims to move from reactive detection to proactive management.

METHODOLOGY

The proposed frame work, FlowTrace, addresses the issues of current IoT-based water leakage systems by combining real-time sensing, intelligent analysis, and preventive response within a cost-effective platform. Unlike traditional reactive systems, FlowTrace includes four coordinated modules: detection, prevention, monitoring, and intelligence for complete leak management.

A. System Architecture

The FlowTrace system uses an ESP32 microcontroller as both a processor and communication unit. It connects to many distributed sensors that continuously monitor hydraulic and environmental parameters.

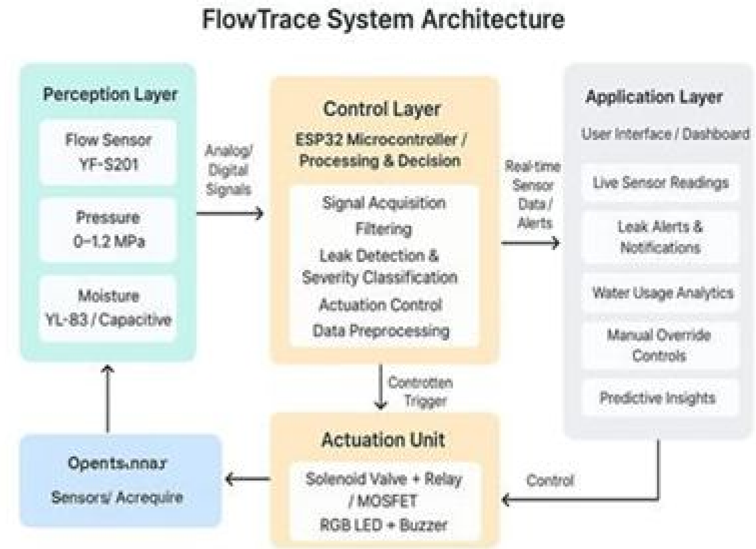

Fig.1. System Architecture

These sensors include the flow sensor (YF-S201), pressure transducer (0-1.2 Mpa), and moisture pads (YL-83).The locally processed sensor readings are sent over Wi-Fi or, longer distances, using LoRa/GSM. All data is logged into a cloud database that users can visualize and analyze through a web portal, using Thing Speak.

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B. Automatic Leak Prevention and Control

The solenoid valve automatically stops the flow of water during severe leaks. The relay module isolates the low-voltage control logic (3.3V) from the 12V solenoid circuit, providing the necessary power. If a high flow rate and a pressure drop are detected, the ESP32 triggers the valve closure to avoid false alarms. A manual reset ensures that restoration occurs only after corrective action.

C. Water-Usage Tracking and Behavioral Analysis

Using the YF-S201 flow sensor, FlowTrace tracks flow rate and total water consumption in real-time. Data analytics like threshold deviation and moving-average smoothing helps detect unusual consumption patterns, such as night time water flow. Visualizations, like cloud dashboards and daily summaries, aim to improve user awareness and water conservation efforts.

D. Leak Severity Classification and Alerts

FlowTrace classifies leak severity based on the level of deviation from flow, pressure, and moisture readings:

- Level 1(Low): Minor drips, intermittent moisture (less than 10% deviation)
- Level 2(Medium): Continuous leakage with a medium pressure loss of 10-30%
- Level 3 (High): Major bursts with more than 30% flow deviation or more than 20% pressure drop

Alerts are signaled through LEDs (green, yellow, red) and an audible piezo buzzer. A manual push button allows users to silence alarms or reopen the solenoid valve.

E. Pressure Drop Based Early Detection

The pressure transducer continuously monitors pipeline pressure, the ESP32 detects gradual pressure drops, pinpointing hidden micro-leaks or cracks. This early-warning capability is not available in traditional systems.

F. Communication and Web Integration

FlowTrace takes advantage of the ESP32's built-in Wi-Fi to send sensor data to the cloud for real-time visualization. Through the responsive web dash board, users can view real- time flow, pressure, valve status, and leak severity. When an anomaly is detected, graded alerts are sent via messages, or dashboard notification. LoRa integration allows for scalable deployment in rural or municipal grids, maintaining low power usage.

G. Power and Safety Design

The system runs on a 12 V DC supply that is stepped down to 5 V using an LM2596 buck converter. A 2 A fuse and transient suppression diodes offer protection against over current and voltages pikes. A Li-ion backup battery with a TP4056 charging module ensures uptime during outages. All components are housed in an IP65 enclosure for water resistance and safety. The overall hardware interconnection of the sensors, actuators, and control units in shown in Fig.2.Itshowshow the power supply, sensing units,ESP32 controller, and output modules are integrated to achieve an automated leak detection, prevention, and alerting

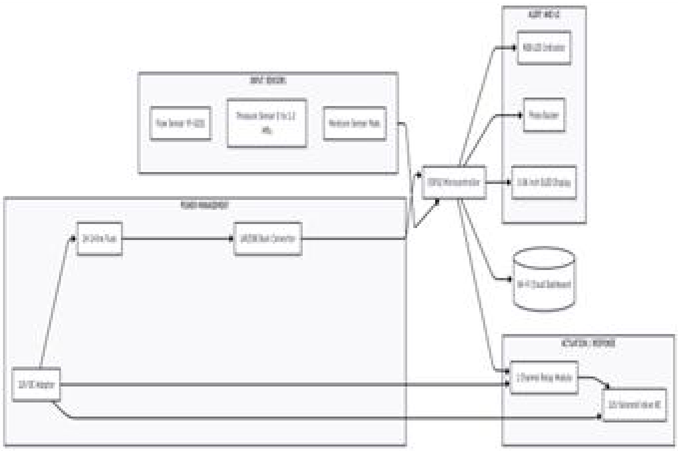

Fig. 2. Hard ware Block Diagram

H. System Work flow

- Sensors for flow,pressure, and moisture continuously collect data.
- The ESP32 processes and analyzes signals to find anomalies.
- Severity classification decides the alert and solenoid valve control logic.
- Data is sent to the cloud for storage and visualization.
- Users receive real-time notifications and access to live dashboards.

The work flow of the proposed FlowTrace system is shown in Fig. 2. Sensor nodes collect flow/pressure real-time data, which is sent to the cloud plat form.

The ML-based detection module processes the data and determines the existence of leaks and their severity. The cloud serves alerts and visualizations to users on the dashboard and sends automatic notifications for maintenance when possible. At the same time, IoT node executes solenoid valve control to avoid water waste while major leaks are occuring.

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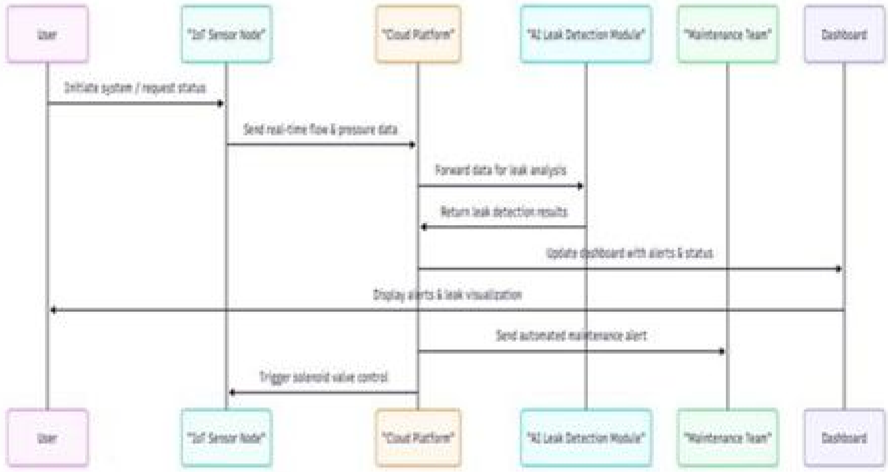

Fig.3. System Work flow

I. Prototype Implementation

A prototype was built using PVC pipes and a 10-L tank, featuring leaks of different diameter to simulate different scenarios: drip, moderate leak, and burst.

J. Limitations and Future Scope

While FlowTrace functions reliably, some limitations still exist:

- Limited AI Integration: The current rule-based thresholds can be improved with TinyML for better prediction.
- Internet Dependency: Wi-Fi disruptions can delay alerts; local caching can help.
- Environmental Effects: Temperature and humidity may influence sensor accuracy.

Future work will involve integrating lightweight machine learning algorithms for predictive maintenance and expanding the system to smart city water networks with hybrid cloud-edge intelligence.

RESULTS AND DISCUSSION

The proposed FlowTrace, an IoT-based smart water leakage detection and management system, was implemented and tested on a prototype pipeline model to assess its performance in detecting, alerting, and preventing water leaks in real time. It combines multi-sensor data collection with dual communication modes, LoRa and GSM, for scalable and remote supervision.

A. Experimental Setup

The hardware included an ESP-32 38-pin NodeMCU-32 Dev Board as the central processing unit. This was then connected to a YF-S201 water flow sensor, a soil moisture sensor, and a pressure sensor. Additionally, a 5V active-low relay module was used to operate a 12V solenoid valve for controlling the water flow during leak conditions. The buck converter maintained voltage stability for the connected components while an OLED module displayed real-time readings. LoRa Ra 01 and SIM800L modules enabled long- range and GSM-based data transmission.

B. System Testing and Sensor Response

These conditions included Normal Flow, a Minor Leak, and a Major Leak. We continuously logged flow, pressure, and moisture readings. We then compared these readings for deviations that indicated any potential leak events. The analysis of the data showed that during leaks, pressure decreased while moisture increased. Major leaks had immediate spiked in flow and a related rise in moisture content. Minor leaks displayed a slower but steady drift pattern.

TABLE II. Experimental Readings and System Response

Condition	Flow Sensor Reading (L/min)	Pressure(Pa)	Moisture (%)	System Status	Output Action
Normal Flow	3.5–6.5	Stable($1.2x\ 10^8$)	<20	Normal Operation	No Alert
Minor Leak	1.0–2.5	Slight Drop	35 –50	Warning Stage	LED Warning
Major Leak	>8	Sharp Drop	>70	Critical	Valve OFF+ Buzzer +SMS alert

C. Dashboard and Communication Results

We visually represented the real-time sensor data on the FlowTrace dashboard using an OLED and cloud interface. This setup allowed users to see flow rate, pressure, and moisture parameters all at once. LoRa-based data transmission achieved an average range of about 2.5 km with packet loss below 3%. GSM-based SMS alerts provided additional support during network downtime. The dashboard visualization indicated that alerts were triggered within 1.8 seconds of detecting a leak.

D. Discussion

This proposed system combines sensor fusion, automated actuation, and dual-channel communication in tone compact system. The results confirm FlowTrace's potential to detect and respond to leakage conditions in near real-time while ensuring energy efficiency and reliability. Future work will incorporate predictive analytics with cloud-based data learning to optimize threshold calibration and further enhance early warning capability.

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Fig.4. Cloud Dash board for real-time leak monitoring and analytics

CONCLUSION AND FUTURE WORK

This work presents FlowTrace, an IoT framework designed to improve water leakage management through smart sensing, preventive control, and user-focused monitoring. The paper reviewed current IoT methods and highlighted some key issues: reactive detection methods, limited data integration, and low user engagement. FlowTrace combines automatic shut-off control, tracking water usage, classifying leak severity, and detecting leaks early based on pressure within a cost-effective platform.

The FlowTrace system offers a solid base for smart water management. It opens up important opportunities for improvements in scalability, intelligence, and automation. Future development may focus on the following:

AI-Driven Leak Prediction: Integrating machine learning models to identify pipeline stress, which helps detect potential leaks or pressure drops before failures occur?

Cloud Analytics and Visualization: Creating a mobile application dashboard for real-time analytics, tracking historical data, and controlling valves remotely.

Energy Autonomy: Developing solar-powered charging systems that enable continuous operation in remote or off-grid locations, boosting the system's sustainability.

Network Scalability: Expanding the system into a multi-node LoRa mesh network to support large-scale pipeline monitoring across city grids, farms, or industrial areas.

REFERENCES

1. M.R.Islam, S.Azam, B.Shanmugam and D.Mathur,"An Intelligent IoT and ML-Based Water Leakage Detection System," IEEE Access,vol. 11, pp. 123625-123649, 2021.
2. M.A.Ayamga and C. I. Nakpih,"IoT-Based Water Leakage Detection and Localization," in Proc. IEEE Global Conference on Internet of Things,2020.
3. M.Essouabni,J.ElMhamdi and A.Jilbab," Advanced IoT Techniques for Detecting Water Leaks in Supply Networks with LoRa WAN," IEEE Access, vol. 12, pp. 14521-14530, 2024.
4. Y. P. Kumar, R. J. Pravachana, S. K. Dilshad and M. Jhansi, "IoT-Based Water Leakage Detection using Machine Learning Approach," in Proc. Int. Conf. on Communication and IoT Systems, 2024.
5. O.Atanane,A.Mourhir,N.Benamar and M. Zennaro, "Smart Buildings: Water Leakage Detection Using Tiny ML, "IEEE Internet of Things Journal, vol. 10, no.2, pp. 1554-1565, 2023.
6. M.R. Islam,S. Azam, D.Mathur and B. Shanmugam," A Review on Current Technologies and Future Directions of Water Leakage Detection in Water Distribution Networks,"IEEEAccess,vol.10,pp.118021-118041,2022.
7. A.Vijayan,R.Narwade and K.Nagarajan,"Real-Time Water Leakage Monitoring System Using IoT-Based Architecture," in Proc. IEEE Int.Conf. on Communication and Electronics Systems, 2019.
8. B.Bakhtawar, A.Fares and T.Zayed, "A IoT-Driven Leak Detection in Real Water Networks Using Hydrophones," Water ResourcesManagement,2024.
9. X.Li, et. al., "Water Leak Detection and Localization with IoT and Light weight Deep Learning," IEEE Trans. On Instrumentation and Measurement, vol. 72, pp. 1-10, 2023.
10. S.Rajalakshmi,P.K.Reddy and A. Suresh, "IoT-Based Real-Time Water Leakage Detection using Cloud and Wireless Sensor Networks," in Proc. IEEE Int.Conf .on Sustainable Computing and Systems,2023