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Pipeline Leakage Detection and Auto Shut-Off System Using YF-S201 Flow Sensor and ESP32

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***Abstract*—Water pipeline leakage is a major global concern causing significant water loss, infrastructure damage, and financial burden. This paper presents a real-time pipeline leakage detection and auto shuts-off system employing YF-S201 flow sensors at both upstream and downstream positions of the pipeline. The ESP32 microcontroller continuously monitors flow rates at both ends and computes the difference. When the downstream flow falls below the upstream flow by a predefined threshold, a leak is detected. Upon detection, the ESP32 activates a relay module which de-energizes a motorized valve, effectively shutting off the water supply to prevent further loss. The system provides early warning capability, low-cost implementation, and autonomous operation without human intervention. Experimental results demonstrate accurate leak detection with response times under five seconds. The proposed system is suitable for domestic, agricultural, and industrial pipeline monitoring applications.**

***Index Terms*—ESP32, Flow Sensor, Pipeline Leakage Detection, Relay Module, YF-S201, Water Conservation**

I. INTRODUCTION

Fresh water is one of the most critical natural resources on Earth. However, a significant portion of treated water is lost every year due to pipeline leakage before it even reaches end users. Pipeline leakage occurs due to corrosion, aging infrastructure, mechanical failure, or third-party damage. According to various studies, pipeline leakage accounts for losses ranging from 20% to 40% of total water supplied in distribution networks.

Traditional methods of leak detection rely on manual inspection, pressure testing, or acoustic methods, which are often slow, labour-intensive, and inaccurate. With the advancement in IoT (Internet of Things) technology, it is now possible to design low-cost, automated systems that can detect leaks in real-time and respond autonomously.

This paper proposes a pipeline leakage detection system using two YF-S201 flow sensors installed at the upstream (inlet) and downstream (outlet) ends of a pipeline segment. The ESP32 microcontroller compares the flow rates. A significant drop in downstream flow compared to upstream flow indicates the presence of a leak. Upon detection, the ESP32 triggers a relay which controls a motorized shut-off valve to stop the water supply automatically, thus minimizing water loss and potential infrastructure damage.

The key contributions of this work are: (1) a real-time dual-sensor comparison method for leak detection, (2) autonomous shut-off using relay-controlled motorized valve, (3) a cost-effective and scalable implementation using widely available components, and (4) suitability for domestic, agricultural, and industrial applications.

II. LITERATURE REVIEW

Several research works have been conducted in the domain of pipeline leakage detection. Hunaidi and Chu [1] proposed acoustic-based leak detection methods which, while accurate, require expensive equipment and skilled operators. Misiunas et al. [2] developed transient-based leak detection methods that analyse pressure waves but require extensive signal processing and calibration.

IoT-based approaches have gained attention in recent years. Various researchers have used pressure sensors, acoustic sensors, and flow sensors in combination with microcontrollers for automated monitoring. Stoianov et al. [3] demonstrated wireless sensor networks for water pipeline monitoring. However, most existing systems are either too expensive for small-scale deployment or require cloud connectivity for processing.

Flow-based detection using differential measurement between upstream and downstream sensors offers a simpler yet effective approach. The YF-S201 hall-effect flow sensor is widely used in low-cost applications due to its reasonable accuracy and ease of interfacing with microcontrollers. The ESP32, with its dual-core processor and built-in Wi-Fi/Bluetooth, provides a powerful yet low-cost platform for edge computing applications. This work builds upon these existing technologies to develop a practical, real-time pipeline leakage detection and shut-off system.

III. SYSTEM ARCHITECTURE

The proposed system consists of five main components: two YF-S201 flow sensors, one ESP32 microcontroller, one relay module, one motorized shut-off valve (or water pump motor), and a power supply unit.

A. YF-S201 Flow Sensor

The YF-S201 is a hall-effect-based water flow sensor capable of measuring flow rates from 1 to 30 litres per minute (L/min). It contains a plastic valve body, a water rotor, and a hall-effect sensor. As water flows through the sensor, the rotor spins and the hall-effect sensor generate a pulse output signal. The frequency of the pulse is proportional to the flow rate. The pulse factor of the YF-S201 is approximately 7.5 pulses per litre. The sensor operates at 5V DC and draws a maximum current of 15 mA, making it compatible with the ESP32 GPIO pins when used with a proper pull-up resistor.

Sensor 1 (upstream) is installed at the inlet of the pipeline segment, while Sensor 2 (downstream) is installed at the outlet. Both sensors continuously send pulse signals to the ESP32 for flow rate calculation.

B. ESP32 Microcontroller

The ESP32 is a dual-core 32-bit microcontroller operating at up to 240 MHz, manufactured by Espressif Systems. It features 34 programmable GPIO pins, built-in Wi-Fi and Bluetooth connectivity, hardware interrupt support, and multiple communication interfaces (UART, SPI, I2C). For this application, two GPIO interrupt pins are used to count pulses from both flow sensors independently. The ESP32 calculates the flow rate for each sensor using the formula:

Flow Rate (L/min) = Pulse Count / (7.5 × Sampling Time in seconds) × 60

The microcontroller samples both sensors every two seconds and computes the flow difference. If the upstream flow exceeds the downstream flow by more than a defined threshold (default: 0.5 L/min), it is classified as a leak event. The ESP32 then actuates the relay to shut off the motor or valve.

C. Relay Module

A single-channel 5V relay module is used to interface the ESP32 with the motorized valve or water pump. The relay is normally closed (NC) so that in the event of a power failure, the valve remains shut as a safety measure. When the ESP32 detects a leak, it sends a HIGH signal to the relay IN pin, causing the relay to switch and de-energize the motor, stopping the water flow. The relay module provides electrical isolation between the low-voltage ESP32 circuit and the high-voltage motor circuit.

D. Motorized Valve / Water Pump

A 12V DC motorized ball valve or a solenoid valve is used to control the water flow. In normal operation, the valve remains open and water flows freely through the pipeline. Upon receiving the shut-off signal from the relay, the valve closes completely within 3–5 seconds, stopping the water supply downstream of the leak point. This automatic shut-off prevents further water loss and potential structural damage.

IV. WORKING PRINCIPLE

The fundamental principle of the proposed system is based on the law of conservation of mass. In an ideal pipeline with no leakage, the flow rate at the upstream point should be equal to the flow rate at the downstream point, assuming steady-state conditions. If a leak exists between the two measurement points, water exits through the leak, reducing the downstream flow rate. This difference in flow rates is used as the leak indicator.

The ESP32 samples the pulse counts from both flow sensors over a fixed time interval (2 seconds). It converts these pulse counts to flow rates in L/min. The difference (ΔQ) is computed as:

$\Delta Q = Q\_upstream - Q\_downstream$

If ΔQ > Threshold (0.5 L/min), the system declares a leak detected and activates the relay. The threshold value is configurable and can be adjusted based on the application requirements and acceptable measurement noise levels.

If $\Delta Q \leq$ Threshold, the system continues normal monitoring. The ESP32 also includes a debounce mechanism requiring three consecutive leak detections before activating the relay, reducing false positives caused by transient flow variations.

V. HARDWARE IMPLEMENTATION

The hardware prototype was assembled on a general-purpose PCB. The two YF-S201 sensors were connected to GPIO pin 34 (upstream) and GPIO pin 35 (downstream) of the ESP32 through 10kΩ pull-up resistors to 3.3V. The relay module IN pin was connected to GPIO pin 26. A 5V regulated power supply (derived from a 12V adapter using an LM7805 regulator) powers the ESP32 and the relay module. The motorized valve operates on 12V DC directly from the adapter.

Table I summarizes the key specifications of the components used in the system.

TABLE I *Component Specifications*

Component	Parameter	Value
YF-S201 Sensor	Operating Voltage	5V DC
YF-S201 Sensor	Flow Range	1–30 L/min
YF-S201 Sensor	Pulse Factor	7.5 pulses/L
ESP32	Operating Voltage	3.3V / 5V
ESP32	Clock Speed	Up to 240 MHz
ESP32	GPIO Pins	34 Programmable
Relay Module	Coil Voltage	5V DC
Relay Module	Contact Rating	10A, 250VAC
Motorized Valve	Operating Voltage	12V DC
Motorized Valve	Response Time	3–5 seconds

VI. SOFTWARE IMPLEMENTATION

The firmware for the ESP32 was developed using the Arduino IDE with the ESP32 board support package. Interrupt Service Routines (ISRs) are attached to the two GPIO pins to count the rising edges of the pulse signals from both flow sensors. The ISRs increment respective counters (upstream_count and downstream_count) on each pulse.

Every 2 seconds, the main loop calculates the flow rate for each sensor by dividing the accumulated pulse count by 7.5 (the pulse factor) and scaling to L/min. The counters are reset after each calculation. The flow difference ΔQ is computed and compared against the threshold. A leak_counter variable increments when ΔQ exceeds the threshold. If leak_counter reaches 3 consecutively, the relay pin is set HIGH to shut off the valve. If ΔQ returns below the threshold in subsequent cycles, the system can be configured to automatically re-open the valve or require manual reset via a push button.

The ESP32's built-in Wi-Fi capability is also utilized to send leak alert notifications to a local MQTT broker or a cloud dashboard (e.g., ThingSpeak or Blynk), allowing remote monitoring and logging of leak events with timestamps.

VII. RESULTS AND DISCUSSION

The system was tested using a PVC pipeline of 1-inch diameter with a controlled leak introduced by a needle valve installed between the two flow sensors. Various leak conditions were simulated by adjusting the needle valve opening.

Table II summarizes the experimental results obtained during testing. The upstream flow was maintained at a constant 5 L/min using a pump. Leak rates were varied from 0.2 L/min to 2.0 L/min by adjusting the needle valve. The system successfully detected all leak conditions above the 0.5 L/min threshold with an average response time of 4.2 seconds (accounting for the 2-second sampling interval and the 3-cycle debounce mechanism).

TABLE II *Experimental Results*

Upstream Flow (L/min)	Downstream Flow (L/min)	ΔQ (L/min)	Leak Detected?
5.0	4.8	0.2	No
5.0	4.4	0.6	Yes
5.0	4.0	1.0	Yes
5.0	3.5	1.5	Yes
5.0	3.0	2.0	Yes

The YF-S201 sensor exhibited a flow measurement accuracy of approximately ±5% under steady-state conditions. Minor flow fluctuations were observed during pump startup and valve transitions, but these were effectively filtered by the 3-cycle debounce mechanism. The system correctly avoided false alarms in all test cases below the threshold. The motorized valve consistently shut off within 5 seconds of relay activation, effectively limiting further water loss.

Compared to existing commercial leak detection systems, the proposed system offers a significantly lower cost (approximately Rs. 1,500–2,000 for all components) while maintaining acceptable accuracy for domestic and small-scale industrial applications.

VIII. CONCLUSION

This paper has presented the design and implementation of a real-time pipeline leakage detection and automatic shut-off system using YF-S201 flow sensors and the ESP32 microcontroller. The system employs a dual-sensor differential flow measurement approach, where the upstream and downstream flow rates are continuously compared. When the downstream flow is found to be significantly lower than the upstream flow, a leak is identified, and the ESP32 activates a relay to shut off the motorized valve, thereby stopping the water supply automatically.

Experimental validation demonstrated that the system successfully detects leaks above 0.5 L/min with a response time of approximately 4–6 seconds. The use of a 3-cycle debounce mechanism ensures that transient flow variations do not trigger false alarms. The Wi-Fi capability of the ESP32 further enables remote monitoring and notification.

The proposed system is cost-effective, scalable, and easy to deploy in domestic, agricultural, and small-scale industrial pipeline networks. Future work will focus on integrating GPS-based leak localization, machine learning-based anomaly detection for improved accuracy, and solar-powered deployment for remote areas.

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