

INTERNET OF THINGS-BASED WATER PIPE LEAK DETECTION SYSTEM

Daffa Hanif Widyatma¹⁾, Anhar²⁾, Ery Safrianti³⁾ and R.A Rizka Qori Yuliani Putri⁴⁾

^{1, 2, 3, 4)} Teknik Elektro, Universitas Riau,

Kampus Bina Widya, KM. 12,5 Pekanbaru, Riau 28293

e-mail: daffa.hanif1471@student.unri.ac.id¹⁾, anhar@lecturer.unri.ac.id²⁾, esafrianti@eng.unri.ac.id³⁾, rizkaqoriyulianiputri@lecturer.unri.ac.id⁴⁾

ABSTRACT

Leaks in pipelines are a very important issue and should not be underestimated in terms of handling and resolution. If a leak in a pipe is not addressed immediately, it can cause adverse effects, such as a decrease in water flow efficiency, and in some conditions, it can even stop the flow of water completely. Therefore, a water pipe leak detection system is needed to be implemented in homes. In this research, a prototype of a water pipe leak detection system consisting of a 4-branch and a T-branch was built to simulate piping conditions in users' homes. This system uses a water flow meter sensor as a leak detection sensor by comparing the difference in water discharge readings between sensors. meter water flow sensor is a sensor that is very suitable for this task. The water flow meter sensor works on the principle of hall effect and can read the water flow rate precisely and accurately with a reading accuracy of 6–10%. The system is IoT connected to blynk for easy monitoring and maintenance by the user. From 10 experiments conducted, the system successfully detected leaks with 100% success rate. The delay that occurs when sending data from the microcontroller to blynk is 67 ms.

Keywords: Blynk, detection system, water flow meter, water pipe leakage

I. INTRODUCTION

INDONESIA faces major challenges in meeting water needs as its population grows. The issue of water scarcity has been a concern since 1998 and is worsening, particularly in the capital and several areas of Java Island. Ironically, this occurs despite more than 70% of Indonesia's territory being water. Water scarcity occurs when demand exceeds availability [1][2]. Leaks in pipes are a serious problem that can reduce efficiency or stop water flow if not addressed promptly [3]. In 2023, leaks resulted in the wastage of 708 million m³ of clean water, equivalent to 12.87% of total national production [4]. The main causes are old and poorly maintained pipe infrastructure, as well as unstable water pressure in the distribution system [5].

The methods currently used to detect leaks are still often done manually, for example, by checking directly at the distribution location or based on reports from users about leaks [6]. This method is less effective because it takes a long time to detect leaks [7]. To increase efficiency and effectiveness in handling leaks, it is necessary to develop a more sophisticated detection system that utilizes automatic sensor technology and is connected via the Internet of Things (IoT) to users.

IoT systems have been used in detecting water leaks. Suriya [8] developed a prototype water leak detection system using two flow sensors and a solenoid valve. When a leak is detected, the valve closes automatically, sending a notification to the operator. The research [9] proposed a design for a water pipe leak detection system with a liquid flow meter at the end of the circuit, which detects leaks if the water discharge is lower than the normal value. Perdana [10] initiated a pipe leak

detection system using a water flow sensor and solenoid valve which can close the water flow if there is a leak. The study [11] aims to explore the effectiveness of thermography as a non-destructive technique for detecting leaks in embedded pipes through heat transfer analysis from periodic thermal images. In the research [12], the authors designed a water pipe leak detection system based on a water flow sensor with low power consumption and a WSN network to expand the range.

The leak detection system in this research differs from previous research. In previous studies, solenoid valves were not commonly used to cut off water flow, and the sensors employed tended to be expensive, rendering them unsuitable for water leak detection systems, particularly in homes. In addition, the GUI system is built on a web-based platform and is difficult for users to access. Therefore, this research proposes a prototype for water leak detection using an Android-based application to make it easier for users to monitor and configure their devices. This prototype is also equipped with a buzzer to inform of a leak. This prototype design is very suitable for home applications because the testing is adapted to the characteristics of the water distribution system in households. The sensors and solenoids used are energy-efficient and low-cost so that they can be applied effectively in the field.

II. METHOD

To design the leak detection system, we develop software and hardware that becomes a physical model of a functioning system and is an early, useful version of the system.

A. System Planning

This system planning utilises the Node MCU ESP 8266 module, which is used as a microcontroller and data processor to obtain data from the water flow sensor. The data is then processed and sent to Blynk and the solenoid valve for monitoring and action. The flow meter sensor used in this prototype measures the flow rate or volume of fluid flowing in the pipe. The Flow Meter Sensor uses a rotor that rotates when water flows. This rotor is connected to a microcontroller that is capable of calculating the number of revolutions per minute (RPM) [13][14].

A solenoid valve is used in this prototype to shut off the water flow when a leak is detected. When an electric current activates the solenoid coil, the resulting magnetic field will move the poppet or plug. On a normally operated solenoid valve, open (NO), the magnetic field will pull the poppet or plug down, thus closing the fluid flow [15][16]. The prototype can be seen in Fig. 1.

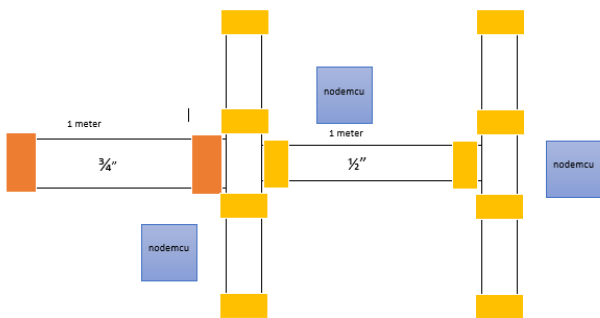


Figure 1. Prototype Design of Water Pipe Leak Detection System

The prototype design uses pipes with sizes of $\frac{3}{4}$ inch and $\frac{1}{2}$ inch to adapt to actual conditions in home installations [17]. The *cross 4* and *letter T* branches are also intended to simulate the piping conditions in the house where there are many branches. The system consists of 12 *water flow* sensors controlled by 3 microcontrollers to monitor 6 pipe sections.

In each section of the pipe there will be 2 water flow sensors, 1 at the beginning and 1 at the end of the pipe. The results of the water discharge readings from each sensor will then be compared and the difference calculated. If the difference in water discharge exceeds the previously set threshold value, the system will conclude that a leak has occurred [18]. The working system of the pipe leak detection system can be seen in Figure 2, the following is an explanation of each step in the diagram:

1. Microcontrollers and sensors are mounted on a series of pipes
2. Start by turning on the *power* supply from the power bank, then each flow meter sensor will read the water flow passing through the pipe.
3. The data from the sensor will be sent to the microcontroller for analysis and comparison of data between sensors. If there is a difference in the

value of the water discharge data above the pre-determined threshold value, the system will detect a leak in the water pipe.

4. Once a leak is detected, the system will give a command to the solenoid valve *at* the beginning of the pipe circuit to close the water flow valve.
5. All data can be monitored via blynk. After repairs are made to the water pipe line, the *solenoid valve* can be opened via the blinker.
6. Finished.

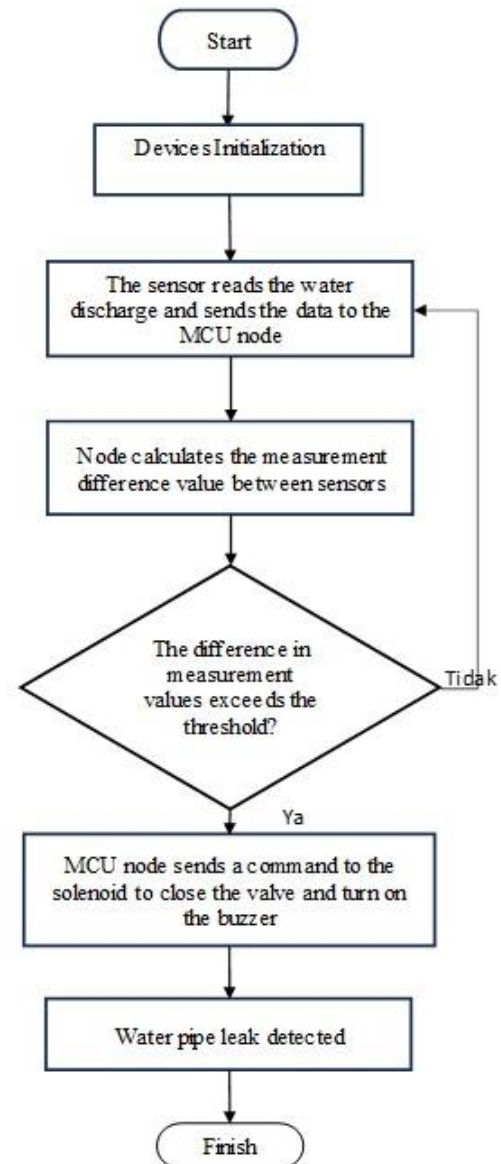


Figure 2. System Design Flowchart

B. Electrical Circuit Design

The design of the electrical circuit in this system aims to simulate the arrangement of electronic components virtually, so as to minimize the risk of errors during the physical assembly process. This design process was carried out using the Wokwi platform.

In Fig. 3, it can be seen that the system uses one microcontroller connected to four flow meter sensors for

each section. These four sensors will read the water discharge in two pipe sections, with two sensors in each pipe section. The water discharge data that has been read will be sent to the microcontroller for comparison between the sensors. If the difference in discharge between sensors exceeds the set limit, the microcontroller will conclude that there is a water pipe leak. The buzzer will then sound, and a notification will be sent to Blynk.

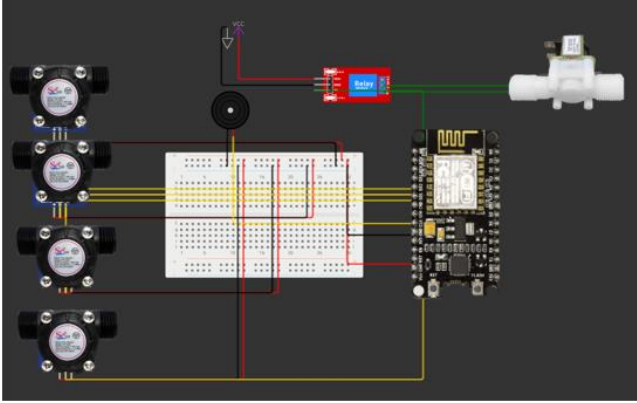


Figure 3. Leak Detection System Circuit

C. Blynk Interface Design

In this system, the application interface is designed not only as a means to execute system commands or functions, but also to provide an intuitive and efficient user experience [19]. This application plays an important role in the monitoring and control process of sensors connected to the NodeMCU microcontroller, and it's easy for people to use[20]. Through this interface, users can monitor data in real-time and remotely control devices, thereby supporting overall system performance in terms of effectiveness and ease of operation.

The Blynk interface is shown in Fig. 4. A switch at the top is helpful for manually opening and closing the valve. The pipe status for each piece is then shown below.

D. Prototype Testing

The purpose of prototype testing is to identify errors present in the system and to implement necessary revisions. This phase is crucial for guaranteeing that the system operates without errors.

1) Water Flow Meter Sensor Testing

Water flow sensor testing is carried out by comparing the water volume value read by the sensor with the water volume measured with a measuring cup. The test also tests the minimum water discharge value that can be read by the sensor. The difference between the value read by the sensor and the actual value will be calculated as the error value[21]. These two tests were carried out to determine the capability and accuracy of reading water discharge data carried out by the *water flow* sensor.

2) System Testing

System testing is carried out by simulating water pipe leaks in the circuit with various test scenarios. The conditions tested were leaks when the tap was in use, leaks

when the tap was not in use, small leaks, medium leaks, and moderate leaks. This test aims to see whether the system can detect leaks accurately and also determine the appropriate threshold value for this system.

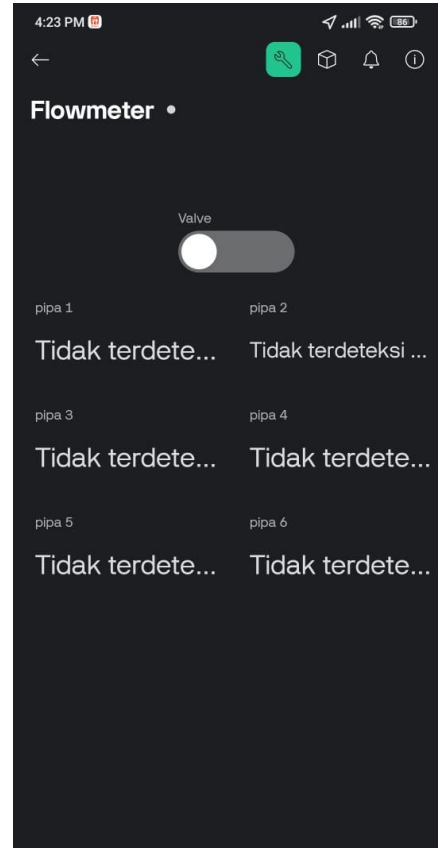


Figure 4. Blynk Interface

3) Delay Testing

Delay testing involves measuring the time it takes for data and notifications to reach Blynk. This test is performed by recording the time before sending the notification and when the user receives it. The goal of delay testing is to determine how long it takes to send data to Blynk.nk.

III. RESULTS AND DISCUSSION

A. Water Flow Meter Sensor Sensitivity Testing

The water flow sensor sensitivity test was carried out 10 times. Table 1 shows the results of the minimum water discharge measurements that can be read by the water flow sensor, namely 133 and 220 mL/min. Of the 10 tests conducted, a minimum water discharge of 220 mL/min dominated the test results. This is because the water discharge of 133 mL/min is too small, so it is difficult to simulate it.

B. Volume Comparison Test

Volume comparison testing was carried out on sensor 1 and sensor 2. The volumes tested were 500 mL and 1000 mL and testing was carried out 10 times for each volume and sensor.

TABLE I
WATER FLOW SENSOR WATER DISCHARGE MEASUREMENT RESULTS

No	Minimum readable flow (mL/Min)
1	220
2	220
3	133
4	220
5	133
6	220
7	220
8	220
9	133
10	220

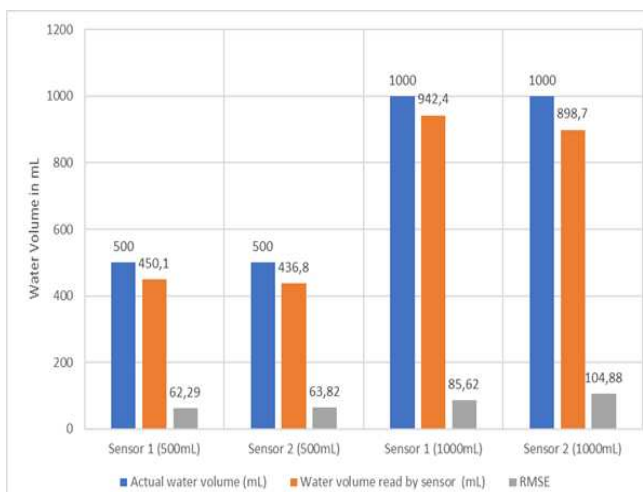


Figure 5. The comparison between the actual water volume, the volume measured by the flow sensors, and the corresponding RMSE

Fig. 5 presents the comparison between the actual water volume, the volume measured by the flow sensors, and the corresponding RMSE (Root Mean Square Error) values for each sensor at two test volumes (500 mL and 1000 mL).

For the 500 mL tests, Sensor 1 recorded an average reading of 450.1 mL and Sensor 2 recorded 436.8 mL, both showing a downward deviation from the true value. The calculated RMSE values were 62.29 mL and 63.82 mL, respectively. These results indicate that both sensors tend to underestimate the actual volume, likely due to minimum detectable flow thresholds and slight flow fluctuations during manual water pouring.

In the 1000 mL tests, Sensor 1 and Sensor 2 measured average volumes of 942.4 mL and 898.7 mL, respectively. The RMSE values increased to 85.62 mL and 104.88 mL, reflecting greater deviations at higher flow volumes. The larger RMSE values suggest that the error grows proportionally with flow rate, which may be caused by turbulence or limitations in the sensor's pulse-counting precision at higher discharge speeds.

Overall, the RMSE across all tests ranged from approximately 62 mL to 105 mL, equivalent to 6–10% of the actual measurement range. This demonstrates that the water flow sensors provide acceptable accuracy for prototype-level IoT leak detection, though there remains room for improvement in calibration, flow stabilization, and error compensation.

C. System Testing

1) Threshold Value Determination Test

The *threshold* values to be tested in this test are 350, 300, 250, and 200 mL/Min. In this test, 9 conditions were carried out to simulate water usage and leaks. These conditions are as follows:

1. Condition 1: Output tap opened 100%, leakage 0%
2. Condition 2: Output valve opened 100%, leakage 30%
3. Condition 3: Output valve opened 100%, leakage 50%
4. Condition 4: Output valve opened 50%, leakage 0%
5. Condition 5: Output tap opened 50%, leakage 30%
6. Condition 6: Output valve opened 50%, leakage 50%
7. Condition 7: Output valve opened 30%, leakage 0%
8. Condition 8: Output valve opened 30%, leakage 30%
9. Condition 9: Output valve opened 30%, leakage 50%

TABLE II
THRESHOLD VALUE TEST MEASUREMENT TABLE 350 ML/MIN

Condition	Water flow sensor 1 (mL/Min)	Water discharge sensor 2	The actual situation	State read by the system
1	5733	5466	No leaks	No leaks
2	5466	5600	Leaking	No leaks
3	6000	4000	Leaking	Leaking
4	3200	3066	No leaks	No leaks
5	4000	2666	Leaking	Leaking
6	4800	1866	Leaking	Leaking
7	1066	1066	No leaks	No leaks
8	2533	933	Leaking	Leaking
9	4933	666	Leaking	Leaking

In table 2 it can be seen that in the *threshold* value test of 350 mL/Min, there was an incorrect reading by the system in condition 2. Condition 2 should read “leak” but the system does not detect any leak. In the other hand, in table 3 it can be seen that in testing the *threshold* value of 300 mL/Min there was no incorrect reading by the system. All reading results are in accordance with actual conditions.

TABLE III
THRESHOLD VALUE TEST MEASUREMENT TABLE 300 ML/MIN

Condition	Water flow sensor 1 (mL/Min)	Water discharge sensor 2	The actual situation	State read by the system
1	5466	5600	No leaks	No leaks
2	5600	5200	Leaking	Leaking
3	6000	3600	Leaking	Leaking
4	3333	3600	No leaks	No leaks
5	4400	3066	Leaking	Leaking
6	5600	1733	Leaking	Leaking
7	533	400	No leaks	No leaks
8	1733	400	Leaking	Leaking
9	5066	133	Leaking	Leaking

TABLE IV
250 ML/MIN THRESHOLD VALUE TEST MEASUREMENT

Condition	Water flow sensor 1 (mL/Min)	Water discharge sensor 2	The actual situation	State read by the system
1	5466	5600	No leaks	Leaking
2	5600	5066	Leaking	Leaking
3	6000	3733	Leaking	Leaking
4	3600	3866	No leaks	Leaking
5	4133	3466	Leaking	Leaking
6	5466	2133	Leaking	Leaking
7	266	266	No leaks	No leaks
8	1466	266	Leaking	Leaking
9	4400	133	Leaking	Leaking

TABLE V
200 ML/MIN THRESHOLD VALUE TEST MEASUREMENT TABLE

Condition	Water flow sensor 1 (mL/Min)	Water discharge sensor 2	The actual situation	State read by the system
1	5333	5600	No leaks	Leaking
2	5600	5333	Leaking	Leaking
3	5733	3733	Leaking	Leaking
4	3466	3866	No leaks	Leaking
5	4000	3066	Leaking	Leaking
6	5333	1466	Leaking	Leaking
7	266	133	No leaks	No leaks
8	1466	266	Leaking	Leaking
9	4666	0	Leaking	Leaking

Table 4 shows that in the *threshold* value test of 250 mL/Min, the system misreads conditions 1 and 4. Conditions 1 and 4 should read “no leak”, but the system reads them as leaks.

In Table 5, it can be seen that when testing the threshold value of 200 mL/Min, the system misread the

values in conditions 1 and 4. Conditions 1 and 4 should read “no leak”, but the system reads them as leaks.

In the four tests that have been carried out, the most suitable threshold value for the water pipe leak detection system is 300 mL/Min. At a threshold value of 300 all readings made by the system correspond to actual conditions.

2) Whole System Testing

This test examines the conditions read by the system, valve *status*, and notifications received by blynk. This test uses a threshold value of 300 mL/Min with a 100% output tap condition and 30% leakage. Testing was carried out on six test pipes.

TABLE VI
OVERALL SYSTEM TEST RESULTS

Pipe	State read by the system	Valve condition	Blynk notification
1	Leak detected	Close	Sent
2	Leak detected	Close	Sent
3	Leak detected	Close	Sent
4	Leak detected	Close	Sent
5	Leak detected	Close	Sent
6	Leak detected	Close	Sent

Table 6 shows that during the system testing the six pipes were able to detect leaks that occurred. Valve also successfully closed on all six tests and notifications were successfully sent to blynk.

D. Delay Testing

Delay testing was carried out 10 times, sending data to blynk. The results can be seen in Fig. 6.

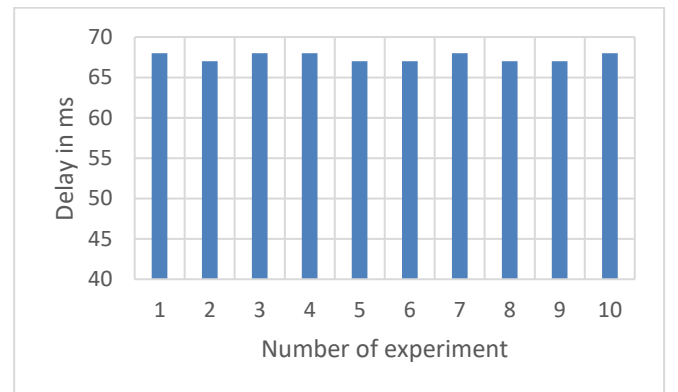


Figure 6. Delay testing for ten times sending data to blynk.

Fig. 6 presents the delivery delay ranges between 67 and 68ms. This delay is relatively low, but the results of the *delay* measurement depend on the capabilities and quality of the WiFi used to connect the device.

IV. CONCLUSION

This prototype water pipe leak detection system can work as expected. The system is capable of monitoring water flow, detecting leaks, and sending data to users

accurately and quickly. However, the testing were conducted on a laboratory scale with a constant water flow rate; variations in pressure and turbulent flow conditions were not tested. The system's leak detection mechanism still relies on a fixed threshold of 300 mL/min, which is not yet adaptive to the dynamic conditions of real water distribution networks. Moreover, the communication system depends on Wi-Fi connectivity, and its performance under poor or unstable network conditions has not been evaluated. For future work, the system can be improved by developing AI- or Machine Learning-based algorithms to predict and detect leaks through real-time analysis of flow and pressure patterns, as well as by integrating additional pressure sensors to enhance detection precision.

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