Prototype Design and Implementation of Water Distribution Pipeline Leak Detection based on the Internet of Things (IoT)

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Abstract. Water leakage in water distribution networks is a significant issue that leads to problems such as potential value of wasted water, service delivery disruptions, and revenue losses. This paper aims to design a prototype system for detecting water pipe leaks using the Internet of Things (IoT) technology. The design used two types of sensors, pressure sensors and water flow sensors. It also incorporated the ADS1115 module as a converter, which was connected to a NodeMCU ESP32 microcontroller. The results of water pressure values and the amount of integrated discharge detection read by the sensor was sent to Thinger.io, and the leak notifications were sent through Telegram Bot at 5-minute intervals. Based on the field-testing result with a scheme of three faucets, one of them placed at the end of the pipe design and sets at opening angles of 40°, 60°, and 90°, it was found that in an ideal system, when the water consumption was high, the pressure tended to be low, resulting in minimal leakage. Conversely, when the water consumption was low or there was a blockage in the piping system, the pressure increased, leading to more leakage. Reducing the pressure can decrease the flow rate, which in turn reduces water loss. The opening angle of faucets also affects the leakage level, as variations in the angle produce different pressures.

Keywords: ADS1115, Pressure Sensor, Telegram Bot, Water Flow Sensor, Water Leak Detection.

1   Introduction

Water is one of the natural resources that is important for the existence of our ecosystem. In the midst of the global water crisis, the Indonesia Ministry of Public works and Public Housing (PUPR) stated that the level of water loss (Non-Revenue Water) in Indonesia reached 33,72%, equivalent to IDR 9,6 trillion per year [1]. Water in Indonesia is distributed through a complex pipeline network, vulnerable to damage and leakage due to both internal and external factors. This water loss represents the difference between the volume of water distributed and the volume of water consumed and recorded [2]. Bernoulli's principle stated that fluid pressure and velocity through a pipe have a significant role to optimize system performance and efficiency [3]. Water

leak prevention must be carried out through all processes starting from design, construction, and maintenance because preventing leaks is complicated and requires expensive costs. Water leakage in the pipe distribution system will lead to problems such as the potential value of wasted water, service delivery disruptions to consumers, and revenue losses [4]. Currently, when there is a leakage in the water pipe distribution system, the restoration requires considerable time and effort because it is usually identified manually by looking directly at the condition and mostly leads to significant water loss.

The Internet of Things (IoT) aims to expand the benefits and connectivity of the internet by enabling devices to be continuously connected and remotely controlled. Many IoT platforms have been developed, each with unique features and use cases; in [5,6] and [7] with Thinger.io as an example of an Open-Source Platform for the Internet of Thing (IoT).

Many studies about this topic have been proposed for detecting water leakage in the pipe system using microcontrollers and Internet of Things. Santoso et al. studied how to invent water leak detection based on the Internet of Things. Their study focused on water leak detection by comparing water flow before and after leakage. The results showed that leakage is indicated by a measurable difference in water flow rates [8]. The study by Prasetya et al. focused on a pipe leak detection system that can be monitored with an Android application. The results showed that each water flow rate decrease that occurs has an accuracy of determining the leakage rate of 90,2%, while the suitability of reading the number of leakage areas depends on the detection of the leakage area and the classification of the leakage rate [9]. Shinde and Sapre focus on detecting pipe leaks by monitoring the water pressure flowing through the pipes. The microcontroller continuously sends sensor outputs to the cloud server. If the system detects pressure values below the predetermined level or constant pressure with a decrease in water quality, the microcontroller sends a warning message to the relevant staff. A solenoid valve is installed to minimize further water loss by reducing the water flow [10]. Singh et el. Developed a detection system that employs an ultrasonic sensor. This system continuously emits ultrasonic waves into the pipes and tanks, analyzing the reflected signals to determine the presence and location of leaks. While it is capable of accurately identifying the leak's position, the continuous operation of the ultrasonic sensor results in significant energy consumption [11]. Thenmozhi et al. developed an automated IoT-based water leak detection system that can detect leaks in a pipeline network in real time and pinpoint the exact location of the leak by reading the electrical resistance of wires installed along the pipeline. Each area has a unique resistance value assigned. When a leak occurs, the system reads the resistance and identifies the location based on preset values. The location can be known using the resistance value viewed within the mobile app [12]. Perangin-Angin and Sitepu studied the creation of leak detection using pressure transmitter sensors. This study applies to Bernoulli's equation to detect leaks, where the fluid is considered ideal, meaning it does not compress during flow, and both volume and mass remain constant. The result, when there is a leak anomaly, point P_1 > point P_2, or point P_2 will decrease relative to point P_1 [13].

Based on the explanation above, this study focuses on detecting water pipeline leaks using a microcontroller, water flow sensor, and pressure sensor with Internet of Things

(IoT) support. The pressure and flow values can be monitored through the Thinger.io dashboard, and the data logs can be used for further analysis. Real-time notifications about water leakage will be sent through the Telegram application with 5 minute-intervals.

2   Materials and Methods

This research started with a review of published literature and relevant information. The fundamental theories and datasheets of the components used in the study were also examined to provide reference for the implementation. The hardware and software design were developed after gathering the necessary components and studying the literature. The final stage of the research involved testing and analyzing the system's performance.

2.1   Research Location

To start the research, it is necessary to determine the place or location where the research would be carried out. The research location and data collection was conducted at the Electrical Engineering Laboratory, Engineering Faculty, Mulawarman University, Samarinda City, East Kalimantan.

2.2   Overall System Design

A block diagram is necessary to explain the proposed system simply and show the circuit's overall working principle. It is also needed to provide an overview of the prototype for further development. Fig. 1 shows the block diagram of the proposed system, and it illustrates the stages starting from input, process, and output.
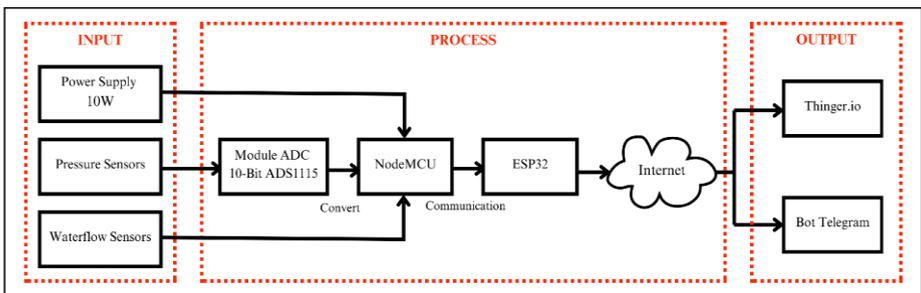

Fig. 1. Block diagram

The proposed system used several components. The pressure sensors provide water pressure values in the form of analog data, which will be read by an ADS1115 module as an analog-to-digital converter. The ADS1115 module is connected to a microcontroller NodeMCU using the 12C protocol. Furthermore, the water flow sensors also

provide water flow rate values. The schematic diagram circuit of the proposed work in this study can be seen in Fig. 2.

The water leakage simulation scheme on the prototype used a water pump to supply the water through the pipeline, and the process is repeated. The pipeline is positioned horizontally or linearly. The leaking faucets release water from the pipeline system, indicating leakage, while faucet 3 assumes water usage in customers' houses and it sets at opening angles of 40°, 60°, and 90°. The leaking faucets are placed between sensor 1 and sensor 2, as well as between sensor 2 and sensor 3. Leakage occurs under two conditions: either faucet 1 or 2 is open, or both faucets 1 and 2 are open. Leakage testing is carried out by monitoring the level leakage rate, set based on the opening leakage faucet angles at 35° and 60°. Meanwhile, the leakage areas depend on the detection of the leakage, which are determined either as Area 1, Area 2, or both Area 1 and 2. The prototype design model of the proposed work is shown in Fig. 3.
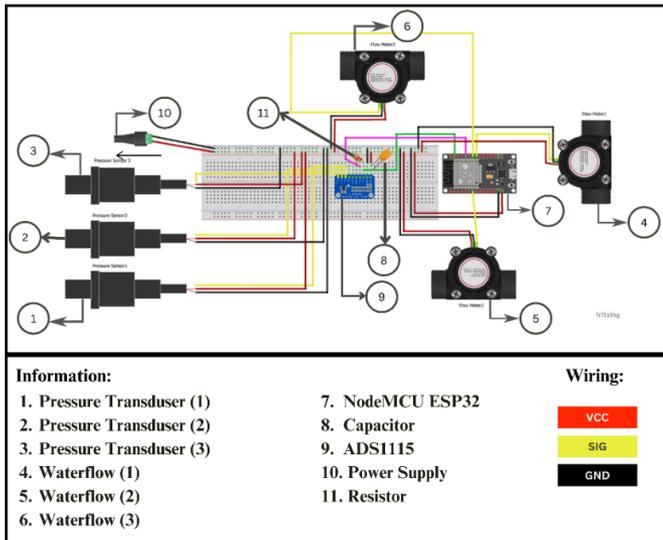

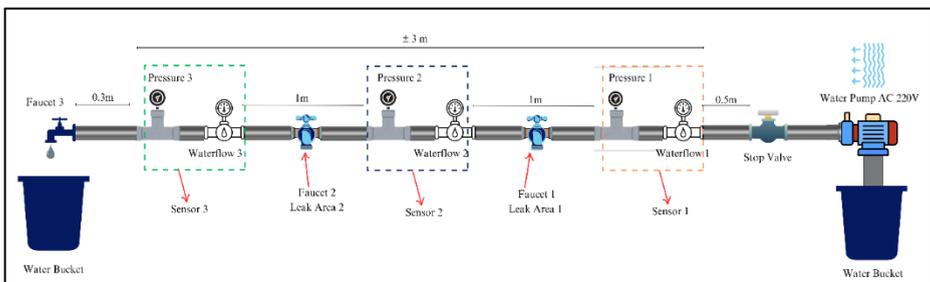**Fig. 2.** Schematic diagram circuit of the proposed work

Fig. 3. Prototype design model of the proposed work

2.3   Research Method

Internet of Things devices have limitations in storage and computational capabilities. Therefore, the system is integrated with cloud storage as a data storage system using the Internet of Things platform Thinger.io. The working principle of this leak detection system is to compare the water discharge conditions monitored in real-time with the specified initial set point. If the absolute difference between the water discharge a and b value ismore than the tolerance value of 4% of the discharge value a, it will be detected as a leak. It is carried out repeatedly until the value is back to normal.

On the other hand, if the absolute difference is not more than the tolerance value, then the flow is normal, and the pipe status is not leaking. In this process, the set point for detecting a leak is based on the difference in the absolute value of the water flow sensor a and the water flow sensor b, where the water flow sensor a is the sensor before the leak occurs and the water flow sensor b is the sensor after the leak occurs. The microcontroller displays the data received to process and send through the internet and it will be displayed on the Thinger.io application. If there is a leakage, it will send notification to the Telegram group. Fig. 4 shows the flowchart of the pipe leakage detection system.
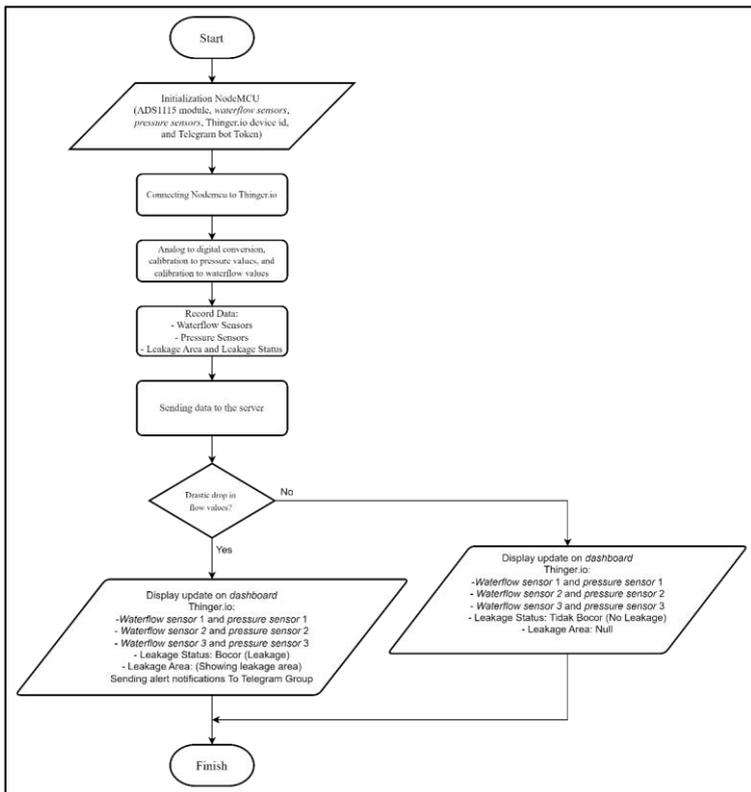

Fig. 4. Flowchart of the pipe leak detection system

3   Results and Discussion

Fig. 5 shows the implementation of schematic diagram circuit. The water leakage monitoring system is connected to the PLN power source and converted into DC current from an adapter.
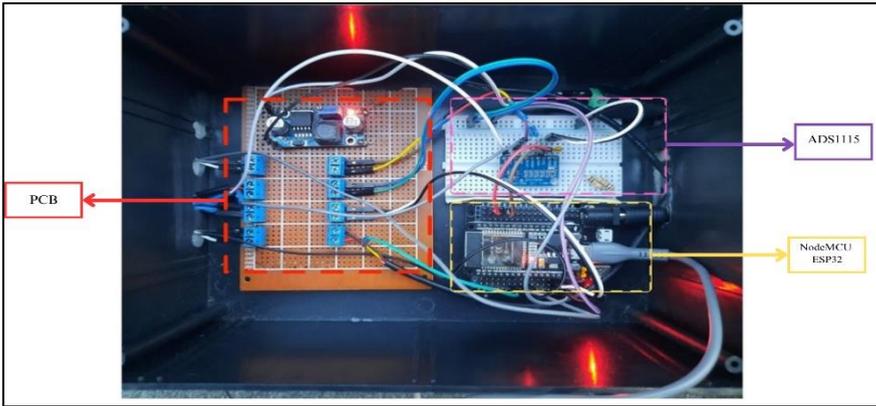

Fig. 5. Schematic diagram circuit implementation

Water flow and pressure sensors are implemented on the pipeline to read water flow and pressure values. When the microcontroller is powered on, all sensors begin monitoring their respective environments and assessing the pipeline's condition. If leakage is detected, the Telegram bot will notify the user. Prototype setting of the water pipeline leakage monitoring system is shown in Fig. 6.

Fig. 6. Prototype setting of the water pipeline leakage monitoring system

Fig. 7 shows a complete circuit and work prototype in a series of data from the sensors collected and uploaded into Thinger.io. The Fig. represents data collected by water flow and pressure sensors, leakage status, and leakage area. The monitoring results show that the monitoring system continuously changes over time, indicating that the values obtained are updated in real-time.

Fig. 7. Water leakage monitoring display on Thinger.io

Fig. 8 shows examples of notifications given to the users through Telegram applications. Thus, the leakage pipeline detection notification through the Telegram bot has worked well, and the system has been successfully established.
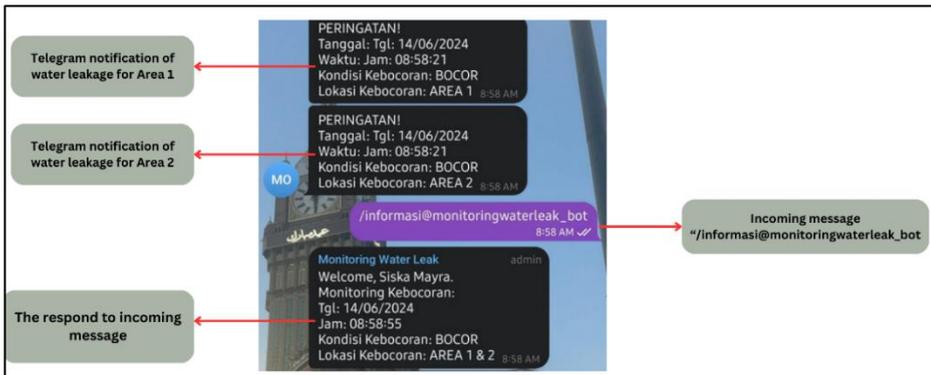

Fig. 8. Telegram notification of water leakage monitoring

Table 1 shows that the output measurements of the ADC input pins on ADS1115 are unstable. This test is carried out to determine the percentage error value of the ADC input pins on ADS1115 by comparing the output voltage reading of the ADS1115 pins with the multimeter. The measurement percentage error shows a more significant pattern that likely happened because of random noise in the system.

Table 1. Testing of ADS1115 Input Pins

No.	ADS1115 Input Pin	Multimeter (V)	ADS1115 (V)	PE (%)
1	AIN1	0.575	0.570	0.9
2	AIN1	0.521	0.520	0.2
3	AIN1	0.517	0.520	0.6

No.	ADS1115 Input Pin	Multimeter (V)	ADS1115 (V)	PE (%)
4	AIN2	0.516	0.527	2.1
5	AIN2	0.517	0.527	1.9
6	AIN2	0.517	0.530	2.5
7	AIN3	0.465	0.469	0.9
8	AIN3	0.472	0.471	0.2
9	AIN3	0.465	0.471	1.3

Testing the water flow sensor is carried out to determine the percentage error value of the water flow sensor when making measurements by comparing the output read of the water flow sensors with the measuring container. The volume of the sensor measurement results is compared with the value of the water volume measured using a measuring container to obtain the percentage error value. The water flow sensors on the pipeline testing results are shown in Table 2.

Table 2. Pipeline water flow sensors testing results

No.	Measuring Container (mL)	Waterflow 1 Reading (mL)	Waterflow 2 Reading (mL)	Waterflow 3 Reading (mL)	Waterflow 1 PE (%)	Waterflow 2 PE (%)	Waterflow 3 PE (%)
1	1000	1021	999	987	2.1	0.1	1.3
2	1000	1026	1000	1005	2.6	0.0	0.5
3	1000	1014	993	1005	1.4	0.7	0.5
4	1000	967	1008	1013	3.3	0.8	1.3
5	1000	1018	1004	1010	1.8	0.4	1.0

Pressure sensors testing is conducted to determine its percentage error by comparing the sensor's output with readings from a pressure gauge. The pressure values of the pressure sensors are compared to a pressure gauge to calculate the percentage error. The results of the pressure sensors test on the pipeline are shown in Table 3.

Table 3. Pipeline pressure sensors testing results

No.	Pressure Gauge 1 (PSI)	Pressure Sensor 1 (PSI)	PE (%)	Pressure Gauge 2 (PSI)	Pressure Sensor 2 (PSI)	PE (%)	Pressure Gauge 3 (PSI)	Pressure Sensor 3 (PSI)	PE (%)
1	12	11.97	0.2	11	10.63	3.4	10	9.97	0.2
2	12	11.56	3.8	11	10.57	3.9	10	9.83	3.8
3	12	11.93	0.6	11	11.01	0.1	10	9.93	0.6
4	12	11.83	1.4	11	10.33	6.1	10	9.98	1.4
5	12	12.12	1	11	10.70	2.7	10	10.37	1

The no leakage experiment is carried out to identify whether or not the system can detect normal conditions without any mistakes, allowing for a clear distinction between normal or no leakage and leakage conditions. The results of the comparison between

no leakage and with leakage experiments are shown through the graph in Fig. 9 and Fig. 10.

Based on the graph with no leakage, the water pressure increases, and the flow rate decreases as the opening angle of the faucet 3 decreases. The decrease in pressure and flow rate occurs even without leaks, potentially due to friction between the fluid and the pipe walls, pipe connections or fittings, a valve in the system, or noise. The smaller the opening angle of faucet 3, the higher the pressure and the lower the flow rate due to a blockage that obstructs the water flow and reduces the space available for water to flow, thereby decreasing the speed and volume of water coming out. Furthermore, the blockages caused by dirt, sediment, or other materials accumulating inside the pipe also reduce the space available for water to flow, thereby decreasing the speed and volume of water exit from the system. Therefore, in an ideal system where the pipe is filled, when water consumption is high, the pressure tends to be low, consistent with the 90° opening of faucet 3.
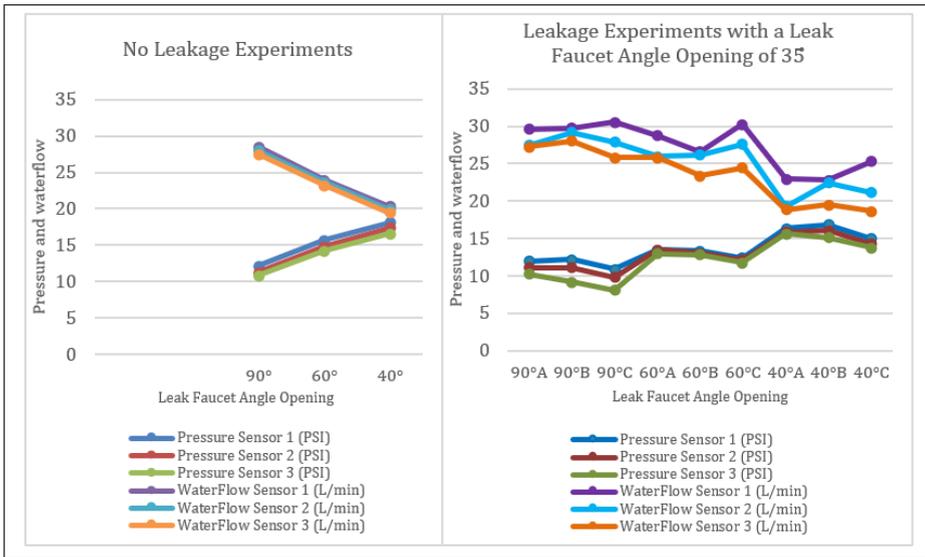

Fig. 9. Comparison of no leakage conditions and leakage conditions with a leakage faucet opening at the angle of 35°

The horizontal axis represents the opening angle of faucet 3 with the letter symbols: letter A represents the opening of leakage faucet 1, letter B represents the opening of leakage faucet 2, and letter C represents the opening of both leakage faucets 1 and 2. The vertical axis represents the values from the pressure sensors and the water flow sensors. Leakage causes more significant fluctuations in pressure and water flow sensor readings. Compared to a graph with no leakage condition experiments, the pressure tends to decrease in conditions with a leak. In contrast, the discharge of water flow tends to increase with the difference between sensor readings that can indicate the leakage area.
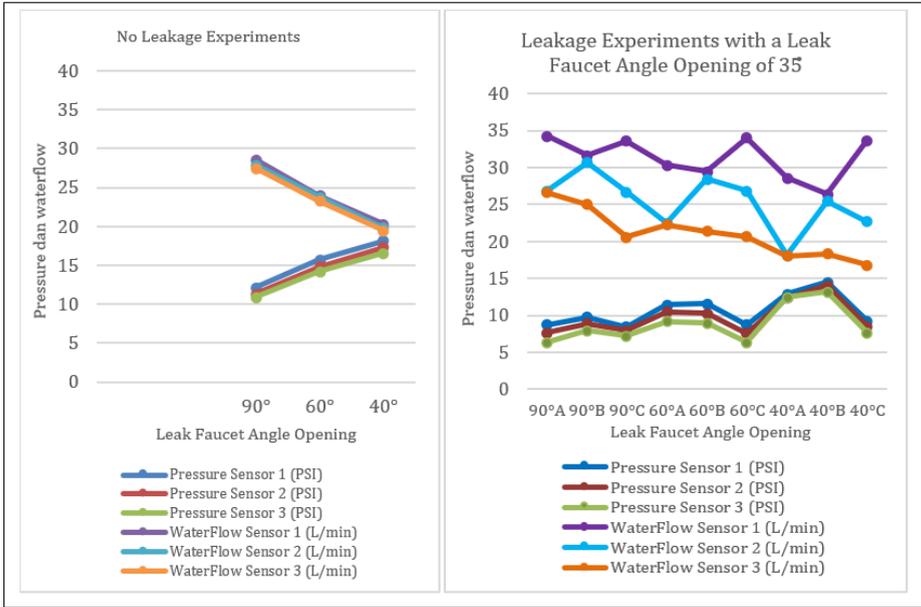
Fig. 10. Comparison of no leakage conditions and leakage conditions with a leakage faucet opening at the angle of 60°

Based on the experiment data of the proposed system, water loss due to leaks will become more prominent along with the larger opening angle of the leaking faucet. This means that opening the leakage faucet to 60° will cause a higher level of water loss than opening the leakage faucet to 35°. Then, based on the test scheme that has been carried out with different faucet 3 opening angles of 40°, 60°, and 90°, the angles have an impact on a higher level of water loss, linear with the opening of the leaking faucet getting larger as seen in the difference of flow discharge on the water flow sensor before and after the leak. In times of high consumption discharge or an ideal system, the pressure tends to be low, followed by a low leakage discharge. Conversely, when the usage is small, or there is a blockage in the piping system, the leakage will increase along with the increase in pressure because the reduced pressure will make the flow discharge shrink, impacting the level of water loss.

4   Conclusions

Based on the research results, it can be concluded that the proposed system in this study has worked as expected. From the result that has been shown, the system identifies leaks by analyzing the difference in the amount of water flow between sensors placed before and after the leak, with a detection threshold set above 4% of the water flow sensor before the leak. The pressure influences the amount of water loss in the system; when the pressure increases, it will lead to more leakage, especially when usage is low

or when blockages are present in the piping network. The implementation of the Internet of Things is a real-time system where all data collected from sensors, such as water flow and pressure sensors, are sent to cloud storage on Thinger.io simultaneously. The user can see the data online on the dashboard or in the data bucket. The Telegram bot for pipeline leak detection notifications also functions effectively and can provide feedback to the user. The data log collected from the leakage monitoring system is expected to be used for further analysis.

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