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IOT-BASED LEAK DETECTION SYSTEMS USING POINT PRESSURE AND MASS BALANCE METHOD: AN EXPERIMENTAL RESEARCH

CHALIDIA NURIN HAMDANI*,
WILDAN AFIF RAFSANJANI, RONI HERU TRIYANTO,
ASTRIE KUSUMA DEWI, ASEPTA SURYA WARDHANA

Politeknik Energi dan Mineral Akamigas Blora, Jawa Tengah, Indonesia
*Corresponding Author: hamdani113@gmail.com

Abstract

Fluid distribution systems are the process of distributing fluid to consumers, including pumps, reservoirs, valves, etc. One of the most common problems in fluid distribution systems is leak detection. Small companies in Indonesia that have fluid distribution in their process business, like Perusahaan Daerah Air Minum (PDAM), are still unable to handle this problem. Recorded on several PDAMs in Indonesia, a tremendous amount of water was lost because of leakage. It reached 38.5% per year. In this research, we have designed a Leak Detection System (LDS) based on the Internet of Things using the Point Pressure and Mass Balance (PPMB) method. ESP8266 microcontroller is used as a central controller on one Master Terminal Unit (MTU) and three Remote Terminal Units (RTU) integrated with the blynk database. PPMB method is realized on the HMI Algorithm using LabVIEW. We did some experimental tests on the LDS and got promising results: LDS can detect and determine a leak's location. Leakage can be optimally detected by using 3 seconds of delay, and the leak's location can be optimally determined by using 10 seconds of delay.

Keywords: IoT, LDS, Mass balance, Point pressure.

1. Introduction

Piping networks are a fluid distribution method that moves fluid from one point to another. The problem that has become an exciting topic in fluid distribution is leakage. Industries or companies will be disadvantaged if there is an undetected fluid leak, so they continue to develop methods and technologies to detect leaks.

Several small companies, such as Perusahaan Daerah Air Minum (PDAMs) in several areas, are still experiencing leaks in distributing water. For example, PDAM Tirta Meulaboh in Aceh has experienced a leak of up to 783,967 m3/year, or 35% of the total production [1]. PDAM Magelang has experienced a leak of up to 438,232 m3/year or 38.53% of the total production [2]. To overcome these leaks, they still use the manual method, by directly inspecting the field or waiting for complaints from the public. Of course, this is inefficient for handling leaks that often occur, so a practical and applicable method is needed to detect leaks.

In general, Leak Detection Systems (LDS) can be divided into non-continuous and continuous systems [3]. Both systems have the same function of detecting and locating leaks. Frequently, the two methods are applied together to increase robustness [4]. In American Petroleum Institute (API) Recommended Practice 1130, LDS must meet four criteria: reliability, robustness, accuracy, and sensitivity [5].

One of the methods used in LDS is point pressure analysis. This method is used in continuous systems with pressure measurements in the fluid distribution pipe. Pressure transmitters are installed at some points on distribution pipes to measure the pressure. Leakages can be detected by detecting pressure drops. This method has a typical minimum detectable leak rate of >5% and a short detection time [6]. This method can be applied by installing pressure sensors at specific points of the distribution pipe to measure and monitor the pressure at those points. Leaks can be detected by measuring the pressure drop. However, this method has drawbacks. In addition to the typical minimum detectable leak rate, which is quite large, this method can only detect spontaneous leaks.

Another method that is often used in LDS is the mass balance method. The working principle of this method is quite simple, namely by comparing the inflow and outflow. This method has a typical minimum detectable leak rate more diminutive than the point pressure analysis method, which is >1%, and can detect spontaneous and creeping leaks [5]. However, the weakness of this method is the long detection time.

On the other hand, industrial technology has reached the industrial era 4.0 [7, 8]. One of the technologies being promoted is the Internet of Things (IoT). In this technology, all equipment (sensors, actuators, controllers, and others) is connected to an internet network to be accessed remotely [9, 10]. With the development of internet infrastructure that has proliferated, with IoT technology, access control, and monitoring can be done easily, quickly, anytime, and anywhere [11, 12].

In this research, we made a prototype LDS simulator based on the microcontroller unit product called Espressif 8266 (ESP8266) with the technical specification that can be seen on its website (https://www.espressif.com/). The method used is a combined method of point pressure and mass balance called the PPMB method, so LDS has a low typical minimum detectable leak rate, short detection, ion time, and spontaneous-creeping leaks do order to pay to 4 main concepts of LDS: accuracy, reliability, robustness, and sensitivity, we added the concept of IoT in the LDS prototype to improve accessibility.

2.Research Method

In general, this research was carried out in two stages: hardware design and software design. The overall Piping and Instrumentation Diagram (P&ID) of the prototype can be seen in Fig. 1. The hardware consists of a prototype of the water distribution system and a prototype of the LDS. The ESP8266 microcontroller program and the Human Machine Interface (HMI) program were designed on software design.

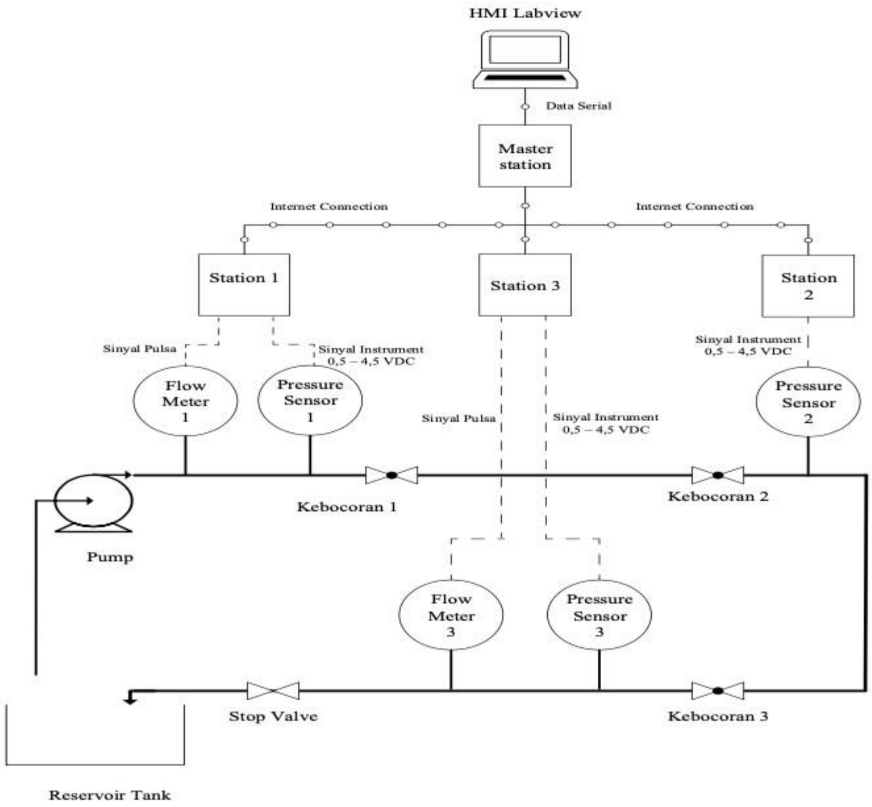

Fig. 1. Prototype P&ID schematic.

The design and implementation results of the water distribution system prototype can be seen in Fig. 2. The prototype was built using a Polyvinyl Chloride (PVC) pipe with a diameter of 0.0127 meters and a total length of 7.5 meters. In this prototype, three measurement stations are installed: the first station is installed with a flow sensor and a pressure sensor, the second station is installed with just a pressure sensor, and the third point is installed with a flow sensor and pressure sensor. Flow sensors in the first and third stations are used to measure the inlet and outlet flow, respectively. This measurement is carried out to validate the mass balance equation as Eq. (1) [13]. Water is pumped from the reservoir tank through all three station points and returns to the reservoir tank. The pump used has a maximum capacity of 0.02 m^3/min.

$$\sum_{i=1}^{N} m_{in,i} = \sum_{j=1}^{N} m_{out,j} \quad (1)$$

where m_{in} and m_{out} are respectively input and output mass.

Each station is equipped with an ESP8266 microcontroller as a Remote Terminal Unit (RTU) in charge of sending sensor measurement results to the central station. This design is inspired by the RTU that has been implemented in smart trash bin systems [14] and smart environment systems [15]. The main station is also made using the ESP8266 microcontroller as the Master Terminal Unit (MTU), which is in charge of storing and processing measurement data from all RTUs. The MTU is connected to the computer as a Human Machine Interface (HMI) via serial communication. All measurement data and other essential parameters will be displayed in an HMI created using LabVIEW software.

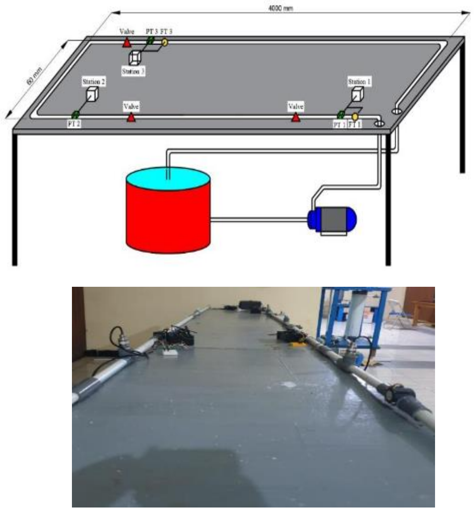

Fig. 2. Hardware design and implementation result.

The ESP8266 microcontroller on each RTU is programmed to read the measurement results from the sensor, display the measurement data on the Liquid Crystal Display (LCD) and send the data to the Blynk database. Blynk is an IoT platform that has been used on many IoT projects, like robotics [16] and smart fanning [17]. All data from the RTU is stored in the blynk database and displayed via the blynk website. Moreover, blynk sent the data to the MTU to be processed and displayed in the HMI with LabVIEW software. In addition to displaying measurement data, HMI is also programmed to be able to process data so that it can detect leaks using PPMB methods.

In the HMI, several parameters are displayed in 3 different tabulations, including the pressure of each RTU, the upstream and downstream flow, and indicators and percentage of leakage. Leakage indicators are alarm indicators and leak location indicators. Pressure and flow measurements are displayed in digital form, gauges, and monitoring charts. The main display of the designed HMI can be seen in Fig. 3.

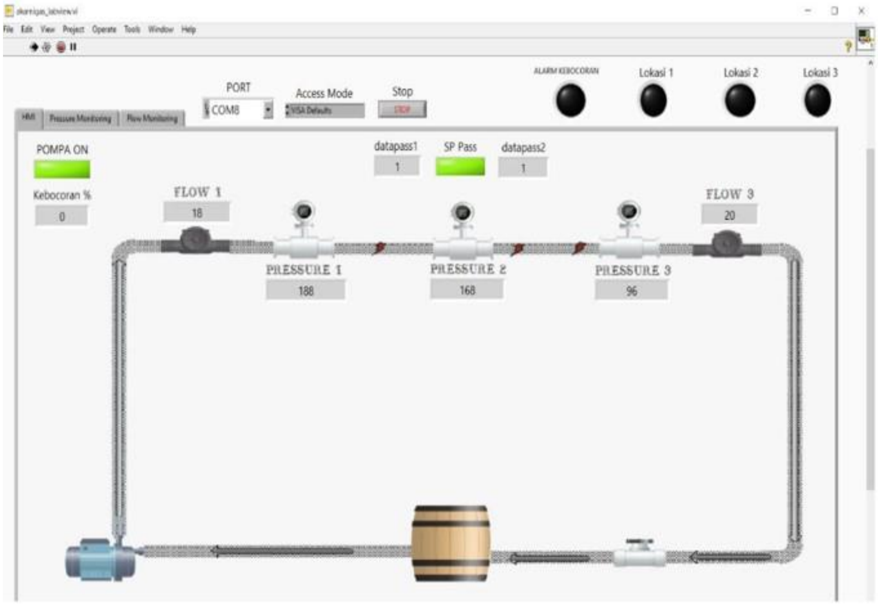

Fig. 3. HMI view.

3.Result and Discussions

Before the LDS testing, all sensors were calibrated using the zero-trim calibration method. This calibration was done to ensure the zero point of the measurement and ensure the sensor could work properly. When there is no pressure, the sensor output voltage is 0.52 V. This value is slightly different from the ideal nominal voltage of 0.5 V. We have tested all pressure sensors and the results can be determined as shown in Table 1. There is a measurement error, with the most significant error being 0.13%.

Table 1. Test model specifications and test conditions.

Ideal Voltage (V)	Ideal Pressure (kPa)	Actual Pressure (kPa)	Error (%)
0.5	0	0	0
1	200	192	0.04
1.5	400	392	0.02
2	600	592	0.13
2.5	800	792	0.01
3	1000	992	0.008
3.5	1200	1192	0.0067
4	1400	1392	0.057
4.5	1600	1592	0.005

The first test was carried out under normal conditions, or there was no leakage. This test aimed to obtain the normal value, which will be used to determine whether there is a leak or not. The results can be seen in Table 2. Pressure measurements on each RTU show different values, which indicate that there are pressure losses in the pipeline network because of pipe friction and bend. However, the flow measurement results show a value that follows the law of mass balance: the upstream flow is the same as the downstream flow.

Table 2. Test model specifications and test conditions.

Pressure in RTU 1 (kPa)	Pressure in RTU 2 (kPa)	Pressure in RTU 3 (kPa)	Upstream Flow (l/min)	Downstream Flow (l/min)
186	175	96	18	18

The next test was carried out by alternately opening the valve at each point: points 1, 2, and 3 to simulate a leak. The experimental results at point 1 can be seen in Figs. 4 and 5. The valve at point 1 begins to open by 30 degrees at 10:19:24 resulting in a change in upstream-downstream flow, as shown in Fig. 4. The value of the upstream-downstream flow immediately changes and reaches a steady value within 3 seconds. This stable value is used to determine whether there is a leak or not. Because of the upstream-downstream flow value difference, the LDS turned on a leak alarm at 10:19:27. The difference between the value of upstream and downstream flows is used to calculate the percentage of leakage. The experiment continued by opening the valve. The difference continued to increase in proportion to the valve opening. However, still, following the law of mass balance, the inflow equals the outflow.

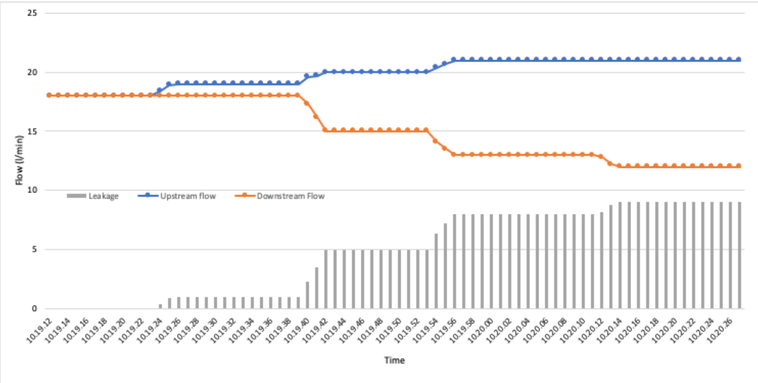

Fig. 4. Upstream and downstream flow on the first leakage simulation.

When the valve at point 1 was opened, pressure in all RTUs changed, as seen in Fig. 5. The pressure drop was obtained by comparing the measured pressure value and normal pressure (Table 2). This pressure drop value was used to determine the leak's location. However, as seen in Fig. 6, the change in the pressure value generated in each RTU due to leakage has different transient characteristics. So that the determination of the leak's location could not be done until the pressure value reached a steady state. From the experiments that have been carried out, the optimum steady-state time in determining the leak point is 10 seconds. From the first valve opening experiment at point 1, LDS could determine the leak's location at 10:19:34, which is at point 1 because RTU 1 has the most significant pressure drop of 38.6 kPa. It also applied to the next valve opening experiment: 40º, 50º, and 60º, which were carried out at 10:19:40, 10:19:54, and 10:20:12, respectively.

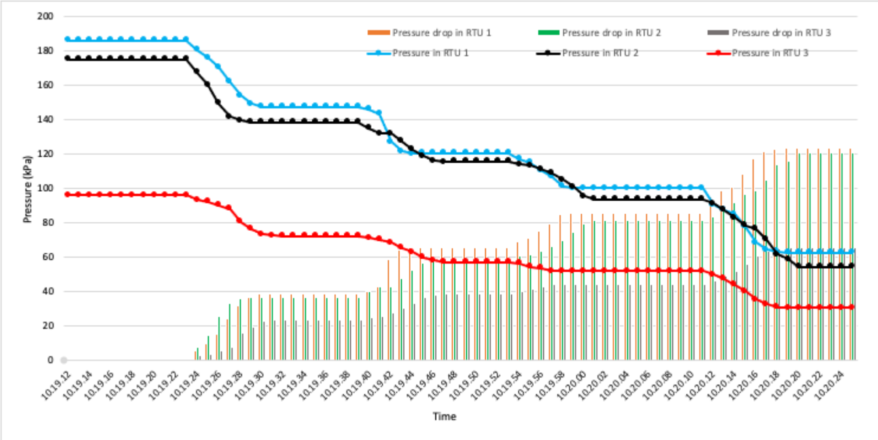

Fig. 5. Pressure and pressure drop on the first leakage simulation.

The third experiment was carried out by opening the valve at point 2, so we could obtain the flow measurement results, as shown in Fig. 6. The valve was opened successively 30º, 40º, 50º, and 60º at 12:04:09, 12:04:25, 12:04:43, and 12:05:04. Upstream and downstream flows changed with an average settling time of 3 seconds when the valve was opened. That is, within 3 seconds, LDS can determine whether there is a leak or not. For example, at the 50º valve opening, the downstream flow drops to 14 l/min, resulting in a difference of 6 l/min concerning the upstream flow.

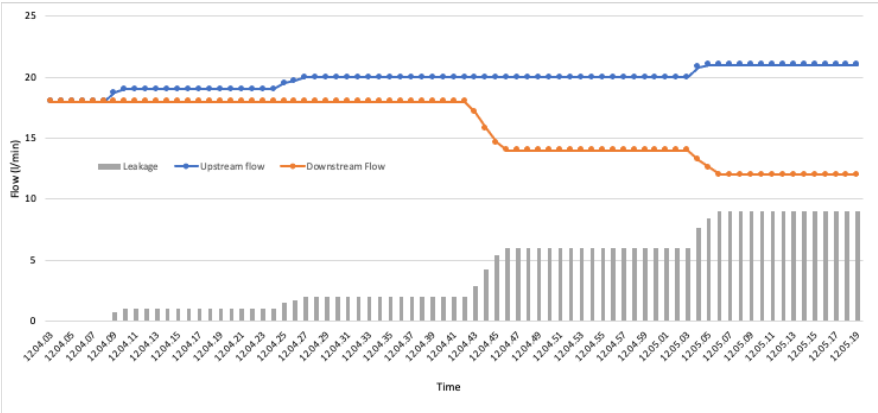

Fig. 6. Upstream and downstream flow on the second leakage simulation.

The results of the pressure measurement on all RTUs in the third experiment can be seen in Fig. 7. When the valve was opened by 40º, the pressure drop value at RTU 1, 2, and 3 was 53.5 kPa, 56.2 kPa, and 31.6 kPa, respectively. This steady-state value was obtained at 8 seconds, 10 seconds, and 5 seconds settling time. The leak's location can be determined accurately at 10 seconds. LDS needs this time to compare the pressure drop in all RTUs. From the steady-state pressure values at RTU 1, 2, and 3, LDS could calculate the pressure drop: 53.5 kPa, 56.2 kPa, and 31.6 kPa, respectively. The pressure drop in RTU 2 is the largest, so LDS turned on a leak alarm at RTU 2.

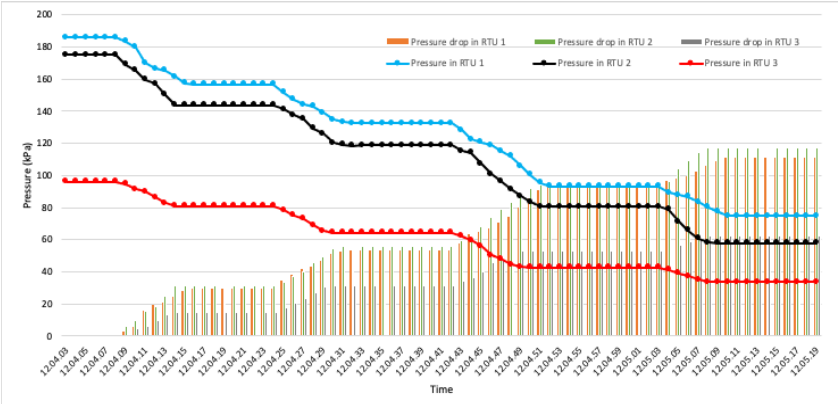

Fig. 7. Pressure and pressure drop on the second leakage simulation.

The last experiment was carried out by opening the valve at point 3. The valve was opened successively at 30º, 40º, 50º, and 60º at 14:13:30, 14:13:47, 14:13:04, and 14:14:21. From this experiment, we got flow measurement results, as shown in Fig. 8. At the 60º valve opening, the downstream flow had decreased to 13 l/min. It means there was a flow difference of 6 l/min concerning normal pressure. As we can see, the 60º valve opening at point 3 produces the same flow difference as the 50º valve opening at point 2. It happened because the normal pressure at point 3 was smaller than at point 2.

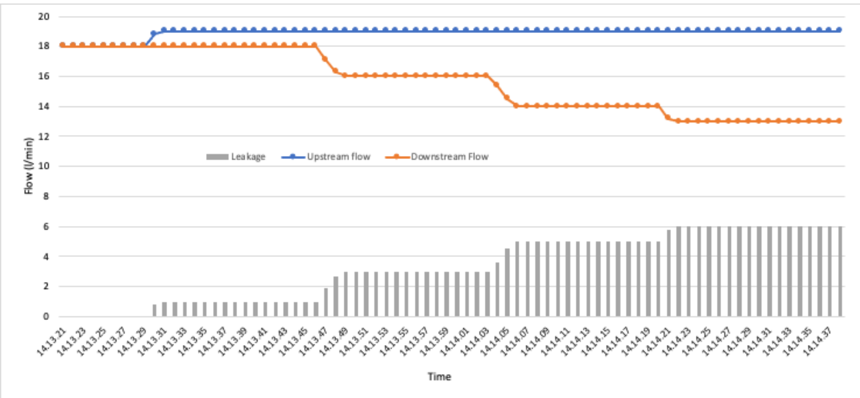

Fig. 8. Upstream and downstream flow on the third leakage simulation.

The results of the measurement of pressure and pressure drop in each RTU can be seen in Fig. 9. At 50º valve opening, the measured pressures at RTU 1, 2, and 3 were 148.3 kPa, 133.3 kPa, and 48.2 kPa, respectively. From this value, the pressure drops at RTU 1, 2, and 3: 37.7 kPa, 42.7 kPa, and 47.8 kPa. LDS detected a leak in RTU 3 because it had the most significant pressure drop compared to other RTUs.

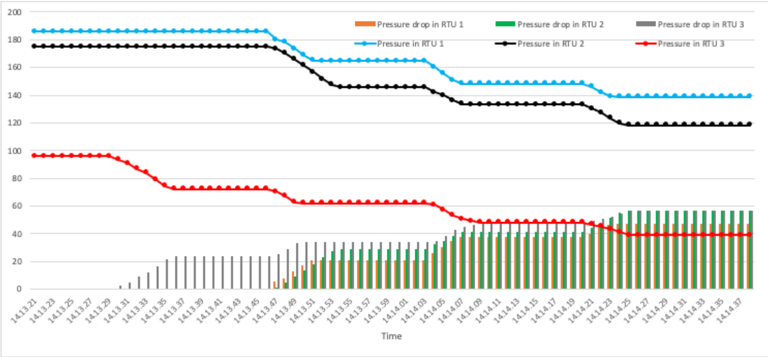

Fig. 9. Pressure and pressure drop on the third leakage simulation.

From the results of all experiments, it can be concluded that LDS worked adequately. LDS can detect and determine the leak's location. Leaks can be detected by LDS by comparing upstream and downstream flows with a delay of 3 seconds. If there is a change in the upstream/downstream flow, the LDS will wait for the steady stream value for 3 seconds and decide whether or not there is a leak. LDS can estimate leak percentage using the upstream and downstream flow differences. The leak's location is determined by an enormous pressure difference between the three RTUs.

4. Conclusions

In this study, LDS has been designed using the point pressure and mass balance method and integrated into IoT using the ESP8266 microcontroller as the central controller. Three RTUs equipped with pressure and flow sensors are placed along with the water distribution simulator, tasked with measuring pressure and flow and sending data from these measurements to the MTU with a sampling time of 1 second. The PPMB method is applied in the MTU algorithm and displayed in a Labview-based HMI. From the leak testing that has been carried out at the three-valve points, LDS can detect and determine the leak's location. The optimal time for leak detection is 3 seconds, and the optimal time for making leak location decisions is 10 seconds. The detection time of the LDS algorithm is very influential in determining the leak's location. In addition, sensor accuracy and internet network quality are also very influential on LDS performance because communication between the RTU and MTU is carried out wirelessly using the internet network. The subsequent development can be done by adding transient modelling to the LDS algorithm so that leak detection can be done faster. The addition of artificial intelligence to the LDS algorithm will increase the LDS's capacity to detect leaks at more than one point, which cannot be done by the method in this study.

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