

Real-Time Underground Plastic Pipeline Water Leakage Detection and Monitoring System

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ABSTRACT

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The leaking of the water pipeline increasingly influences the quality of life and threatens the water supplier in developing countries. Proper method is required to effectively detecting the source for replacement to reduce the loses. Therefore, a water leakage detection with monitoring system is developed to detecting the precise leaking location of a buried plastic pipeline. The real-time pressure data obtained from the pressurized pipeline are transferred to the monitoring system with GUI (graphical User Interface), developed using LabVIEW software. In the experimental execution, a leaking pipeline is designed. Then, few pressure sensors are installed on the pipeline as a primary segment for the detection process. To prevent a false non-leak alarm and malfunction of the pressure sensors, the pressure threshold value and malfunction alarm is set using LabVIEW. Cross-correlation method is implemented that increase the accuracy of the leaking distance estimation. The processing and control unit in this article are manipulated using LabVIEW software and NI myRIO-1900 respectively.

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1. Introduction

Water is an important resource that influences daily human activities. Dealing with the human negligence and pollution that is gradually worsening in the evolving countries, the water distribution system requires undivided attention to improve the quality of life [1]. To provide a clean water resource to 31.7 million people, with a 1.5% annually growing rate in Malaysia, a water distribution network that is usually buried underground was commonly designed by the water supplier industry [2][3]. The economic impact due to the water leakage or water disruption is far worsened, which cannot be underestimated [4].

It is well-known the leakage of the pipeline is very hard to be detected. Challenges increase when it is buried underground and cannot be seen [4-6]. Although technology is rapid growth, defects are unavoidable in the current leakage detection technology, such as an acoustic leaking detection

technique [1, 6, 7]. A recent study emphasized that in most water distribution networks, up to 30% of the water produced from the water treatment plant has a leaking situation along the distribution pipeline [7]. The leakage trouble is doubled for the water supplier industries compared to the common civilian. Water purifying, also known as non-revenue water (NRW) cost is especially high, where NRW is determined as the total quantity per meter received by the consumers versus the total supply of purified water from the water treatment plant [3, 8], which has to be borne by the water supplier industry [6]. As in Malaysia, the NRW achieved a very high percentage of 35.6% [8]. The losses of the total treated purified water volume are estimated at around RM 2.6 billion annually [8], which indirectly influences the country's economic growth [5, 7, 9].

There are a few origins of the pipeline leakage, including corrosion due to the composition of the soil, the usage of the inferior material during the pipeline fabrication, and the aging of the pipeline [1, 9]. Since the underground pipeline is buried beneath, it is almost impossible to execute proper regular inspection even with the high technology tools [1]. Therefore, a wireless monitoring system can effectively overcome this challenging inspection issue.

2. Method

In this paper, the LabVIEW software will be used as a platform to develop the GUI for displaying real-time data for an indication of pressure value, sensor status, and leak alarm to represent the total pipeline prototype, as shown in Fig. 1.

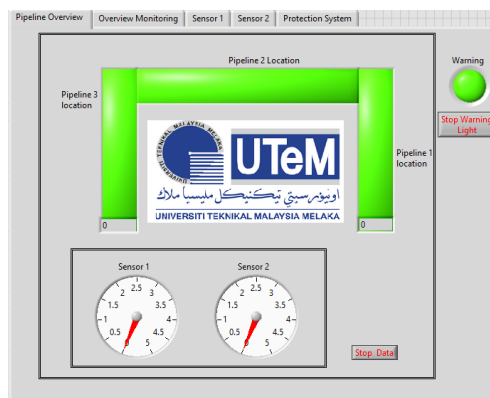


Fig. 1. Main GUI

Wireless data transfer connectivity was established using the NI -MAX between LabVIEW and NI myRIO-1900, as shown in Fig. 2, making the whole prototype less hard wire and more towards to be an automated and smart system and Fig. 3 shows the project flow path.

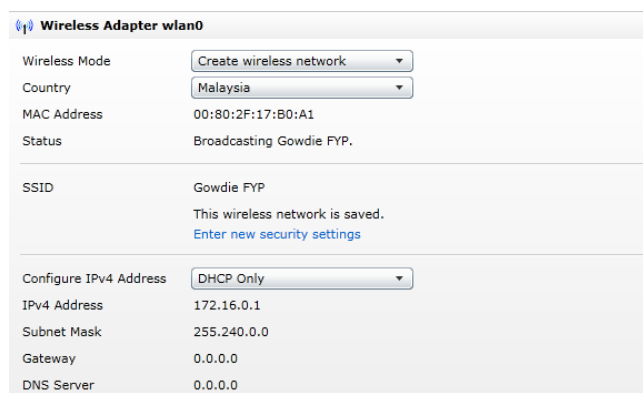


Fig. 2. Wireless Configuration

The user could view the current pressure value in each of the pipelines in the LabVIEW. An alarm indicator will be placed on the front panel of the LabVIEW, which will turn red when the system detects leakage, which also indicates which sensor detects the leakage, thus pinpointing the exact location of the leak. Each of the sensors installed will have an interface indicating the pressure numeric value and the sensor indicator whether it is working or malfunctioning.

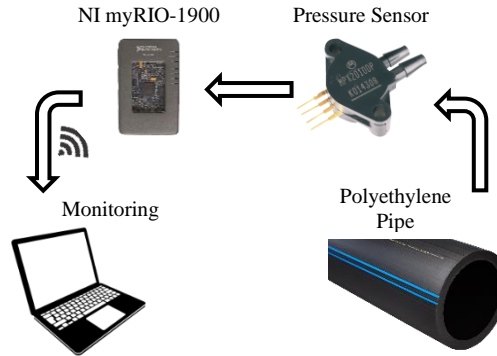


Fig. 3. Project Flow Path

In this project, 1 inch of the nominal size of High-Density Poly Ethene (HDPE) pipe was used with a maximum flow rate for the DC water pump of 840 L/H. There are two pressure sensors installed along the pipeline, and three simulations of leaking valves were installed at a specific distance along the pipeline, as shown in Fig. 4. The total length of the pipeline is 5 meters.

To increase the capability of the system to detect leakage, the cross-correlation technique, as shown in Fig. 5, was implemented to estimate and pinpoint the location of leakage. Cross-correlation is a technique to measure the time delay between two signals by comparing the similarities, and it is usually used in the leaking detection industry as well [10], [11]. Based on the time delay, the location estimation of the leakage can be found. Fig. 5 shows the typical diagram of the multi leakage points of a buried pipeline. From Fig. 5, the measurement of the signal can be modeled by two equations [11, 12, 13].

$$x_1(t) = s_1(t) + n_1(t) \quad (1)$$

$$x_2(t) = s_2(t) + n_2(t) \quad (2)$$

The $s_1(t)$ and $s_2(t)$ represent a signal for the position of leakage at positions 1 and 2, while $n_1(t)$ and $n_2(t)$ are the noise signals measured at positions 1 and 2, and (τ_1, τ_2) are the time delay for $s_1(t)$ and $s_2(t)$ measured at sensor 1 and 2 respectively.



Fig. 4. Pipeline Setup

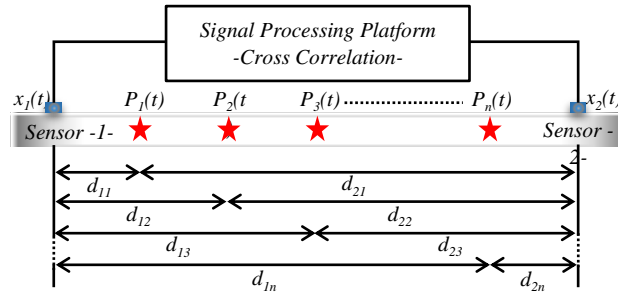


Fig. 5. Schematic diagram of multi leakage point

The cross-correlation between two signals, $x_1(t)$ and $x_2(t)$, is defined by the following equation.

$$C_{x_1x_2} = E[x_1(t)x_2(t + \tau)] + E[n_1(t)n_2(t + \tau)] \tag{3}$$

Equation (3) is then divided into two parts. The first part represents the leakage signal cross-correlation, while the second part is the noise of cross-correlation. From the correlation, the expressions for distances d_1 and d_2 as;

$$d_1 = c \cdot \tau_1 \tag{4}$$

$$d_2 = c \cdot \tau_2 \tag{5}$$

$$d_1 - d_2 = c \cdot (\tau_1 - \tau_2) = c \cdot \tau \tag{6}$$

$$d_1 + d_2 = D \tag{7}$$

$$d_1 = \frac{D+c\tau}{2} \tag{8}$$

$$d_2 = \frac{D-c\tau}{2} \tag{9}$$

Where d_1 is the Distance of leakage from sensor 1, d_2 = Distance of leakage from sensor 2

3. Results and Discussion

After the hardware and software development has been integrated, data collection is the next step, and the result obtained is discussed thoroughly in this Section. There are two parts of experimental testing in this Section. The first is the statistical analysis, and the second is the cross-correlation technique. Statistical analysis is the crucial part of this project as it is a test to determine the differences between the values of pressure ideal and leakage conditions in the pipeline.

The total length of the pipeline is about 5 m long. There are two pressure sensors installed, which are in the pipeline 1 and pipeline 3. At each pipeline 1, 2, and 3, there 3 simulation leak valves installed to simulate a leakage situation, as shown in Fig. 4. In an ideal condition, there is no leakage present along the pipeline, and the pipeline is theoretically being operated in a normal condition without no water loss. The reading obtains for both sensors are as follows.

The average reading in Table 1 was determined from 5 different readings taken every minute in 5 minutes. Sensor 1 is placed at pipeline A, while sensor 2 is placed at pipeline B. Based on the reading, there is a sudden drop in the voltage of sensor 2. This may be due to the insufficient pressure supply in the pipeline since the location of sensor 2 at pipeline C is quite far.

Table 1. Reading in an Ideal Condition

Parameters	Sensor 1 (Voltage)	Sensor 2 (Voltage)
Average reading	1.00	0.39
Minimum reading	0.98	0.39
Maximum reading	1.00	0.41

Fig. 6 shows the simulation valve location installed at pipelines 1, 2, and 3. When a leak in pipeline 1 is simulated, the reading is tabulated as shown in Table 2. From the Table, the average sensor reading for the leaking condition in pipeline 1 is 0.93 V, while the sensor 2 average reading is 0.32 V. There is a slight drop in both pressure sensors reading from their ideal voltage value reading. The drop situation in the voltage reading for both sensors can be expected as water is flowing out from the simulation of the leakage valve along pipeline 1.

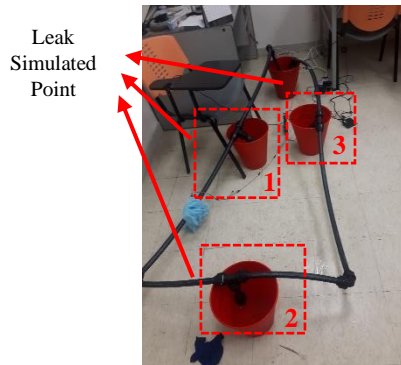


Fig. 6. Simulation of Leakage at pipelines 1, 2, and 3.

Table 2. Simulation of Leak at Pipeline 1

Parameters	Sensor 1 (Voltage)	Sensor 2 (Voltage)
Average reading	0.96	0.33
Minimum reading	0.95	0.32
Maximum reading	0.97	0.34

When a leak in pipeline 2 is simulated, the reading is tabulated as shown in Table 3. From Table 3, the average reading for leak condition in pipeline 2 in sensor 1 is 0.95 V, while sensor 2 average reading is 0.34 V. There is a slight drop at 0.04 V and 0.06 V for sensor 1 and sensor 2, respectively, from its ideal condition value reading. It is also different in voltage reading compared to when leak 1 is simulated. Simulation of a leak at pipeline 2 shows a smaller value compared to leak 1 simulation. This is associated with the distance of the leak point to the sensor. Since the distance of the leak is 2.5 m from both sensors 1 and 2, the water pressure will take a longer time to produce the same amount of reading as during the simulation of a leak at pipeline 1. With the same flow rate applied for all the experimental testings, the reader could validate the hypothesis that the longer the distance of the leak source to the sensor, the lower the voltage reading obtained by the sensor. From the experimental test, the minimum and maximum readings for sensor 1 are 0.95 V and 0.97 V, respectively. While the minimum and maximum readings for sensor 2 are 0.32 V and 0.34 V, respectively.

Table 3. Simulation of Leak at Pipeline 2

Parameters	Sensor 1 (Voltage)	Sensor 2 (Voltage)
Average reading	0.96	0.33
Minimum reading	0.95	0.32
Maximum reading	0.97	0.34

When a leak at pipeline 3 is simulated, the reading is tabulated as shown in Table 4. From Table 4, the average reading for leak condition in pipeline 3 in sensor 1 is 0.98 V, while sensor 2 average reading is 0.36 V. There is a slight drop at 0.02 V and 0.03 V for sensor 1 and sensor 2, respectively, from its ideal pressure value reading. The reading from Table 4 also differs during the experimental testing on the leak at pipeline 1 and pipeline 2 simulations. The reading obtained in the simulation of a leak at pipeline 3 shows a smaller reading compared to the other two experiments. As discussed earlier, this is due to the distance of leakage to the sensor. From the experimental test, the minimum

and maximum reading for sensor 1 are 0.97V and 0.99V, respectively. While the minimum and maximum readings for sensor 2 are 0.35 V and 0.37 V, respectively.

Table 4. Simulation of Leak at Pipeline 3

Parameters	Sensor 1 (Voltage)	Sensor 2 (Voltage)
Average reading	0.98	0.36
Minimum reading	0.97	0.35
Maximum reading	0.99	0.37

Based on the data collected in [Table 1](#), [Table 2](#), [Table 3](#), and [Table 4](#). The reader could obtain the relationship between the distance of leakage and leakage. The data trend is plotted in [Fig. 7](#) for sensor 1 and [Fig. 8](#) for sensor 2. Based on the statistical analysis discussed above, an average reading is determined. The data is crucial to developing logical programming in the LabVIEW software development to differentiate the characteristics of an ideal and leak location. As shown in [Fig. 7](#) and [Fig. 8](#), the reader can see the trend of the relationship graph between voltage and distance for sensor 1 and sensor 2, respectively. For the sensor 1 graph, the relationship between voltage and distance is directly proportional. Based on the trend in [Fig. 7](#), as the leakage location keeps on increasing, the pressure sensor reading will also increase, and when the distance of leakage is 5 m, the voltage reading will approach 1.00 V. This is acceptable as at 5 m, there is no leak occurs due to the length of this pipeline prototype is 5-meters long. For the sensor 2 graph, the trend in [Fig. 8](#) shows the voltage increase exponentially when the distance of the leakage location is increased. Both graphs produce a directly proportional relationship between voltage and distance.

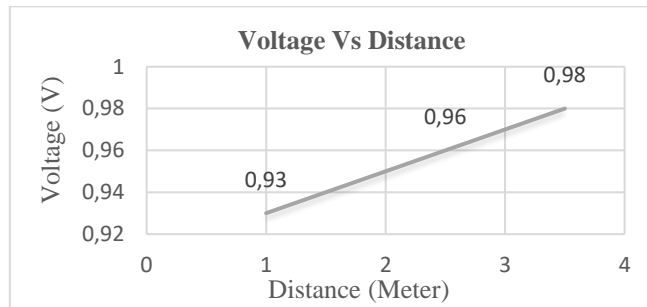


Fig. 7. Sensor 1 relationship graph

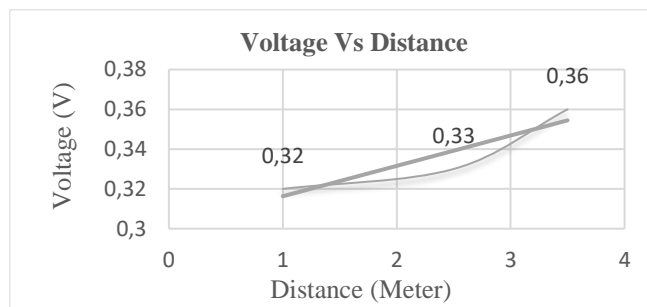


Fig. 8. Sensor 2 relationship graph

To validate the location of estimation via a statistical approach, the cross-correlation technique is used to increase the capability of the total system in detecting leakage location. Firstly, correlation of the signal was done in the simulation of the leakage at pipeline 1. The result obtained is shown in [Fig. 9](#).

Fig. 9 shows the estimated time delay is 2.3 seconds. The correlation coefficient amplitude during a time delay of 2.3 seconds is 0.89. The distance of leak between sensor 1 and sensor 2 can be calculated by inserting the value of time delay and correlation coefficient into equations (8) and (9).

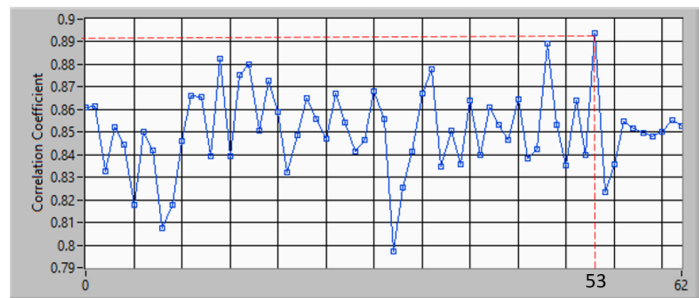


Fig. 9. Cross-Correlation at Leak 1

Both d_1 and d_2 gave an error in the estimated distance, which is 9.6% and 8% error as tabulated in Table 5. The measured distance between sensor 1 and leakage location is 1m, but the estimation leak location via cross-correlation gives 1.48 m, while the measured distance between sensor 2 and leakage location is 4 m, but the estimated distance is 3.60 m. The amount of error displayed in Table 5 is not significant. Thus, the value can be accepted since there are also elbow joints present in the construction of the pipeline that might interrupt the pressure reading. The overall equation of the cross-correlation is represented in equation (3).

Table 5. Estimated Distance at Leak 1

Parameters	Measured Leak Distance, Meter	Cross-Correlation Estimated Distance, Meter	Error (%)
d_1	1	1.48	9.6
d_2	4	3.60	8.0

Equation (3) considered the value of noise generated, and this technique is mostly applied in a straight-line pipeline. Since there are also elbow joints present along prototype pipeline 2 that might interrupt the ideal correlation signal, it also can be considered as the noise signal generated by $n_1(t)$ and $n_2(t)$. In this project, the value of the noise signal generated is neglected. Thus, the amount of error (%) present in the estimation of leakage distance can be accepted if the noise signal is considered.

Next is by correlating signal during simulation of leakage at pipeline 2. The result obtained is as in Fig. 10. As depicted in Fig. 10, the estimated time delay for both signals to become aligned is 0.9 seconds. The correlation coefficient during time delay of 0.9 seconds is 0.89. By using the same equations (8) and (9) to find the estimated distance, the result is tabulated and compared as in Table 6.

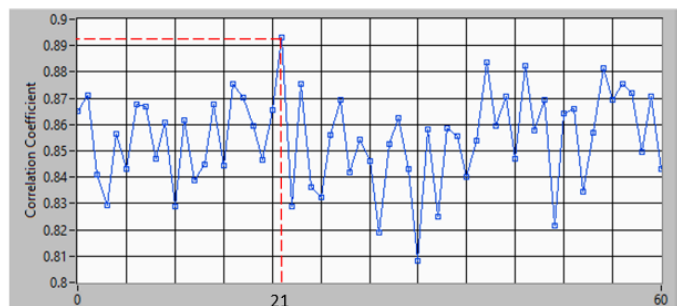


Fig. 10. Cross-Correlation at Leak 2

From Table 6, both cross-correlations estimated distances produce an error of 2% for the distance between leakage and sensor 1 and 0.2% for the error between leakage location and sensor 2. Both errors are in a small percentage, which is 2% and 0.2%, respectively, for d_1 and d_2 . The error might

be due to measurement error during taking the measurement of the distance of leakage from the sensor as students use measuring tape, and since the HDPE is not completely in a straight line, some measurement error might occur during the measurement of the length of the pipeline process. The reader could also notice that during the correlation of signal at Leak 2, the amount of error produced is much smaller with only 2 % maximum error compared to the correlation of signal at Leak 1 with maximum error produced up to 9.6 %. As discussed earlier, noise signal plays a significant role in the equation (3).

Table 6. Estimated Distance at Leak 2

Parameters	Measured Leak Distance, Meter	Cross-Correlation Estimated Distance, Meter	Error (%)
d_1	3	2.90	2.0
d_2	2	2.01	0.2

The location for Leak 2 is pipeline 2 near the elbow joint. The small error produced could be related to the location of the leak, which is near the elbow joint, and since the elbow joint is the noise signal. In this case, with the small amount of error produced, the noise signal could be represented as below by removing the noise signal from the equation (3).

$$n_2(t) = n_1(t) = 0 \quad (10)$$

Lastly, the cross-correlation technique is used to correlate the signal during the simulation of leakage at pipeline 3. The result obtained is shown in Fig. 11. As depicted in Fig. 11, the estimated time delay for both signals to become aligned is 2.5 seconds. The correlation coefficient during a time delay of 2.5 seconds is 0.88. The estimation distance via cross-correlation is tabulated and compared in Table 7.

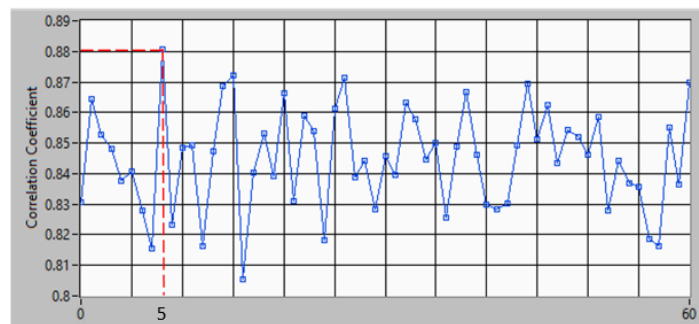


Fig. 11. Cross-Correlation at Leak 3

As clearly shown in Table 7, both cross-correlations estimated distances give an error of 8% for the distance between each sensor and leakage location. The measured distance of leak location for d_1 is 4 meters. The estimation leak location result was 3.6 meters. A slight error of 8% was found from a measured distance. While, for d_2 , the measured distance of leak location is 1 meter, and the result of the estimation of leak location was 1.4 meters. The same percentage of leak location error was found, which is 8%. Based on the earlier discussion, it can be concluded that the error produced at leak 1 and leak 3 simulation points is larger compared to leak 2. Simulation of Leak 2 is small due to the location of the elbow joint, while leak at pipeline 1 and pipeline 3 does not consider the noise signal generated. Thus, the implementation of the cross-correlation technique in this project can be accepted, and the overall equation of cross-correlation (3) can be applied throughout this project.

Table 7. Estimated Distance at Leak 3

Parameters	Measured Leak Distance, Meter	Cross-Correlation Estimated Distance, Meter	Error (%)
d_1	4	3.60	8
d_2	1	1.40	8

The next experiment is the protection system for the microcontroller. The test is done by using the accelerometer sensor embedded inside myRIO-1900. Since the accelerometer is based on three-dimensional directions, which are x , y , and z directions, it is suitable to be used as the protection system when any sudden change in the direction occurs in myRIO-1900. The initial value of the x , y , and z positions of the microcontroller was determined at the horizontal position, as shown in Table 8.

Table 8. Microcontroller Initial Position

Dimensions	Value
x	0
y	0
z	1

Fig. 12 shows the microcontroller protection monitoring system. An indicator representation of each x , y , and z -direction is developed. In a normal position, the color of the indicator will turn green. In the event that there are alterations in the value of the direction, the indicator will turn red indicator as shown in Fig. 13, indicating that the microcontroller is not in a normal position. The initial position value of the microcontroller was used as the threshold value for the normal condition when the system is in safe mode. The protection system will display an alarm indicator in LabVIEW software in an event where the value of x , y , and z are altered from the initial value.

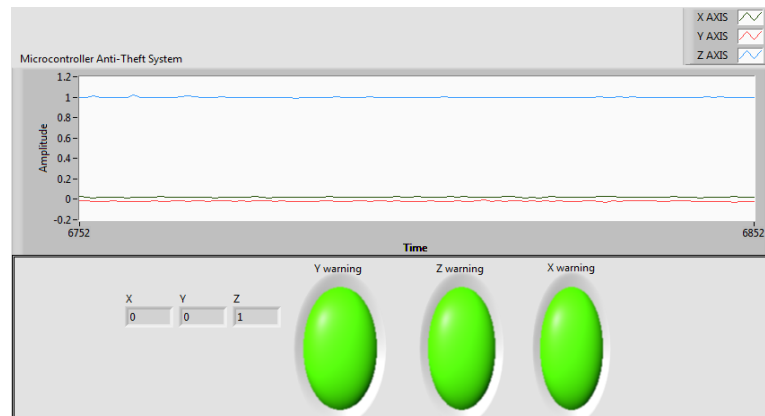


Fig. 12. Microcontroller Protection System Monitoring

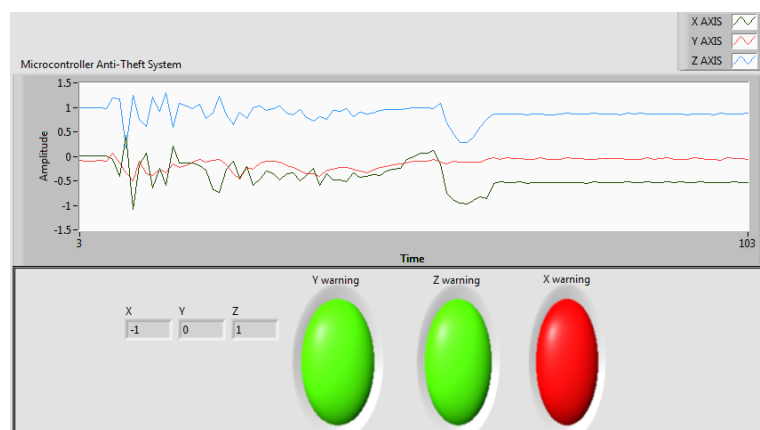


Fig. 13. Example of indicator test during altered in the x -direction

4. Conclusion

By setting the desired threshold in the software development, the total system is able to detect and differentiate between the ideal and leakage conditions of the pipeline. The distance of leakage is

validated by applying the cross-correlation technique between the signal from sensor 1 and sensor 2 to obtain the distance of leakage along the pipeline. From the correlation of two different signals, the distance of leakage can be determined. There is a slight error present in terms of distance in detecting the location of the leakage for each of the simulated leakages by using the cross-correlation technique, but the error is below 10%, and it is acceptable. From the experimental test, this project is a success as it fulfills the objectives of the study, and the output result in the monitoring system is the desired result.

For future work, it is recommended to test this project in a longer pipeline to increase the capability of this system. Different kinds of sensors, such as flow sensors or velocimeters, can be implemented in this project. The usage pressure sensor only gives a slight difference in pressure drop due to the input pressure is not high enough and installing a pressure sensor makes the testing to be called destructive testing (DT), which is not convenient for a pipeline. Other leak detection methods, such as an acoustic method, could be implemented in this project.

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