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Pipe leakage detection system with artificial neural network

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ABSTRACT

This project aims to develop a system that can monitor to detect leaks in water distribution networks. It has been projected that leakage from pipelines may lead to significant economic losses and environmental damage. The loss of water from leaks in pipeline systems accounts for a large portion of the water supply. Pipelines are maintained throughout their lives span; however, it is difficult to avoid a leak occurring at some point. A tremendous amount of water could be saved globally if automated leakage detection systems were introduced. An embedded system that monitors water leaks can efficiently aid in water conservation. This project focuses on developing a real-time water leakage detection system using a few types of sensors: water flow rate sensor, vibration sensor, and water pressure sensor. The data from the sensors is uploaded and stored by the microcontroller (NodeMCU V3) to the database cloud (Google Sheets). The data that is stored in the database is analyzed by artificial neural network (ANN) by using Matlab software. An application is developed based on results from ANN training to detect the leakage event. Implementing the proposed system can increase operations efficiency, reduce delay times, and reduce maintenance costs after leaks are detected.

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1. INTRODUCTION

Pipelines are becoming a more popular method for transporting bulk water in many nations since it is a safe and cost-effective alternative. Each year, a large number of new pipelines are arranged and built-in public and worldwide. Pipeline leaks can potentially cause a wide range of natural disasters and financial problems [1]–[6]. The outflow of treated water from this country is higher than 4,27 billion liters due to ageing pipelines. A leading expert warns that unless reactionary measures are taken, more will be wasted. The consequences of this problem may also harm society [7]–[11].

For example, a water treatment plant pipeline leak at Sungai Selangor caused a water cut in October 2020. In a statement, Air Selangor reported that more than 686 areas in Petaling Jaya, Gombak, Klang, Shah Alam, Kuala Lumpur, and Hulu Selangor districts were affected. Societies and economies are negatively impacted by this situation [12]. A pipeline can leak for various reasons, such as incorrect installation, the movement of soil around the pipeline, the depth of placement of the pipeline, and the material of the pipeline itself. In order to minimize damage, leak detection that is accurate and enables a quick response is imperative [13].

As per the specification report by Ranhill SAJ 2018, clean water shall be used for pipe leak testing, and air trapped inside the system shall be exhausted via a vent. A pressure test conducted at the end of 24 hours, and the rate of loss has been calculated by dividing it by time [14]. A long time is required for this method to yield a result, and it is less accurate.

This project proposes using a piezoelectric sensor, flowrate sensor, and pressure sensor attached to a steel pipe to detect pipeline leaks. Any leakage detected will be sensed by the sensor, and data automatically been sent to the cloud (Google Sheets). Then, artificial neural networks (ANNs) has been used to analyze the data to determine the degree of leakage in the pipe.

A pipe leak occurs when liquids and gases escape from the pipeline through a leak or crack. A relationship between leak outflows and flow conditions of water distribution systems must be defined to understand pipe leakage conditions. The relationship between these two variables is crucial in water distribution systems. The leak outflow, Q_L, depends mainly on the effective leak area $C_L A_L$- defined as the product of the discharge coefficient $C_L$and of the leak area A_L- and on the total head inside the pipe, H, or on the piezometric head, h. Other quantities can also be considered, as pipe thickness, discharge conditions (in air/submerged), ratio Q_L/Q_u (with Q_u being the discharge upstream the leak), and, for large leaks, leak shape [15], [16]. In steady-state conditions, the general equation

$$Q_L = aH^b \tag{1}$$

is often used [17], that includes the Torricelli's equation

$$Q_L = C_L A_L \sqrt{2gH} \tag{2}$$

when a= $C_L A_L (2g)^{1/2}$ and b=1/2. The (1) is used both at a global/district area scale, with H being a "mean pressure" over the district and Q_L is the flow entering the district and at a local scale, considering a single leak. In both cases, on a local as well as on a global scale, the variation of $C_L A_L$ with H can be used to explain the increase of the b exponent with respect to Torricelli's formula [18].

An artificial neural network (ANN) is a simulation model that simulates the way of the human brain analyses, and processes information. With ANN, problems that are impossible or difficult to solve by human or statistical standards are resolved. As a result of self-learning capabilities, this computing system is able to produce better data analysis. ANNs consist of hundreds or thousands of artificial neurons, called processing units, interconnected by nodes. A processing unit consists of an input unit and an output unit. Input units receive information in a variety of forms and structures based on internal weightings, and neural networks are learning about information to produce an output.

ANNs with feed-forward connections have connections between processing units that do not form a cycle. The input layer, hidden layer, and the output layer of this ANN are all made up of layers. It is the first and most straightforward type of ANN and be implemented in this proposed system.

2. RESEARCH METHOD

This project aims to develop a pipeline leak detection system that operates in real-time, using the ANN [19]–[23] and internet of things (IoT) [24]–[26]. Wireless communication is possible with this system. A cloud server hosts the outputs data of the system, which is analyzed by ANN. As a result of the cost and instrumentation limitations, vibration sensors module (SW 420), flowrate sensors (YF-201), and water pressure sensors (SKU SEN0257) have been used to sense vibration, flowrate, and pressure from the pipeline.

2.1. Methods

In this project, the vibration sensor, flow rate sensor, and pressure sensor has been used to detect water leaks. As a result, the sensor does not obstruct water flow but simply senses the vibration, flowrate, and pressure and collects the data. Microcontrollers are used in this project to read data from multiple sensors and monitor pressure, vibration, and flowrate. Data has been collected and uploaded to the cloud by the system. A neural network from MATLAB software has been used to analyze the stored data. Then, a minimalist application is developed based on ANN analysis results to detect leaks. The flowchart in Figure 1 provides an overview of the overall process.

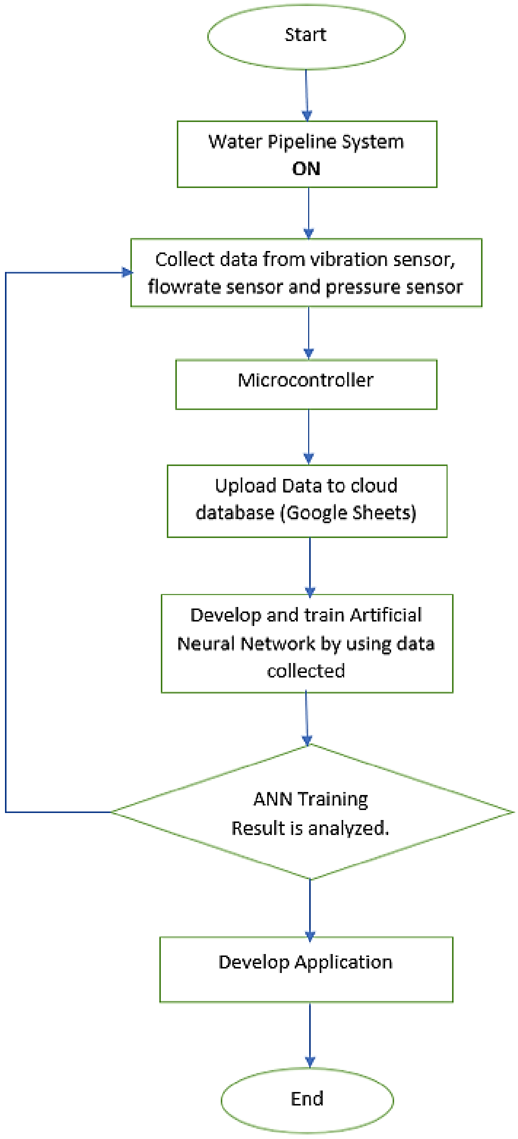

Figure 1. The flowchart for overall process flow

3. RESULTS AND DISCUSSION

3.1. Flowrate

According to Figure 2, two types of water flowrate data were taken. There were the flowrate data for the pipeline system with no leakage and with a leakage event. The unit of measurement for the above data distribution is liters per minute (L/min). The flowrate data for a pipeline system with no leakage event is higher than the flowrate data for a pipeline system with a leakage event. Due to no leaks in the pipeline, water flows in one way without being disturbed by changes in flow velocity (V). The water would flow outside the pipe if the leak occurred in the pipeline. This may affect the flow velocity of water when such an event occurs. When a leak has occurred, the flow of water becomes slower. Based on Figure 3, flowrate (Q) is defined to be the volume (v) of fluid passing by some location through an area during a period of time (t). Based on (3), the flowrate value (Q) decreased if the velocity of water decreases.

$$Q = \frac{v}{t} \tag{3}$$

3.2. Vibration

Figure 4 gives a comparison of vibrations based on two different data samples. Vibration data from pipeline systems that had a leakage and those without a leakage show significant differences. Vibration data for leakage events is very high compared to vibration data without leakage events. The pipe produced a force that resulted in an unstable flow of water outside the pipe that caused this situation to occur. Despite the absence of leakage on this pipeline system, vibrations do occur. However, they are deficient in comparison with the vibration reading on the pipeline system with an event.

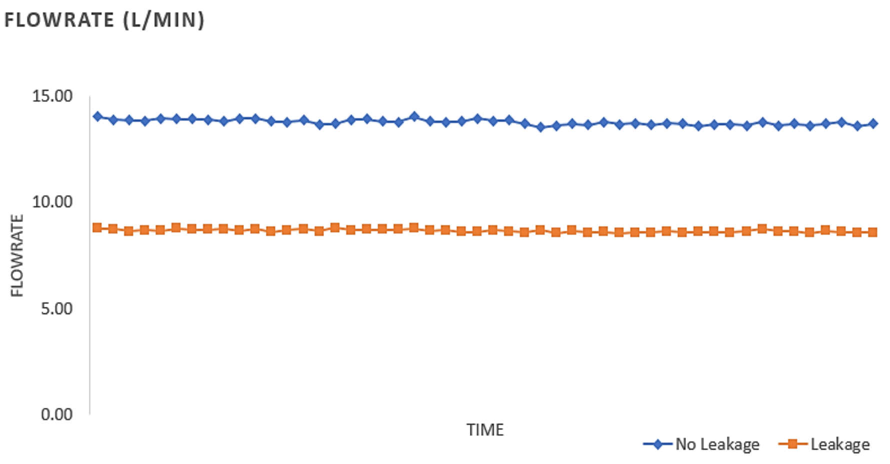

Figure 2. Flowrate result comparison

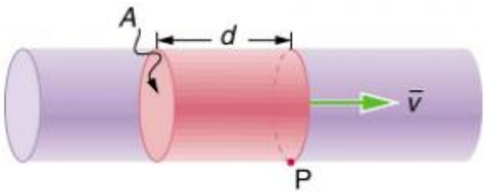

Figure 3. Flow rate and its relation to velocity

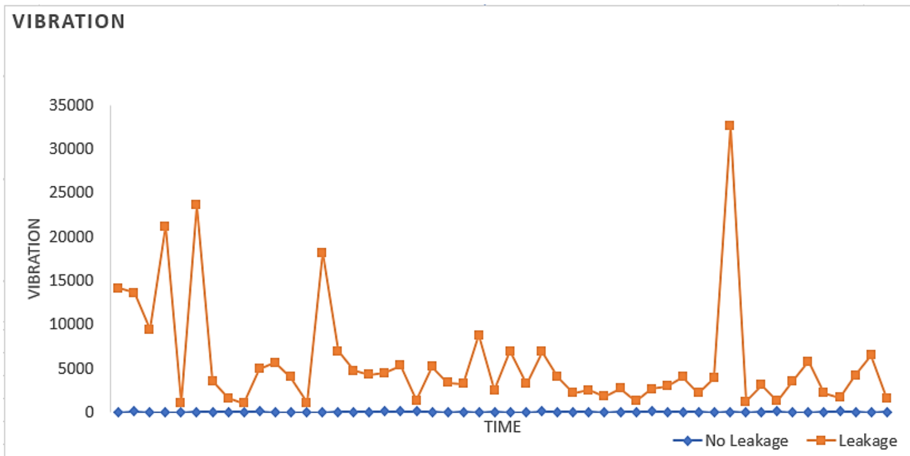

Figure 4. Vibration result comparison

This project finds vibration to be a particularly sensitive parameter because of many external disturbances that can prevent the data from being read properly from the vibration sensor, for example, the vibration from the water pump, or the presence of unwanted movement close to the pipeline system. Figure 5 shows the precautions taken while working on this project to obtain accurate data and reduce an external disturbance.

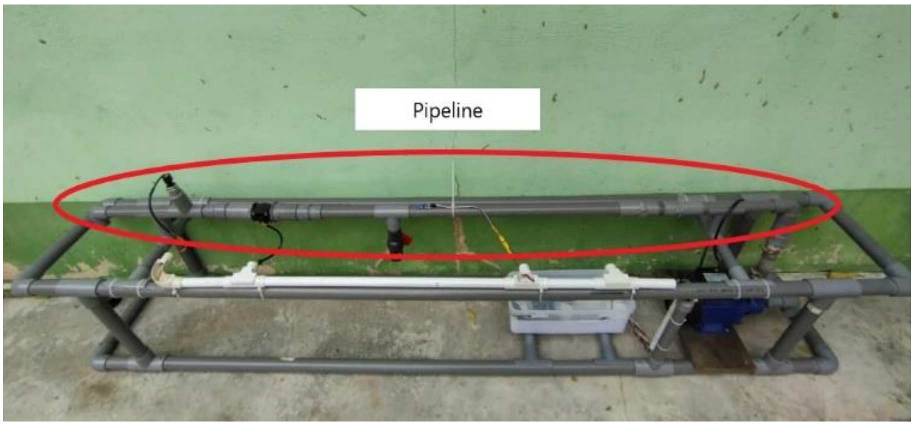

Figure 5. The frame that supports the pipeline system

3.3. Pressure

Figure 6 shows the different results of pressure reading data for pipeline systems with leakage and no leakage. Based on the results, the pressure data reading from the pipeline system shown in Figure 5, with a leakage event is lower than pressure data for pipeline systems with no leakage event. It is because the pressure in the pipeline system is decreased due to the existence of the leakage.

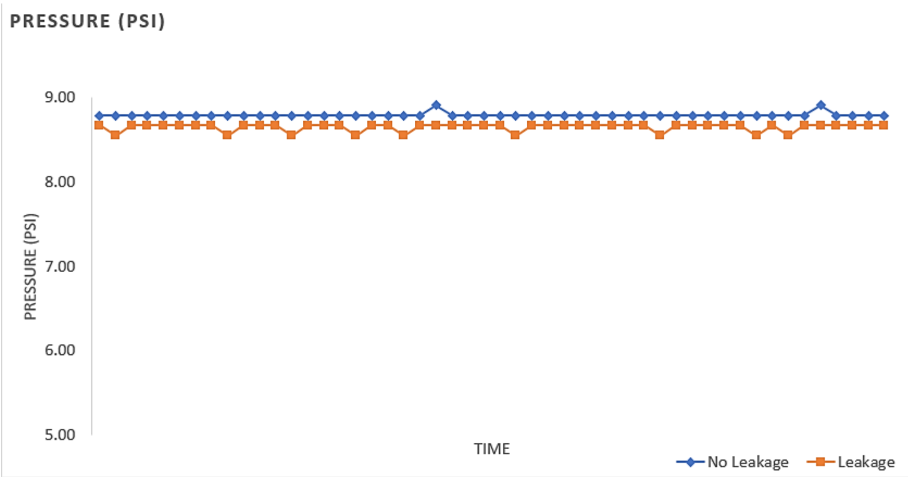

Figure 6. Pressure result comparison

3.4. Liquid output

Figure 7 shows the results of the liquid output of the pipeline system for leakage event and no leakage event. From the results of both of the liquid output, the result is increased directly proportional over time. But there is a noticeable difference in term of the gradient of the results. The gradient liquid output results for no leakage event in the pipeline system is steeper than results for leakage event in the pipeline system. This is because of the difference in the volume of water flow through the pipeline. When the leakage has occurred, water flows outside the pipe and caused the loss of volume of water in the pipeline.

3.5. Result of artificial neural network (ANN)

In order to develop this ANN, it needs many data to develop a more stable and accurate ANN. In this project, the amount of data used to develop ANN is more than 3000 data for both types of data leakage and no leakage event. This ANN consists of a single layer and 10 nodes. Figure 8 to 11 show the result of ANN training, validation, testing and correlation coefficient R^2 for this project respectively.

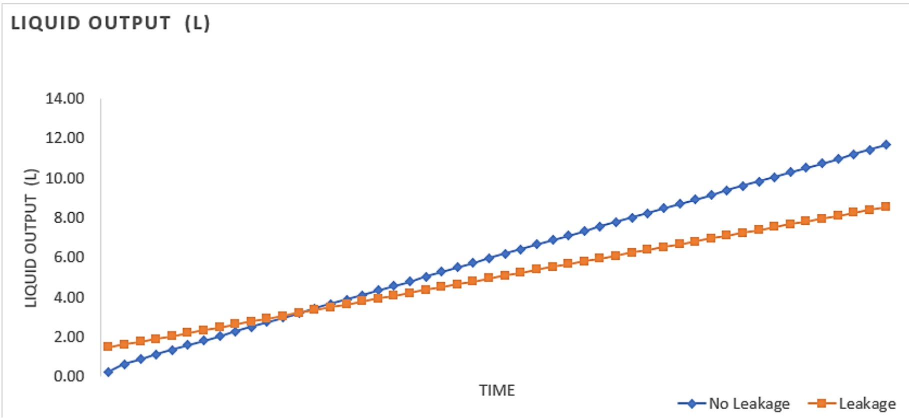

Figure 7. Liquid output result comparison

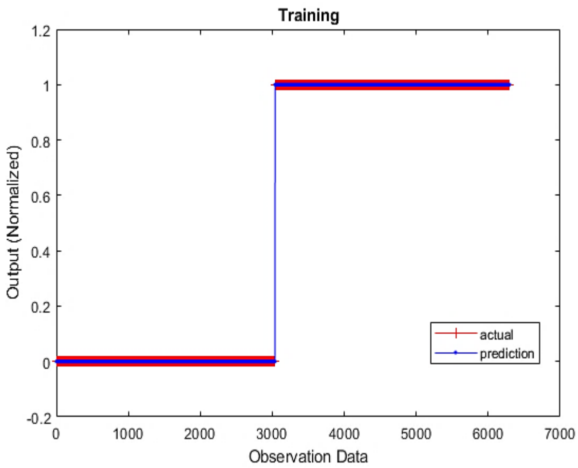

Figure 8. Results of ANN training

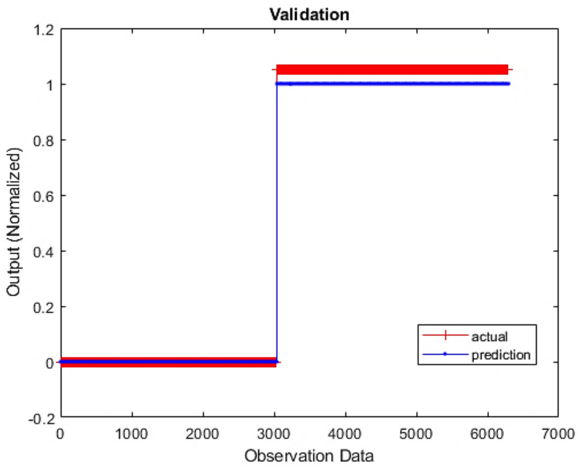

Figure 9. Results of ANN validation

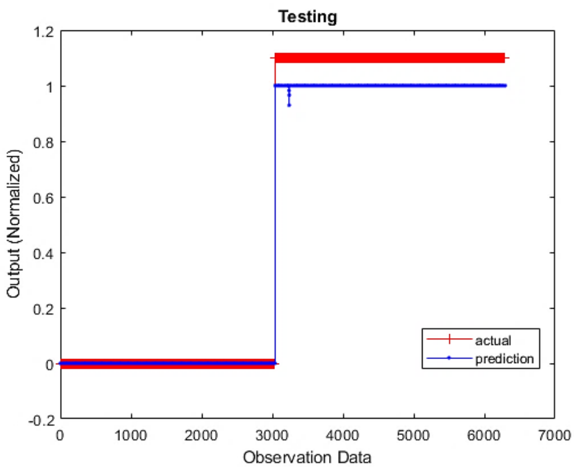

Figure 10. Results of ANN testing

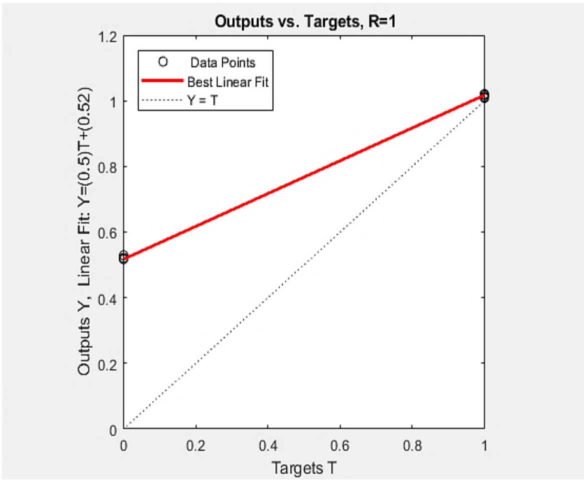

Figure 11. Results for output vs target

3.6. Result of application development

An application is developed to the interface for the user to key in the sensor reading. This application has been determined the existence of leakage events based on the data given by the user. This application interface is developed by using application designer on MATLAB Software, and the functionality of the application is determined based on ANN training results. The application is extracted from the MATLAB software and is a standalone application in extension format (exe). Figures 12 and 13, show the result "NO LEAKAGE" and "LEAKAGE ALERT!!!" when the random untrained data for no leakage event and leakage event on the pipeline system is key in by the user to the application.

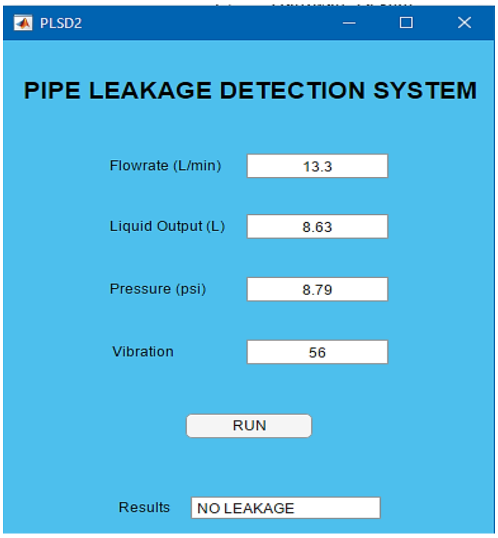

Figure 12. Application result for no leakage event data

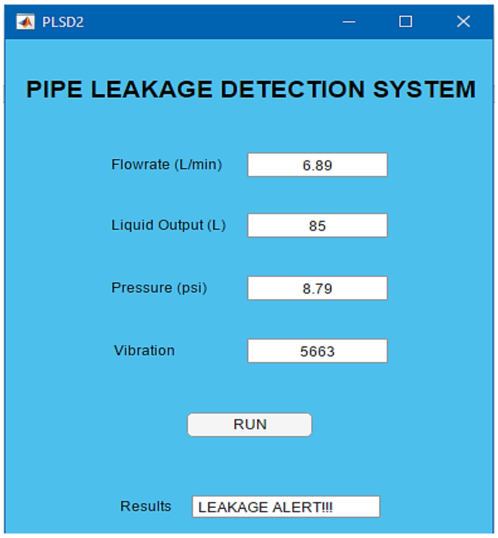

Figure 13. Application result for leakage event data

4. CONCLUSION

In conclusion, this project is developed successfully. With an algorithmically programmed approach, it can determine leakage on pipelines based on real-time data. Additionally, the data was uploaded to the cloud database, which can be used as a reference or record in the future. In addition, the pipe leakage detection system based on ANN application has been successfully developed and can detect the leakage event with real-time data from the sensor. This project also includes an application representing the interface of the system. As well as being effective, easy to use, and compatible with a wide range of devices, this application also works properly.

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