Hydroinformatics based technique for leak identification purpose – An experimental analysis

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Abstract. Analysis of single point pressure transient signal has the potential of providing information on the pipeline system. The technique uses the frequency response and experiments are satisfactory for low-frequency bandwidth. The concept behind this approach is that reflections are detected by leak-induced disturbances. Such reflections are often very difficult to identify, particularly because of excessive noise. The common approach to boost the analysis is to use a data denoising approach. The wavelet transforms for leak detection in water pipelines are proposed in this article. The wavelet filter is optimally calibrated using maximal kurtosis values and is chosen for leakage detection. The suggested approach is tested using high-noise laboratory test signals. The findings show that the method is superior to current signal processing methods for the conditions used. The system permits not only the detection of leakage but also the location and evaluation of its magnitude with errors of less than 7%.

Keywords: Hydroinformatics; Pressure Transient; Wavelet; Leak; Non Revenue Water.

1. Introduction
The differential within the quantity of water produced in between distribution is referred to as non-revenue waters. This is linked to many causes, such as system leakage through the pipe. Water failure is a common concern and a critical issue for water management [1]. Statistical research showed that Malaysia’s usual non-revenue water level was in 2010, at 29.4 per cent, leading to large currency, weight, and supply crises and abuse of living. [2]. In 2017, the average grew to 35.3% [3]. The effect can therefore refer us to the negative consequences and actions of governments. High non-revenue water amount makes a negative reputation for water supply authorities [4]. It reflects the delicacy of the water distribution network [5]. The consequence will also have negative implications on infrastructure and the ecosystem. [6]. The operators of water supplies have a negative thought about strong non-income sewage. This is the issue of the instability of the water supply [7] [8].

There are several ways to reduce and manage non-revenue water [9]. A very economical approach is responsive monitoring as the concern is normally verified by the customer or noted by the own operations of the companies. The procedure can be tolerated in locations in which the supplies are sufficient or great value for money. In comparison, the effective maintenance of the leakage consists of two techniques, a regular survey and leakage monitoring. Continuous review is a reason to watch for
leaking pipes and adjust and interpret the metered flow into the temporary zone to track night traffic in large volumes. Flow control is the tracking of leakage in areas or regions and optimises leak detection activities [10]. However, traditional leak detection systems are often expensive and must be chosen for more advanced techniques in a developing nation. The sales plan would also be a drawback.

The leak detection analysis can be pioneered in finding the leak and taking measures for business. The dilemma we have to solve, though, is the desire to benefit from the industry. The running expenses must be smaller to save revenue. Knowledge must be provided to more performance and accuracy. Method review can be replicated to track the pipe network system. The transient pressure technique may indeed evaluate leakage detection [2]. For example, transient analysis may provide critical leak detection, including an exact transient model for a device. [11]. The benefits of transient analysis and the number of problems in a single method can be catastrophic further explanations. [11]. In all these studies, the identification of signal reflection is an important element. The most generally employed signal processing techniques used in transmission pipelines are correlation, cepstrum and wavelet analysis [12]. Most leak detection work is directly linked to water pipelines. This is because the flow of water is also correlated with excessive quantities of noise. Weak Signal Noise Ratios (SNR) along with reflection produced by geometric pipeline properties, such as joints or valves, make it increasingly hard to detect water leakages in the process.

It is necessary to convert the time domain signal into the frequency domain in order to reveal the consequence of the signal pulse. Previously there have been several transformation techniques such as Fourier (FT), Short Time Fourier (STFT), and Hilbert Transform (HT). Wavelets Transform (WT) is a sort of study of ways to measure signal time and frequency. It can evaluate with different distinguish ratios; however, it also has the capacity to represent the sectional characteristics of the signal in terms of time domain and frequency domain. This is a sectional analysis approach that is ideal for consistent signal analysis, time and frequency identification, anomaly monitoring and denoising with a fixed-size window but changeable appearance and a growing time and frequency range [13]. Wavelet Transform in this study is used to analyse reflection signal generates from the leak on pipeline and remove the signal noise with the use of a morlet as a mother wavelet.

2. Wave propagation in pipes

Multiple sensors, include pressure, flow metres, and valve sensors are needed for existing monitoring procedures. The motion of the wave may be identified at a fixed point below the surface with a change of pressure [14]. Consequently, improvements in the structure of the pipeline such as the valve, intersection, block and leaks would reflect. This reflection is called a pressure wave, which passes through the pipeline at the sound speed [10, 15]. The pressure wave is simulated with the time domain based on modelling techniques in the transmission line. Wave can also be observed by fluid particle movement. The wave time can be captured by forming a pressure wave with a single remote sensor at a certain spot. Speed is the distance that the wave travels to that distance from the time the wave travels. Where \( l = \text{length} \), \( t = \text{time} \) and \( a = \text{speed of sound} \). The pipeline length can be determined by several times in pipelines with sound speed.

\[
l = ta \tag{1}
\]

The speed of sound is formulated from multiplying of fluid properties which are \( \gamma \), \( Ru \), and \( M \) and also the temperature in degree Kelvin.

\[
a = \sqrt{\frac{\gamma RT}{M}} \tag{2}
\]

The tube is supposed to be rigid since flexible tubes slow down the system speed. The waves of pressure only travel in the fluid.
3. Experimental design

A pressure sensor is used in this research to obtain the signal reaction produced by the solenoid valve. The solenoid valve is normally closed during the operation and irregularities in the water hammer are caused by the opening and closing of the valve for three consecutive periods. The test data was obtained using MATLAB tools.

The research was conducted in a 152.3-m (Fig. 1) platform circular loop experimental test rig. The device consisted of Medium High Density Polyethylene (MDPE), an external 60-mm cross section, medium diameter within the 55-mm and 2.6-mm cross-section of thickness. A round hole with different sizes in diameter was fitted on 49.7-m (Fig. 2) from the pipeline sample act as the leak. A water surface storage is connected to the tube exit from the tube locks. This protects fast expansion phenomena of the pressure waves and decreases the adverse pressure wave, since data are affected in the transducer. The testing process has a driven sound speed of 524.3 ms⁻¹. Fig. 1 shows the pressure sensor and the solenoid valve that is positioned 58.9-m (Fig. 2) metres away from the electrical motor to prevent disturbance during the data acquiring. The product of friction is caused by the flow of the water and humidity from the channel. This approach is frequently used in dam research. The concept was taken from the use of pressurised water progression in the pipeline system. The pressure transient reaction occurs hypothetically when the water movement is interrupted suddenly, by shutting or opening the valve in the pipeline system. In combination with the pipeline system, the wave propagation of water will be produced, as are the wave propagation characteristics as a leak detection method, and the pipeline network. The wave of the pipeline network travels with several other signals according to the size of the leak, leak duration, tube-style function and pipe diameter.

Fig.1 illustrated the experimental test platform in the Fluid Mechanic Laboratory at the University of Malaysia-Pahang. The fire hydrant cap was designed and manufactured to fitted the solenoid valve and the pressure sensor for the test run. The solenoid valve generates water hammer phenomena in both components of the device and a pressure sensor is used for signal acquisition. In certain situations, the system may be shut down with the abrupt opening or closing of the valve and the pump failure. This produces a "water hammer" on the pipeline. This phenomenon also affected both pressurise pipe structures and caused sudden pressure change and pipe collapse [16]. This effect is generated by the solenoid valve (Fig. 1) for creation of a water hammer in pipeline system. The same situation is developed in actual situations in a pressure condition in the underground pipe [17].

Figure 1. Experimental test rig in laboratory scale.
4. Results and discussion
The test starts by obtaining the transient pressure signal from a test rig using MATLAB. The acquired signal regains the properties of the pipeline overall. Water hammer waves dispersed in both directions along with the pipeline system away from the outburst source via the speed of sound in the water pipeline system. The tests were performed with the MDPE pipe. 10kHz of sampling frequency were sample at 1 second. The NI-9234 card and DASYLAB were used in the data acquisition phase then the signal further analysed using CWT through MATLAB platform. A clear transient (fig. 3a and 3b) can be seen at the start of the response signal indicates the opening and closing the solenoid valve. In the raw response, no other important features were available since the reflection signal was masking in the signal noise. As illustrated in Fig. 3(a) and 3(b), the raw signal failed to detect clear reflection signal generates from the leak and any disturbances in the pipes. Therefore, the further analysis is needed to extract the information contained in the signal response. The reflected signal was combined with the Morlet as a mother wavelet for every data set. The signal then analysed by continuous wavelet transformation (CWT). The small scale of the mother wavelet recognises that the frequency is high [18]. Wavelet compressed the signal and vice versa.

![Figure 2. Experimental test rig sketch.](image)

![Figure 3. Raw signal (a) No-leak pipe (b) Raw signal for leak pipe.](image)

The step of signal analysis began with the signal denoising through the wavelet-based filter by tuning the maximum value of kurtosis. This is because the background noise and modulations of the reflected signal are too strong in the analysed data. The denoised signal then transformed into time-frequency representation and time-frequency (TF) spectrum through CWT as shown in Fig. 4,5,6 and 7. The plots had uniform time \( t_r = t / Tc \), where: \( T_c = 2l / c \) is the characteristic time of the pipe; \( l \) is the length of a pipe; \( c \) is the speed of the wave of pressure. In Fig. 3, the rising spikes at \( t = 1 \) sec are equal to the start of the solenoid valve shock wave. The pressure wave then travels along the pipe and reflects the upstream reservoir. At \( t_c = 1 \) the pressure wave enters the valve and reflects and induces a rapid pressure
drop. The shock wave proceeds to pass from the valve into the tank, smoothing and attenuating it in time vice versa [19].

The repetitive pattern and the rapid changes in the pressure signal were obvious in the wavelet maps where absolute intense values were almost consistently located in time (Fig. 4 to Fig. 7). Irregularities in the pressure signal that fit the start of the open-closing solenoid valve and the locations of the reflected waves are illustrated by the presence of instant frequency and energy (Fig. 4 to Fig. 7) of the reflected signal. These phenomena were more visible at a larger scale, as the wavelet coefficients are very small for smaller scales for all time.

**Figure 4.** Healthy pipeline system (a) Time-frequency representation (b) Wavelet spectrum.

**Figure 5.** 1 mm leak (a) Time-frequency representation (b) Wavelet spectrum.
Figure 6. 3 mm leak (a) Time -frequency representation (b) Wavelet spectrum.

Figure 7. 5 mm leak (a) Time-frequency representation (b) Wavelet spectrum.

Referring to the Fig. 4-7, the enlarge time scale (1 sec - 1.5 sec) results of wavelets transform for the signal with the various condition of the size of the leak. The Fig. 4 shows the result for a healthy condition pipeline without any leakage tapping on the pipe. From the observation (Fig. 4), on both TF representation and spectrum, at all along with the position of time, $t = 1$ to $t = 1.5$ (sec), there was no strange frequency developed and energy (amplitude) of the signal was consistent. The result was very contrasting when compared to the Fig. 5 – 7 where the leak are simulated at the position 47.9-mm ($t = 1.18$ sec). Fig. 5 – 7 illustrate the TF representation and wavelet spectrum of the signals contain leak 1-mm, 3-mm, a 5-mm in diameter. As shown on Fig. 5 – 7, at the distanced where the leak was simulated on the pipeline system, the energy (amplitude) and instant frequency were appeared. The amplitude of the reflection signal slightly increases align with the increasing the leak size. The measured pressure signal provides much more information on the system than is purely necessary for the identification of leaks. While it was chosen intentionally for the experimental apparatus to prevent changes in the pipe characteristics, some other unwanted reflections can occur. In addition, as with any experimental signal, a certain noise rate is inevitable. In the wavelet diagram, both at larger and smaller scales, local
maximum lines are present outside the tank and leakage. The experimental data was tabulated on the table as below.

**Table 1.** Comparison of the position of pipeline features between measured and experimental position.

| Pipe Feature | Measured Distance (m) | Measured Times (sec) | Analysed Distance (m) | Analysed Times (sec) | Error % |
|--------------|-----------------------|----------------------|-----------------------|----------------------|---------|
| No-Leak      | -                     | -                    | -                     | -                    | -       |
| 1-mm circular hole | 48.1                 | 1.19                 | 49.3                   | 1.17                 | 2.5     |
| 3-mm circular hole | 48.1                 | 1.19                 | 49.3                   | 1.17                 | 2.5     |
| 5-mm circular hole | 48.1                 | 1.19                 | 51.1                   | 1.21                 | 6.2     |

5. Conclusion

To conclude, the early identification of leaks will prevent waste and harm to users. Any suggested method for early leak detection should be efficient, quicker and cheaper. For low reliability leak signal, CWT displays the ability to detect the leak in the water pipeline as the decomposition signal. The transformation of the wavelet has been shown to effectively eliminate the noise from the leak signal. Conversely, the study of the wavelet transforms presented in this article capable of detecting local singularities due to a leak. In addition, the use of a proper wavelet transformation enables the selection of information on the existence of a leak from other peculiarities. For better accuracy and consistency, the results outlined in this study should also be checked by varying the environmental and field condition during the experimentation.

Acknowledgements

The author wants to thank University Malaysia Pahang for the support, facilities and sources for this research. The acknowledgement is also to University Malaysia Pahang for providing internal grant RDU190346, Postgraduates Research Grant Scheme (PGRS) PGRS1903174 and Ministry of Higher Education (MOHE), Malaysia grant FRGS/1/2017/TK03/UMP/02/1 (RDU170121).

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