Improvement of Cepstrum Analysis for the Purpose to Detect Leak, Feature and Its Location in Water Distribution System based on Pressure Transient Analysis

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ABSTRACT

Nowadays, pipeline system is one of the powerful technologies to be implemented in the real world. It is very essential for transporting fluid especially water from one point to the next point. But the pipeline system will also defect as leaks due to many reasons. Pressure Transient signal is a newly developed method to detect and localize leak phenomena since the signal has information about that phenomenon .The basic principal is the fact of water spouting out of a leak in pressurized pipe that generates a signal, and the signal may contain information to whether a leak exists and where it is located. To extract this signal, many signal analysis methods were implemented by researchers such as cross-correlation, genetic algorithm, and wavelets transform. Cepstrum analysis is proposed as a method to extract leak and pipe feature information from pressure transient signal by considering this method to analyse non-stationary data. Since in the real test, the originality and pure data are hard to be captured due to noise generated from environment and the noise level ratio is very low, pre-processing method as a filtering technique is implemented to analyse the real signal before the signal goes through cepstrum analysis as post-processing method. This research focused on the improvement of cepstrum analysis in order to extract information about the leak, pipe feature, and its location. In this research, cepstrum analysis was proposed as Post-Processing method. Discrete Wavelets Transform (DWT) and Principal Component Analysis (PCA) were proposed as Pre-Processing Methods. The pressure Transient

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signal was analysed using Matlab software. The results satisfactorily predicted the leak location as the comparison analysis using theoretical calculation and experimental results were just 0.4% to 3.8%. Therefore, PCA and DWT were recommended as data pre-processing methods to improve cepstrum analysis result.

Keywords: *Principal Component Analysis (PCA), Discrete Wavelets Transform (DWT), Cepstrum Analysis, Pressure Transient*

Introduction

Water is an important part that contributes towards the increase of economic growth of a country. In the recent decade, water has been one of the major interesting research subjects due to water pollution and Non-Revenue Water (NRW) conflict caused by growing the human population. Referring to Water Economy Network (WEN) 2016, water scarcity is rapidly enhancing the number one global resource concern. Within twenty years, the on-going shortage of clean and accessible fresh water will be from 300 million cubic meters to 2.8 billion cubic meters [1].

One of the most current and significant discussion among world's researcher is water leakage from water distribution network. The main causes of leaks are due to aging pipelines, corrosion, erosion, excessive pressure resulting from operational error and water hammer (caused by rapid opening and closing valve). [2] conducted one of the first global surveys that reported water loss from several different countries and cities which discovered that they varied from low level of 9% in Germany to a high level of 43% in Malaysia. Most countries fell into the range of 20% to 30% of Non-Revenue Water (NRW). Regarding to the report submitted by International Water Association (IWA) and AWWA Water Loss Control Committee's 2003 [3], they estimated that 5 to 10 billion kWh of power generated each year in the United States was wasted water which either lost via leaks or not paid by customer. It also appeared that between treatments plants and consumer, 25 to 50% water was lost due to leakages.

For this reason, minimizing water loss in transport is very essential. They are demanding critical needs for new techniques of leaks detection and location in water distribution network. Most of the technologies nowadays rely on method devices procedure and acoustic technique. Commercialized methods that were implemented included ground penetrating radar which detected the point of low electric impedents along the pipe indicative of ponding [4] [5], and the use of electromagnetic techniques to find a break in metallic pipes. This method typically captures leaks information if measurements are within 2 m of the breech for electromagnetic techniques, and up to 250 m for acoustic methods, impeding their application to long transmission mains. Meanwhile [6]; [7] used tracer gas injection and ADEC 2000 [9] by implementing liquid sensing cable to capture and localize water leak approaches.

Commercialized method is widely seen to have weaknesses when water distribution network is mainly buried underground since the method has limitation to detect and capture small leaks due to small changes in pressure drop. It is only clear to detect large leaks than small ones due to high-pressure drop caused by system and presence of water in the pipe buried. Besides that, commercialized method was not designed to detect and locate pipe feature identity. Acoustic techniques were widely used since fluid spouting out from pipeline generated high-frequency oscillation on the pipe wall and transducer was used as a device for capturing the data [8]. For this problem, acoustic techniques were unreliable methods since these techniques were ineffective if the noise created by the leak was small, attenuated quickly or was obscured by other background noises. Otherwise, this technique was typically labour intensive and was often imprecise [9].

The Pressure Transient analysis on-going method is used as a new technique since using this method not only can detect a leak, it also captures other pipe feature reflection. Transient phenomena is generated due to sudden changes in fluid propagation that filled in pipelines system and caused by rapid pressure and flow fluctuation in a system such as rapidly closing and opening valve or pump failure. These phenomena will provide pressure waves propagation along the pipeline system with the speed of sound in the fluid. The propagation waves that travel with constant speed along the system will provide and capture pipe characteristic due to reflected wave from various boundaries such as a junction, pipe feature, outlet, reservoir and presence of the leak. Due to effectiveness and cost reduction, a variety of leak detection methods was developed based on pressure transients such as reflected wave or timing methods, transient damping method, frequency response method, Genetic Algorithm techniques and inverse transient analysis.

In the recent two decades, most researchers focused on the properties of pressure transient for leak detection. [10] used properties of transient pressure waves for leak detection in outfall pipes through the effect of a leak on wave propagation which was then established over the numerical result. The result was compared throughout laboratory experiment. Location of leakage was achieved by the timing of reflected pressure waves and speed of sound. The occurrence of transient damping determined the presence of a leak and the timing of the damping indicated its location. [11] also investigated the same methods through unsteady pressure waves initiated by closure of an upstream valve known as pressure transient techniques. In their research, they applied the analysis of time history of pressure during a transient event presence to determine the location of the leak by measuring the time for wave to propagate from the leak point to measurement section.

Sheffield Group also implemented the same method for leak investigation and location [1]. [12] and [13] applied reverse engineering techniques with a model that was optimised to fit experimental transient data. This method was reliably used to identify leaks and pipe feature. [14] implemented cross-correlation analysis as a method to analyse transient pressure signal. These techniques worked using the first reflection of the pressure wave from the disturbance in the flow profile caused by leaks in the system. [15] proposed Orthogonal Wavelets Transform charge as data decomposition method or filtering method and cepstrum analysis as post-processing method.

Previous studies and several types of research focused on cepstrum analysis method since this method was proposed as a better alternative way to autocorrelation function in the detection of echoes and transient events in seismic signal in time domain [16]. In pressure transient analysis, echoes are presented from the reflected signal which is generated by the pipe feature such as leak [17]. Otherwise pipe features include elbow, T-joint, and reducer. This can be referred to Oppenheim and Schafer [18] for further information on cepstrum analysis and its application. Since in the real test, the originality and pure data are hard to be captured due to noise generated from environment and the noise level ratio is very low, pre-processing method as a filtering technique is implemented to analyse the real signal before the signal goes through cepstrum analysis as post-processing method. [19] implemented matched filtration method as data pre-processing method before going through cepstrum analysis. The experiment was conducted along 80 meters of pipeline without installing any pipe feature except leak. In this experiment, pressure transient waves were generated manually through rapid opening and closing valve. Other researchers such as [15] and [11] used solenoid valve as a tool to generate pressure transient wave. Furthermore, [20] practiced wavelets analysis as data filtration method to increase the signal of noise ratio. Next, the data was analysed using cepstrum analysis. [17] investigated the same method using cepstrum analysis. In his work, wavelets filtering procedure was based on Orthogonal wavelets and [21] transformed the purpose as data filtering method. The data were decomposed at different level with different frequency bands. Lowering the level resulted to lower frequency element of this process. Recent work from [22] presented cepstrum analysis to detect reflection point in water distribution network. In their work, they proposed Orthogonal Wavelets Transform as data filtration method. The same procedure and methodology was practiced by [15] to detect and localize leak reflection in water pipeline network.

Their research proved that cepstrum was capable in identifying periodic events in signal and it was the best method to detect and localize leak. It has not been previously applied in a systematic way to the problem of identifying pipe feature reflection in the pipeline system.

These previous studies have successfully captured and located leaks using various analysis of pressure transient signal. In order to improve accuracy and perform complex detection, a new signal analysis is proposed and compared with the existing methods. The objective of this paper was to detect leaks, pipe feature and its locations. In this study, we proposed to implement non-stationary data called Discrete Wavelets Transform (DWT) and Principal Component Analysis (PCA) as pre-processing methods to filter noise signal and enhance post-processing result. In this paper, Cepstrum analysis was proposed as post-processing method. This paper presented the results on the application of this technique.

Wave Propagation in Pipe

The propagation of the wave is described as a disturbance phenomenon that propagates through a medium from one point to another point as a result of consumption of energy and momentum change through a small displacement of molecules between two points [1]. The disturbance phenomena that occurred in the pipeline was transferred through the fluid molecules and caused a wave in the medium. Water hammering method through rapid opening and closing valve is one of water disturbance system operations. The magnitude of the hydraulic transient relies on how fast the operation is performed.

Water hammer phenomena

Water hammer is described as the phenomena of resulting hydraulic transient or wave occurrence in the pipeline system. This is due to shock pulse that constitutes from rapid opening and closing of valve or the starting and stopping of pumps [1].

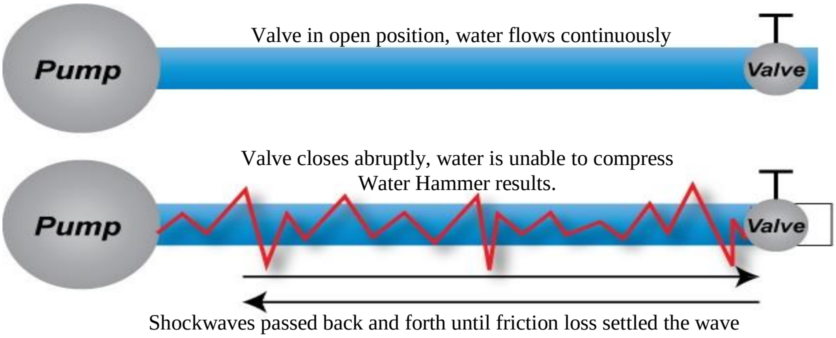


Figure 1: Water Hammer

Figure 1 illustrates the mechanism of water hammer phenomena in the pipeline system. This phenomenon happens when the tubes are not adequately secured or supported. These will create rebounding waves that cause the tubes to vibrate and hit against the supporting structure producing the noise indicated to this phenomenon. Hydraulic shocks may occur and damage the pipe feature such as joint, valve, reducer, and elbow. To avoid and minimise the effect of water hammer, an alternative method can be applied such as reducing the water velocity flow in the pipe, reducing the inlet pressure of water in the system, closing manually operated taps slowly and by fitting slow acting solenoid valves.

Propagation of transient pressure wave in pipe

When the pressure wave travels along the pipeline system, at every discontinuity of the system such as pipe feature (junction, elbow, bending, leak) and change of pipe diameter due to diffuser, the wave is partially reflected back, partially transmitted forward and some of it will also be absorbed to discontinuity of the system [23]. As shown in Figure 2, by neglecting energy losses along the pipeline system, and at the singularity, the reflected wave added to transmitted wave equals to the incident wave [9].

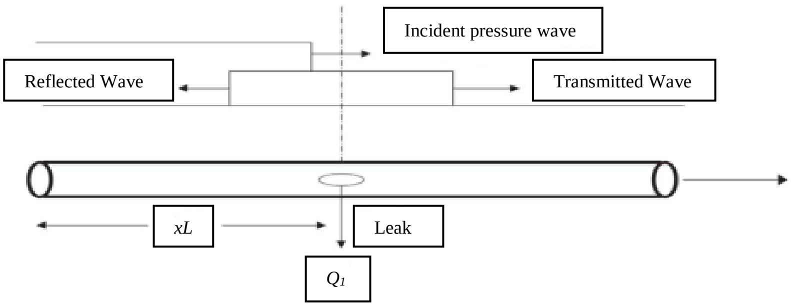


Figure 2: Conceptual wave reflection on pipeline system

As shown in Figure 2, when leakage or ruptures occurred at certain places on pipeline system, there will be a change in the pressure balance which is generated by the friction of the water with the wall of the pipeline. The reflection wave will be detected if there is any blockage such as a hole, junction, crack and rupture [24].

Methodology

In this paper, the signal response generated by solenoid valve was recorded using a pressure sensor. During the experiment, a solenoid valve was set to normally closed condition; thus, water hammer phenomena was induced by immediately opening and closing the valve with three consecutive times for each of data which was then captured by DasyLab Software.

Experimental Setup

The experimental test was regulated in a circular loop pipeline system with 38.2 meter long. The network was constructed using Medium High-Density Polyethylene pipes (MDPE) with outer diameter of 32 millimetres, 27 millimetres of internal diameter and 2.6 millimetres of mean thickness. A couple of pipes that featured 90-degree elbow, T-joint, Reducer and artificial leak simulator was installed along the pipeline system. The outlet of the pipe was kept connected to a free surface tank where the water from the pipe end was discharged. This was due to prevent sudden expansion phenomena of the pressure waves while negative pressure wave could be minimized as it will affect the collected data from the transducer.

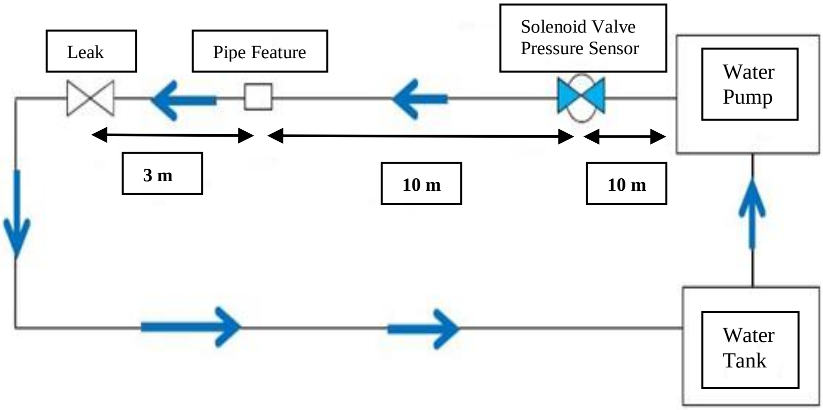


Figure 3: Schematic Diagram

Schematic diagram above (Figure 3) shows the pressure sensor and solenoid valve were installed 10 meters away from the electric pump to avoid too much noise during data collection. This is due to wave characteristics as turbulent flows when the water exits from pump outlet, and the flow approaches laminar or steady state condition due to distance travelled. This phenomenon is generated by friction from wall pipe due to water flow and damping. Therefore, 10-meter-long distance from pump to the sensor is adequate to reduce the noise. Each pipe feature is installed to the system with the range of 3-meter-long. This procedure is to avoid the development of data and amplitude produced by every feature that overlaps each other. Referring to the Doctoral Thesis written by Maninder Pal of Loughborough University, [19][25] stated that the speed of sound in MDPE pipe with outer diameter of 32mm, inner diameter of 32.2mm and thickness of 2.4 mm was 239.27 meter per second. The total length of the system was 38.2 meter long.

Basically, the method used for the research mainly uses pressure transient respond. This method is commonly used as the basic technique in pipeline leakage detection method. The idea is proposed from the usage of pressure transient flow of water in the pipeline network. Theoretically, pressure transient respond occurs when there is a sudden change in the flow of water by closing or opening the valve in the pipeline network. As the phenomena happened inside the pipeline network, wave propagation of water will be created along the pipeline network and also the characteristics of wave propagation will be used as a medium to detect leak and pipe feature along the pipeline network. The wave inside the pipeline network will propagate with different signal depending on the size of leak, distance of leak, the type of pipe feature and distance of pipe feature.

In a few cases, the system will shut down due to sudden opening or closing of valve and malfunction of the pump. This crisis will generate “water hammer” that occurs in the pipeline system. This phenomenon took in all of the pressure pipe systems, frequently causing strong vibration and destruction of pipeline system [24]. To generate this phenomenon, solenoid valve is utilised as a tool to create water hammer along the pipeline system. This situation to create the same phenomenon happens in real life when there is pressure disorder that occurs through the underground pipe. The switch is used to control solenoid valve in order to create water hammer along the pipeline and pressure sensor is utilized as a tool to capture the reflected signal from pipe characteristic. PreSystem (NI-DAQ) works as a system to convert analogue signal capturing the pressure sensor to digital signal that is analysed by laptop or PC. The water is commuted in the system as long as the pump operates continuously.

The system which consists of pipe feature will affect the pipeline behaviour and the captured reflected signal response from this behaviour will be retrieved from the transducer. Even though this signal response will influence the analysis of the experiment data, this research focuses on leakage that exists in the pipeline. The theoretical distance of leak “A” is measured as 13.5 m and “B” as 25.5 m. The leak is simulated on the pipeline system by drilling a hole at some distances and small valve is attached in order to control it to be opened or closed.

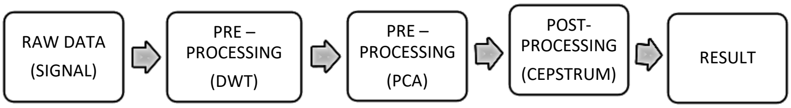


Figure 4: DWT, PCA and cepstrum Analysis Steps

Pre-processing method

Data pre-processing method is an important stage in signal processing method of data mining process [26]. This method is often loosely controlled, resulting in out-of-range values, impossible data combination, and missing values. The data are required to be analysed carefully to avoid misleading result. Data pre-processing methods include cleaning, normalization, transformation, selection and feature extraction.

Discrete wavelets transform

DWT is introduced as the first processing method in order to lower noise level ratio. Otherwise, DWT is implemented as a method to overcome the deficiency and to speed up the wavelets transform [1]. In numerical analysis and functional analysis, Discrete Wavelets Transform (DWT) is defined as the wavelets transform which is a discrete sampled signal. This method is applied to discrete the data sets and produce it as the discrete outputs. This method works by transforming the signal and data vector which resembles the Fast Fourier Transform (FFT) to a set of discrete measurement [27]. It is called as the Discrete Wavelet because the wavelets function being used in DWT can only be scaled and translated in discrete steps. The parameters *a* and *b* showed in formula 1 can be sampled by employing a power of two logarithmic discretizations in which the scale parameter a is discretized on the logarithmic basis and the translation parameter b is then linked to the scale parameter [1]. The results of *a* and *b* are reformulated as;

$$a = 2^m,\ b = n \times 2^m \tag{1}$$

For practical application, the power of two logarithmic scales is the simplest and efficient discretization method which is also known as sampling on a *Dyadic Grid* [1]. The discrete wavelets transform of a continuous time signal was finally obtained as;

$$T_{m,n} \int_{-\infty}^{+\infty} x(t) \frac{1}{\sqrt{2}} \psi(2^{-m} t - n) dt \tag{2}$$

According to the multiresolution analysis, the DWT acts as a dyadic filter. The signal was decomposed into a tree structure of wavelets details and wavelets approximation at various levels.

Principal component analysis

Interpretation of Principal Component Analysis (PCA) is a statistical procedure to be used as an Orthogonal transformation to convert it into a set of observations which are possible to become correlated variable into a set of value within linearly uncorrelated variable known as principal component [28]. The dimension of the original data matrix is denoted by Z(n,k), N is defined as a number of captured data in each analysis, and K represents the number of block size as shown in formula 3.

$$Z_{(N,K)} = \begin{matrix} \text{Day 1} \\ \\ \text{Day 2} \end{matrix} \begin{pmatrix} Q_{1,1} & Q_{1,k} \\ & \\ Q_{N,1} & Q_{N,K} \end{pmatrix} \quad \textbf{(3)}$$

In previous study, data compression technique may lead to a significant loss of information. Therefore, it is crucial to find a compression technique that keeps as much possible information from the original flow. Implementation of PCA reduces the original k-dimensional space of the inflows into a smaller A-dimensional subspace and preserves the maximum amount of information [29]. PCA transforms every single data, constituted by K inflow measurements into a new simplified measurement [29]. The advantage of using this method is the data will be compressed by reducing the dimension without much loss of information.

Cepstrum analysis

Cepstrum analysis is defined as an anagram of the spectrum or the Inverse Fourier transform (IFT) of the algorithm to estimate the spectrum of the signal. This technique uses a nonlinear signal that is used in a variety of applications. The function was generated in 1963 when [16] were working on the signal which contained the echo and Bogert observed that the logarithm of the power spectrum of the signal had additives periodic component. The most common type of cepstrums are real spectrum, power spectrum, and phase spectrum.

This method was implemented by Sheffield group as the signal analysis technique to detect water pipeline leakage. The cepstrum technique was used to analyse a series of different pipe network, both leak and non-leak pipes. This method showed that leak that occurred in the pipeline system corresponded to the amplitude of the peak. Fundamentally, the cepstrum mechanism is performed by Fourier transform the signal (FT), log function of the signal and continued with the last step of Fourier transform back the log signal. Thus, the cepstrum is also interpreted as the Inverse Fourier Transform (IFT) [30].

Mathematically : cepstrum of signal = FT(log (FT (the signal)))
Algorithmically: signal → FT → log → FT → cepstrum

The implementation of cepstrum analysis has two types; power cepstrum and complex cepstrum. The latter is reversible back to time signal and it is a good tool for detection of local singularities within a pressure time history. The complex cepstrum is defined as;

$$C_{A=}F^{-1}(\log A\{f\}) \quad \textbf{(4)}$$

where A{ f } is complex spectrum of a{t}. It can also be interpreted in terms of the phase and amplitude at each frequency by;

$$A\{f\} = F\{a(t)\} = A_R + jA_I\{f\}. \quad \textbf{(5)}$$

By taking the complex logarithm of equation (5), it gives

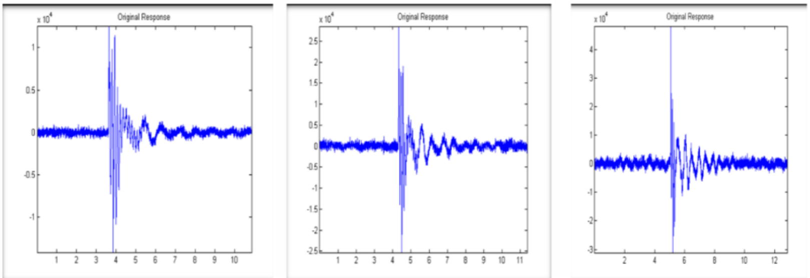
$$\log A(f) = \ln|A(f)| + j\phi(f) \quad \textbf{(6)}$$

where $j = \sqrt{-1}$ and $\phi(f)$ is phase function.

The inverse transformed equation (6) was the complex function of frequency with the logarithm of amplitude as the real part and phase as the imaginary part. In the context of cepstrum analysis, the time parameter was referred to as frequency. The periodic structure in logarithm spectrum can be detected using utilization of cepstrum. It has the ability to detect families of both harmonics and sidebands with uniform spacing. On the other hand, cepstrum is also able to separate the source and transmission path effects, bringing to the signal on the effect of deconvolution [15].

Result and Discussion

The experiment data captured from transducer interpreted the pipeline system behaviour and characteristics. The signal that was captured also retrieved the characteristics of the whole pipeline system itself. The pressure transient wave was traveling in both opposite directions away from the burst origin through the speed of sound in water distribution network.



(a) (b) (c)

Figure 5: Signal responses for (a) 1mmHg (b) 2mmHg and (c) 3mmHg with no leakage in the pipeline

A currently captured signal is shown in figure 5. This shows that the opening and closing of the valve produced pressure transient which was transmitted and reflected around the pipe system. The wave was being attenuated through both friction and various pipe characteristics. The original response was recorded at three different levels of pressure: 1mmHg: 2mmHg and 3mmHg. The signals captured using different levels of pressure showed different results. The higher the pressure creates a higher frequency of the signal and this causes the higher amplitude of the signal.

The result was presented based on the original responses obtained from analysis on Discrete Wavelets Transform (DWT) method. Signal masking showed inconclusive value which interpreted that pipeline was associated with any kind of leakage. Thus, the signal response from 2mmHg data was then analysed through DWT. The data was captured 10 times before it went through decomposition process. DWT works as data decomposition method in order to reduce noise from the signal without interrupting the originality of the signal. Decomposition of the signal was interpreted as the factoring, breaking a complex problem or system into the part that can be easier to convey, program, understand and maintain.

During this step, the signal decomposes into full decomposition where the composition of the signal is set as 5 levels by selecting daubechise as wavelets type.

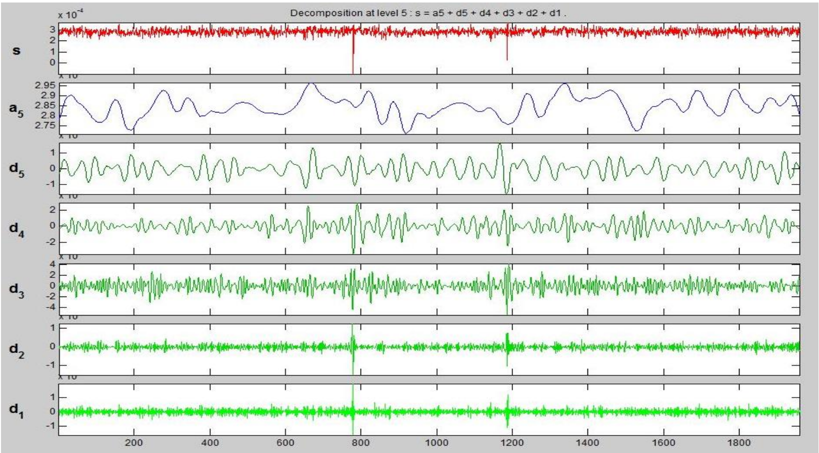


Figure 6: Decomposition of DWT at 5 levels: s=a5+d5+d4+d3+d2+d1

Figure 6 illustrates DWT decompose of the signal at 5 levels. From the interface, during this process, the signals are divided into a portion of different groups. The first portion is a group of low-frequency signal and the last one is portion number 5 which indicates a group of higher frequency signal and noise. This paper presented daubechise as a mother wavelets of DWT. There are several types of mother wavelets of DWT such as Meyer, Haar, Mexican Haar, Symlet, Coifflet, and Daubechies. The previous study utilized the fourth-order of Daubechies wavelets which had a support length of three ($0<t<3$). This type of mother wavelets was previously used in many compressions and filtering applications [31]. The wavelet level represents the discrete of the original data using the Daubechies wavelets function. Every level represents the time behaviour of the signal within different frequency bands. The lower level tallies to low frequency and higher level contains a high frequency of signal [29].

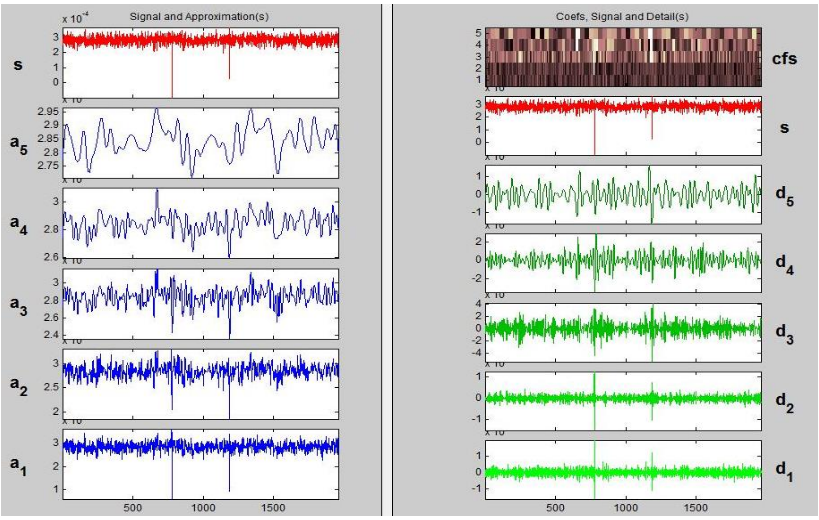


Figure 7: Decomposition of Approximate and Details component

Figure 7 represents the second DWT interface. During this process, the signal is divided and grouped into two modes. The first mode is Approximate Component; in this mode, the signal is represented as low-frequency data with a high scale of amplitude. The second mode is Details Component that represents a high-frequency signal with low amplitude scale. The result was obtained from level 2 to level 5 in order to select the best level for further analysis. From figures 4 and 5, level 2 was chosen as the most appropriate response to be used as a reference for the next analysis.

The second level was chosen to go through the next step of data decomposition method. In this step, Principal Component Analysis was implemented as the second step of data decomposition method. As discussed in methodology, PCA is the statistical procedure that converts a set of observation which is possible to a correlated variable into a set of value through orthogonal transformation [28]. This method was implemented in order to identify pattern data and express the data in a way as to highlight their similarities and differences [32]. The data were compressed by reducing the dimension without much loss of information. This step takes charge in order to isolate the signal from two portions of real signal and noise signal. In this process, Approximate Component as a grouping of the real signal was chosen for analyzing the next step.

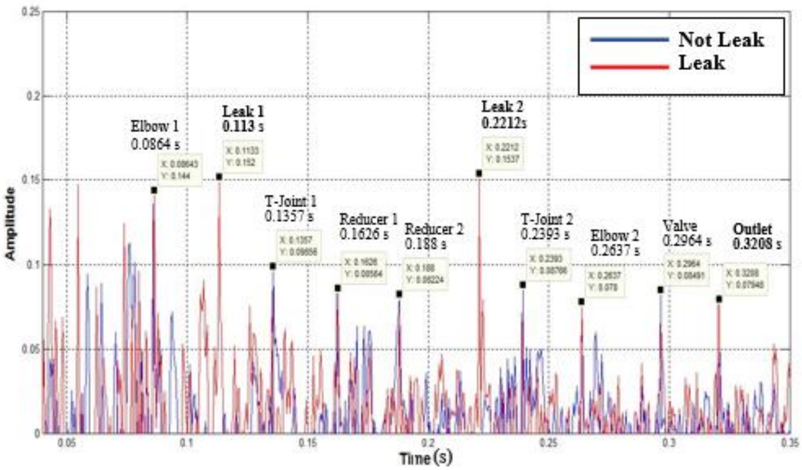


Figure 8: Discrete Wavelets Transform, Principal Component Analysis (PCA) and Cepstrum (Approximate Component)

Figure 8 shows the final result that represents Approximate Components of signal analysis after the data was decomposed twice using Discrete Wavelet Transform (DWT) and Principal Component Analysis (PCA). Cepstrum analysis is subjected to the final step of the analysis. Approximate Component is a group of low-frequency signal and high scale amplitude ratio. By plotting the cepstrum graph from the approximate component, the result improved perfectly. The amplitude of each leak and pipe feature can be observed precisely without the assistance of theoretical calculation.

The processed results of the first experiment that used pipeline distribution network without leak were presented as the blue line as shown in figure 10. Otherwise, the red line represented the second experiment that contained leak data from pipeline network. Both data from the first and second experiments contained pipe feature identities such as the elbow, T-joint, and reducer. The single higher amplitude created by the red line at time 0.1133 represented the first leak while the time 0.212 represented the second leak. The overlap of the red and blue lines represented pipe feature since both data contained pipe feature identity. By consuming this method, it means the raw data are decomposed twice the time, and the desired result is archived perfectly.

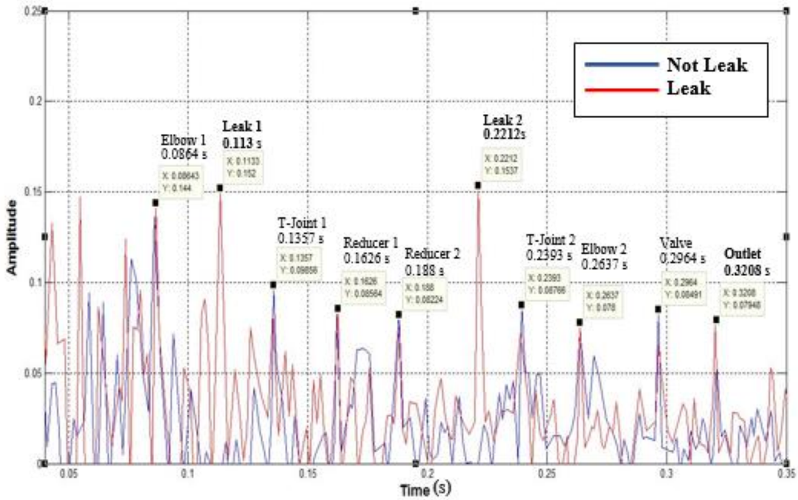


Figure 9: Peak to Peak Data Plot Discrete Wavelets Transform, Principal Component Analysis (PCA) and Cepstrum (Approximate Component)

Figure 9 represents the data from figure 8 after going through peak-to-peak data plot. The leak spikes and feature spikes clearly appeared and observed. This method was in order to get a more perfect and presentable data. There were 8 main features that reflected waves; a couple of elbow, a couple of T-joint, a couple of reducer, a single of the valve and the outlet. Each peak clearly overlapped each other since the blue line represented data with no leak and the red line represented data with leak that had all the identities of main pipe feature. Every single peak seen in the analysed results corresponded to the time travel of wave taken to travel along the pipe reflection point and reflected back. The distance of reflection point from pressure transducers was obtained by multiplying the time delay data corresponding to each peak to the speed of sound and halving this to account for the return journey.

Table 1: Comparison between Theoretical and Experimental Result

Feature	Theory Distance (m)	Experimental Distance (m)	Error %
Elbow 1	10.50	11.09	1.14
Leak 1	13.50	13.38	0.4
T-joint 1	16.50	16.13	0.9
Reducer 1	19.50	19.27	0.2
Reducer 2	22.50	22.14	0.0
Leak 2	25.50	26.22	3.8
T-joint 2	28.50	28.16	0.5
Elbow	31.50	31.60	0.2
Valve	35.60	35.39	0.2
Outlet	38.20	38.32	0.5

Table 1 illustrates the percentage error of the second leak that was observed as high percentage error. This was because of the effect of reducer. The different pipe diameter had different speed of sound. Therefore, the pipe diameter reduced from 35 mm to 25 mm when the water entered the reducer. Therefore, the wave propagated and attenuated differently. These phenomena affected the speed of sound and the reading of data was disturbed.

Conclusion

In this paper, a technique based on the analysis of pressure waves through fluid-filled pipelines in order to detect leak, pipe feature and its location was investigated. Cepstrum analysis was chosen as post-processing method. Even though it is the old method and known for a long time, it is still a powerful one to identify periodic events in the signal. In this research, before the signal takes charge of cepstrum analysis, the signal goes through twice time of data decomposition method in order to reduce noise level ratio. As a conclusion, the pressure transient signal was acquired from the test rig. Furthermore, the pipe features such as T-joint, 90-degree elbow, reducer and valve were also attached on the test rig. Transient's phenomena occurred when there was a disturbance in the flow pipeline system and in this paper, a solenoid valve was used to create water hammer. The wave propagated along the pipeline system and reflected back due to disturbance of the pipeline system. The reflected wave was collected using pressure transducer.

In this investigation, the aim was to improve signal analysis method focusing on leak detection using pressure transient signal in order to identify leak and pipe feature location, accurate result and better result presentation. From this study, it is shown that the combinations of PCA, DWT and

Cepstrum were able to successfully identify and locate feature including leakage in pipeline.

References

[1] M. F. Ghazali, "Leak detection using instantaneous frequency analysis," University of Sheffield, 2012.

[2] C. Lai, "Unaccounted for water and the economics of leak detection," *Water Supply,* vol. 9, p. 4, 1991.

[3] A. W. W. Association, *Leaks in water distribution systems; a technical/economic overview*: AWWA, 1987.

[4] M. Eiswirth and L. Burn, "New methods for defect diagnosis of water pipelines," in *Proc. 4th Int. Conf. on Water Pipeline Systems Managing Pipeline Assets in an Evolving Market, York, UK, BHR Group Ltd*, 2001, pp. 137-150.

[5] D. L. Atherton, K. Morton, and B. J. Mergelas, "Detecting breaks in prestressing pipe wire," *American Water Works Association. Journal,* vol. 92, p. 50, 2000.

[6] E. McAllister, "Pipe Line Rules Of Thumb Handbook," 1988.

[7] P. Black, "A review of pipeline leak detection technology," in *Pipeline systems*, ed: Springer, 1992, pp. 287-298.

[8] A. W. L. C. Committee, "Committee report: Applying worldwide BMPs in water loss control," *Journal (American Water Works Association),* pp. 65-79, 2003.

[9] M. Ghazali, S. Beck, J. Shucksmith, J. Boxall, and W. Staszewski, "Comparative study of instantaneous frequency based methods for leak detection in pipeline networks," *Mechanical Systems and Signal Processing,* vol. 29, pp. 187-200, 2012.

[10] B. Brunone, "Transient test-based technique for leak detection in outfall pipes," *Journal of water resources planning and management,* vol. 125, pp. 302-306, 1999.

[11] B. Brunone and M. Ferrante, "Detecting leaks in pressurised pipes by means of transients," *Journal of hydraulic research,* vol. 39, pp. 539-547, 2001.

[12] D. Covas, I. Stoianov, D. Butler, C. Maksimovic, N. Graham, and H. Ramos, "Leakage detection in pipeline systems by inverse transient analysis–from theory to practice," in *Proc. Sixth Int. Conference on Computing and Control in the Water Industry (CCWI), Leicester, England*, 2001.

[13] M. L. Stephens, A. R. Simpson, M. F. Lambert, J. Vítkovský, and J. Nixon, "The detection of pipeline blockages using transients in the field," in *South Australian Regional Conf*, 2002.

[14] C. P. Liou, "Pipeline leak detection by impulse response extraction," *Journal of Fluids Engineering,* vol. 120, pp. 833-838, 1998.
[15] M. Taghvaei, S. Beck, and W. Staszewski, "Leak detection in pipelines using cepstrum analysis," *Measurement Science and Technology,* vol. 17, p. 367, 2006.
[16] B. P. Bogert, M. J. Healy, and J. W. Tukey, "The quefrency alanysis of time series for echoes: Cepstrum, pseudo-autocovariance, cross-cepstrum and saphe cracking," in *Proceedings of the symposium on time series analysis*, 1963, pp. 209-243.
[17] J. Lighthill, *Waves in fluids*: Cambridge university press, 2001.
[18] A. Oppenheim, R. Schafer, and J. Buck, "The discrete Fourier transform,"*Discrete-time signal processing. Upper Saddle River, NJ: Prentice-Hall*, pp. 541-600, 1999.
[19] A. Klepka, D. Broda, J. Michalik, M. Kubat, P. Malka, W. Staszewski, *et al.*, "LEAKAGE DETECTION IN PIPELINES-THE CONCEPT OF SMART WATER SUPPLY SYSTEM," 2015.
[20] A. Nurul Fatiehah, M. A. Makeen, M. Abdul, and A. Akmal, "Leak Detection in MDPE Gas Pipeline using Dual-Tree Complex Wavelet Transform," *Australian Journal of Basic and Applied Sciences,* vol. 8, pp. 356-360, 2014.
[21] R. Randall, "Frequency analysis (Bruel and Kjaer, Naerum, Denmark)," 1987.
[22] S. Beck and W. Staszewski, "Cepstrum analysis for identifying reflection points in pipeline networks," in *International conference on pressure surges*, 2004.
[23] S. Burn, D. DeSilva, M. Eiswirth, O. Hunaidi, A. Speers, and J. Thornton, "Pipe leakage–future challenges and Solutions," *Pipes Wagga Wagga, Australia,* 1999.
[24] M. Amin, M. Ghazali, M. PiRemli, A. Hamat, and N. Adnan, "Leak detection in medium density polyethylene (MDPE) pipe using pressure transient method," in *IOP Conference Series: Materials Science and Engineering*, 2015, p. 012007.
[25] M. Pal, "Leak detection and location in polyethylene pipes," © Maninder Pal, 2008.
[26] A. Cataldo, R. Persico, G. Leucci, E. De Benedetto, G. Cannazza, L. Matera, *et al.*, "Time domain reflectometry, ground penetrating radar and electrical resistivity tomography: A comparative analysis of alternative approaches for leak detection in underground pipes," *NDT & E International,* vol. 62, pp. 14-28, 3// 2014.
[27] Z. Liu, Q. Hu, Y. Cui, and Q. Zhang, "A new detection approach of transient disturbances combining wavelet packet and Tsallis entropy," *Neurocomputing,* vol. 142, pp. 393-407, 2014.

[28] Y. Ishido and S. Takahashi, "A New Indicator for Real-time Leak Detection in Water Distribution Networks: Design and Simulation Validation," *Procedia Engineering,* vol. 89, pp. 411-417, 2014.

[29] C. Palau, F. Arregui, and M. Carlos, "Burst detection in water networks using principal component analysis," *Journal of Water Resources Planning and Management,* vol. 138, pp. 47-54, 2011.

[30] D.-L. Xu, J. Liu, J.-B. Yang, G.-P. Liu, J. Wang, I. Jenkinson, *et al.*, "Inference and learning methodology of belief-rule-based expert system for pipeline leak detection," *Expert Systems with Applications,* vol. 32, pp. 103-113, 2007.

[31] W. Staszewski, "Wavelet based compression and feature selection for vibration analysis," *Journal of sound and vibration,* vol. 211, pp. 735-760, 1998.

[32] W. Nick, K. Asamene, G. Bullock, A. Esterline, and M. Sundaresan, "A study of machine learning techniques for detecting and classifying structural damage," *International Journal of Machine Learning and Computing,* vol. 5, p. 313, 2015.