Detecting Leak in Gas Pipeline using Continuous Wavelet Transform and Kurtosis

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Abstract— **The detection of the leak detection is the main investigation issue in order to get the fast and reliable leak detection method. Even thought the reasons for these leaks are very well known, some of the current method is quite complicated and not precise. In addition, it is all about time consuming and cost of instalment. In this paper, we proposed a leak detection method using acoustic. The chirp signal injected into the pipeline system and the estimation of the leak detection from the delay time passing by the reflection of pressure wave in the pipeline if there have a leak. Using wavelet as the noise filtering, there can give a useful signal to verify the leak. Wavelet is the tool to de-noise the noise from the original signal and then tuned using maximum values of kurtosis. The main idea is the echoes detection of the pressure wave from the signal given by the original signal. Kurtosis plays the main role as the component to choose the filter parameter because of their nature to measure spikiness. The result shows that the highest value of kurtosis for the pipeline with leak is 6.465 while for the pipe without leak, the highest value for the kurtosis 5.3214.**

Index Terms—leak detection, gas pipeline, wavelet, kurtosis

I. INTRODUCTION

In any application of engineering structure, pipelines are almost the main part to complete the media transport. The pipeline can be used to transfer air, water, oil and other fluids because of their cost and safety. Thus, as the main media transport they should be properly maintained, to avoid leaks. Usually, the leaks occur caused by damage from nearby excavation equipment, accident, terrorism, earth movement or sabotage.

There are two categories which are liquid and gas. Both categories have similar problem associate even though physical properties are different. The leaking and location of leaks needs to detect early. Monitoring any leaking is important in order to prevent any losses of fluid in term of cost. In addition, it can prevent any hazard to the surrounding. Different methods are used to investigate the leaking and their location. It includes visual inspections, acoustic emission, and dynamic pressure measurement. The study on leak detection in acoustic before was done using cross-correlation analysis [1-3], cepstrum analysis [4-6], and also wavelet based-filtering [4, 5, 7, 8].

Transforming the time domain signal into frequency domain is really important in order to reveals the result of signal. Recently, many transforming method such as Fourier transform (FT), Short Time Fourier Transform (STFT), Continuous Wavelet transform (CWT), Discrete Wavelet transform (DWT), and Hilbert transform (HT).

This project proposes a new criterion for new method of signal processing which is Continuous Wavelet transform using Mexican hat as mother wavelet and tuned using maximum value of kurtosis based on experimental data with advance in chirp signal as input sound to the pipeline. The advantage of using CWT is because of the suitability signal processing tools for detection of singularities as discussed by Mallat [9] and Flandrin [10]. The details of algorithm for CWT are discussed in section IV. The reflection of the pressure wave can be detected if there have blockage such as hole, junction, crack and ruptures.

II. WAVE PROPAGATION IN PIPE

Current monitoring procedures require the multiple sensor such as pressure, flow meters or and valve sensor [8]. The passage of the wave can be detected by a change of pressure at a fixed point underneath of surface. So, the changes in the pipeline geometry such as valve, junction, blockage and leaks will create a reflection. This reflection is known as pressure wave that through inside the pipeline at the speed of sound [11]. The pressure wave is simulated using time domain based on transmission line modelling techniques [8, 12, 13]. Wave also can be detected by the motion of fluid particles. The time of reflected wave can be captured by generating pressure wave at certain location together with single remote sensor [1]. Speed is the distance travelled by wave per the time taken for the wave to travel to that distance. The length of the pipeline can be calculated by multiple of the time travel down in pipeline with speed of sound.

$$l = ta \tag{1}$$

The speed of sound formulated from multiplying of fluid properties which are γ, Ru, and M and also temperature in degree Kelvin.

$$a = \sqrt{\frac{\gamma R_u T}{M}} \quad (2)$$

The pipe is assumed rigid because flexible pipes will slow down the speed of the system. The pressure waves only travel in the fluid [1].

III. LEAK DETECTION

The leak detection techniques introduced in order to minimize the losses of medium transported by the pipeline. Three major categories can be divided to classify the technique. The first technique is automated detection which can detect by monitoring system of pipeline network without human operator after the installation while, semi-automated detection need a certain input to perform some task in order to detect the leakage. The third category is manual detection which is using the system and device. It always needs to operate by human [14].

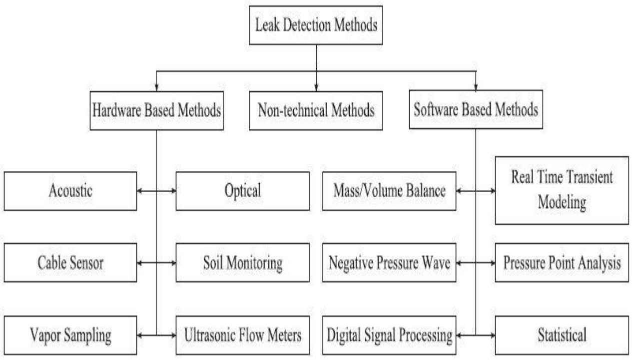


Fig. 1. Classification of gas leak detection techniques based on their technical nature [14].

Fig. 1 show the methods also can be categorized by the major techniques based on their technical nature. Hardware based method can be describe as method that using device as their main component for leakage detection. Compared to software, this method has software as their main component on order to detect the leakage [14].

IV. SIGNAL PROCESSING

Signal processing is a combination of three major parts which are system engineering, electrical engineering and applied mathematics. It is also dealing with operations on our analysis of analogue to represent time-varying physical quantities. Signals of include sound, electromagnetic radiation, images, and sensor readings. The goal of signal analysis is to extract information from the signal to reveal the underlying mechanisms of various physical phenomena.

In the cross-correlation analysis, a signal was produced in the pipeline networks by using either the joint leak or by opening the valve at the downstream end of pipe in order to produce noise and pressure. Then velocity is calculated based on the net travelled distance of measured signal and their time shift. Signals generated using a source at a known location [3]. Cross-correlation techniques also used to identify a number of reflection points in simple pipe networks [1].

After use cross-correlation analysis, they try to use another technique which is ceptrum analysis. This technique is a non-linear signal processing involving the forward Fourier transform of the logarithm of the power spectrum. There are two types of spectrum which is power cepstrum and complex cepstrum. Cepstrum is defined as the Fourier transform of the logarithm of the Fourier transform [15]. It is defines as:

$$C_A = F^{-1}(\log A\{f\}) \quad (1)$$

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

$$A\{f\} = F\{a(t)\} = A_R + jA_I\{f\} \quad (2)$$

Taking the complex logarithm of Equation (1.4) gives

$$logvA(f) = \ln|A(f)| + j\phi(f) \quad (3)$$

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

CWT is suitable for analyzing non-linear and non-stationary signal which is widely happen in real engineering application. The CWT is defined as:

$$W_g(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{+\infty} x(t) g * \left(\frac{t-b}{a}\right) dt \quad (1)$$

where x(t) is the original signal, g(t) is the mother wavelet, b is a translation parameter as locality, a is a dilation or scale parameter and '*' is the complex conjugate. Mexican hat choose as mother wavelet in this case, defined as below.

$$g(t) = \frac{2}{\pi^{\frac{1}{4}}\sqrt{3\sigma}} \left(\frac{t^2}{\sigma^2} - 1\right) \exp\left(-\frac{t^2}{2\sigma^2}\right) \quad (2)$$

For signal processing, wavelet transform is widely used in the application of multi-resolution editing, signal filtering for noise, edge detection, marking reduction, data storage, compression, recognition, enhancement and synthesis of speech. It is powerful tools of application, where wavelet transform is used to detect, localize, identify, classify, compress, store and analyze of power disturbance signals [4, 16].

Wavelet based filtering is a method use to analyses the result of the wave propagates in the pipelines. The idea of this method comes from the detection of echoes reflected from turbulence induced by leak. However, it is hard to detect echoes due to high noise level occurred. Thus in order to identify the echoes, noise needs to be filtered.

Wavelet-based filter is tuned using the maximum value of kurtosis as simulated by Urbanek [7]. The advantages of this method include location of the leak and capable to estimate their severity. Limitation in this method is they need additional measurement channels for recording signal that transmitted from the leak. Hence, the cost increased and gives troublesome for industrial installation [7, 17].

V. EXPERIMENTAL DESIGN

The medium density polyethylene (MDPE) pipe were used in this project with length 58 m and diameter of 6.3 m. MDPE pipe widely use in gas and water distribution system because of their durability and easy to handle.

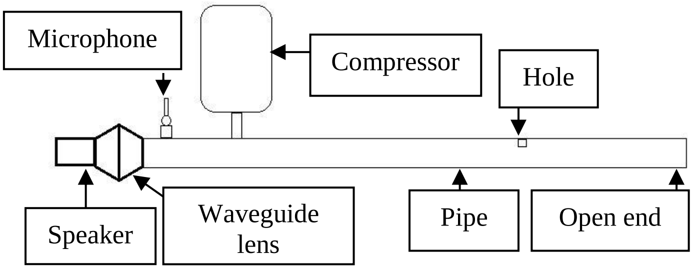


Fig. 2. Basic experiment design

For experimental process, the natural gas which is air will be induced in the pipeline as input. The compressor is the main component to force the air to flow in the pipe. The gas will flow in the pipe and the hole that drilled at 15 m from the front pipe and 42 m to the open end to simulate leak point. The diameter of the hole is 10 mm.

For excitation signal, the speaker used in order to give good propagation. The speaker with closed end and sealed together with a waveguide lens to decrease the noise from surrounding. It has made sure to get the useful signal or output of leakage from the hole. The transmission signal acquired from the wave that catch by microphone and then collected in data by DasyLab. National Instrument (NI) is the component to collect data and DasyLab is the also known as Data Acquisition System Laboratory to save the data. DasyLab will act as a filter of noise. The NI would be synchronized with the transducer and DasyLab using NIDAQ-MX software. The wavelet tool analysis in Matlab used to analyze the raw data to show the significant result.

The data samples at 8192 per second and 20 kHz were acquired in this experiment. The sensitivity of the microphone is 47.89 mV/Pa. The robustness Hamming window chirp signal was injected from the loudspeaker with 20-600 Hz as the transmission signal in this experiment as shown in Fig. 3. This experiment just runs on leak and without leak pipeline for comparison of the kurtosis value.

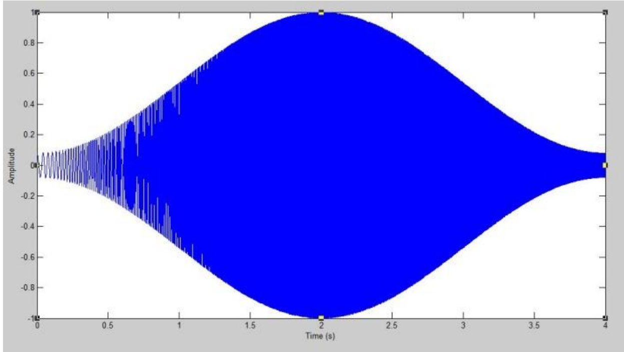


Fig. 3. A Hamming window chirp signal (20-600Hz)

VI. RESULT AND ANALYSIS

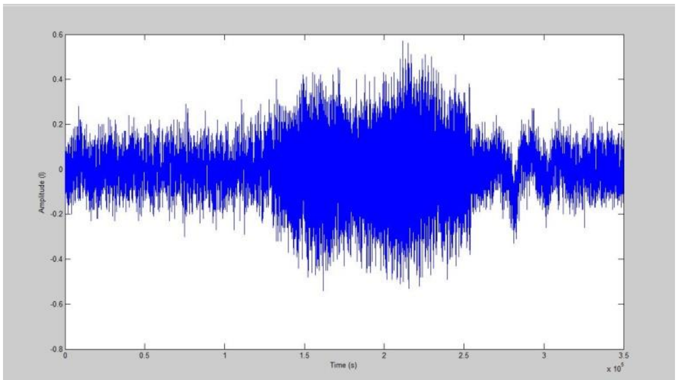
The experimental data from the pipeline were analyzed from the original signal. The experiment tests were carried using MDPE pipe. For every data, the input signal combined with the Mexican hat as mother wavelet. Then, the signal was filtering using continuous wavelet transform (CWT).The small scale interpret that there have high frequency and more compressed in the wavelet and vice versa.

The result of the CWT was computed by kurtosis for all wavelet scales. The reason why kurtosis used in this case is because they can indicate any spikes in signal which is appropriate for detecting short echoes in the pipeline system [7]. The formula of kurtosis is defined as below.

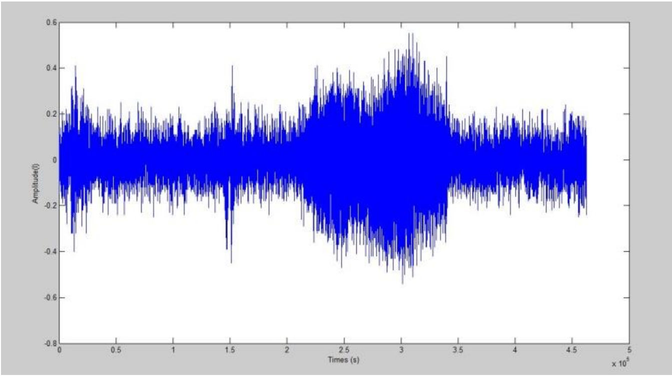
$$K = \frac{\mu_4}{\sigma^4} - 3 \qquad (3)$$

where μ_4 is the fourth moment about the mean, and σ is the standard deviation.

The inverse wavelet transform for the scale exhibiting the largest kurtosis value and give significant result to show the leak energy.



(a)



(b)

Fig. 4. Data of the signal for pipeline (a) without leak and (b) with leak.

Fig. 4(a) shows the signal was filtered in the pipeline without leak using CWT at scale a=20. The result of the signal compared to leak pipeline. In the pipeline with leak filtering by CWT at scale a=64 in step by step mode. The data for pipeline with leak shows in Fig. 4(b) with instantaneous amplitude at 1.5 s. The wavelet scalogram used to show the spectral energy of the signal.

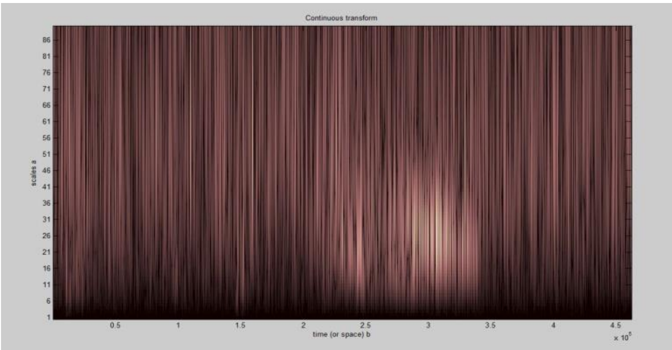


Fig. 5. Scalogram diagram for the pipeline with leak.

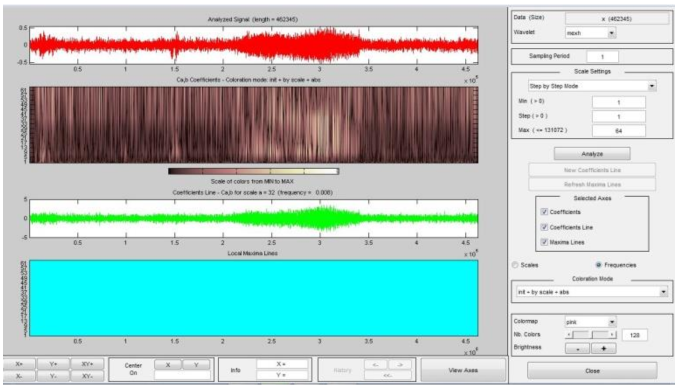
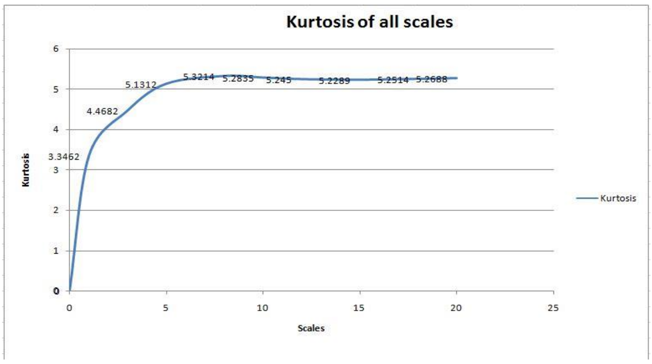
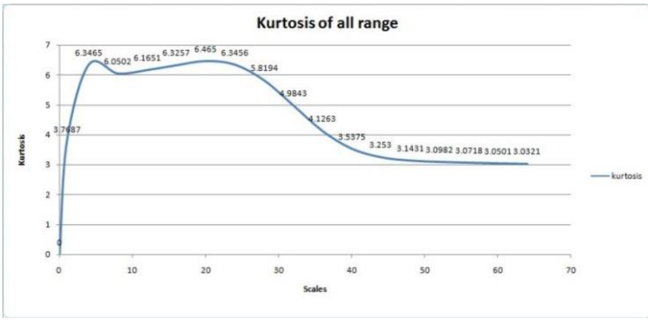


Fig. 6. Wavelet-based filtering signal for the scale parameter a=64 for pipe with leak.

Besides that, to indicate whether leak is detected or not in pipelines, a significant echo will reflect in the construct signal. Furthermore, the highest amplitude can also indicate that area containing leak or not. Inverse continuous wavelet transform will determine the reflected echo based on the highest kurtosis value calculated.



(a)

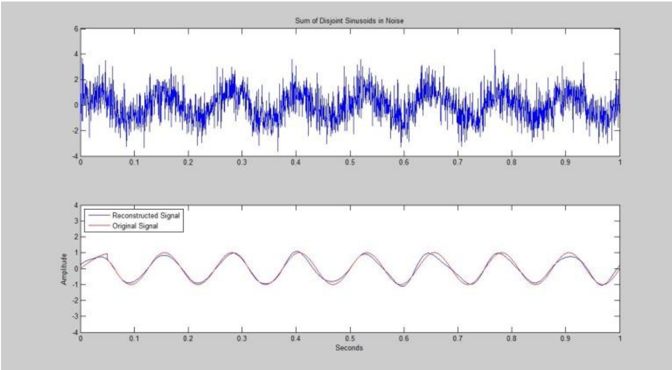


(b)

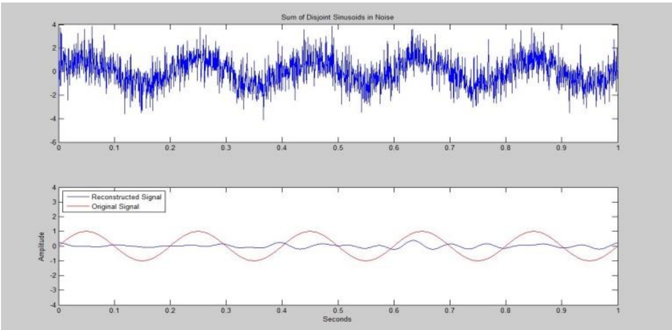
Fig. 7. Kurtosis calculated for all scales: (a) pipe without leak and (b) pipe with leak.

Then, kurtosis high range value for the coefficients obtain after the filter is determined. The kurtosis value is the plot to determine the highest value. Fig. 7 below shows the graph of kurtosis value for the pipelines. For the leak pipeline, the highest value for kurtosis is 6.465 on a scale of 20. The highest value of kurtosis indicates that the most suitable scale to exhibits signal echoes. It is clearly shows the spike compared to kurtosis for pipe without leak, which is the highest value for the kurtosis 5.3214 at scale, a=8.

From the highest value of kurtosis, the signal is inversed based on the scale. Inverse continuous transform can reconstructed the signal to the later form. Fig. 8(a) shows the reconstructed signal for wavelet transform and the time for the leak to occur. The time for the highest amplitude to occur is 0.78 second. Figure 8(b) show the inverse continuous transfer for the pipeline without leak, there is no reflected signal to indicate the leak. Therefore, this proves that there is no leak in the pipelines.



(a)



(b)

Fig. 8. Inversed continuous wavelet transform for signal in pipeline (a) with leak and (b) without leak.

VII. CONCLUSION

As the conclusion, the early leak detection can prevent any waste and avoid harm to people. Any method should be reliable, faster and low cost. For the low reliability, CWT as the decomposition signal shows the capability to detect the leak in gas pipeline. The kurtosis gives good indicator to determine the highest value for both conditions by choosing the scale based on higher value of kurtosis. This method also has more accuracy of reflected to the actual frequency components of signals compared to others. The pipeline without leaking shows the lower value of kurtosis which is 5.3214 compared to value of kurtosis in pipeline with leak, 6.46. Both kurtosis shows leptokurtic distributions.

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