Leak Detection in Gas Pipeline using Hilbert-Huang Transform

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Abstract. This paper proposes a leak detection method using acoustic. The Hamming chirp signal injected into the pipeline system and the estimation of the leak location from the delay time passing by the reflection in the pipeline if there is a leak. By using Hilbert-Huang Transform (HHT), it can give a useful signal to verify the leak. HHT transforms Empirical Mode Decomposition (EMD)and Hilbert Spectrum analysis to perform time-frequency analysis. The leak location can be detected by multiplying by the speed of sound. This simple method gives accurate leak location and easy to implement.

Introduction

This project proposes a new criterion for new method of signal processing which is Hilbert-Huang Transform. This method actually was developed to study ocean wave because Hilbert-Huang Transform can analyse non-linear and non-stationary wave. 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]. The experimental design was conducted using specific material of pipe. The several of parameter also give different results. The detection result can be simplified in term of time and location of the leak.

Wave Propagation in Pipeline

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 [9]. The pressure wave is simulated using time domain based on transmission line modelling techniques [8, 10, 11]. 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 multiplying the time travel down in pipeline, t with speed of sound, a.

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

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]. The leak location in the pipeline can be calculated using this formula:

$$x_{leak} = \frac{at_r}{2} \tag{2}$$

where:
x_{leak}= distance of the leak (m) from measuring section
t_r= time travelling (s)
a=speed of sound (m/s)

Signal Processing

Signal processing is a combination of three major parts which are system engineering, electrical engineering and applied mathematics. 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. 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 [4, 12].

Wavelet based filtering is a method used to analyse 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 the 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. The advantages of this method include the location of the leak and capability to estimate their severity. The limitation of this method is they need additional measurement channels for recording signal that is transmitted from the leak. Hence, the cost increased and gives troublesome for industrial installation [7, 13].

Hilbert-Huang Transform

An alternative data analysis tool has been proposed by Norden E. Huang called Hilbert-Huang Transform (HHT) [14]. This tool consists of two components: a decomposition algorithm called empirical mode decomposition (EMD) and a spectral analysis tool called Hilbert spectral analysis.

The EMD algorithm attempts to decompose any signal into a finite set of functions and transform to the physical instantaneous frequency values. These functions are called intrinsic mode function (IMFs). The algorithm utilized an iterative sifting process which can subtract the local mean from a signal. The sifting process can be compressed as follows:

(1) Determine the minimum and maximum (local extreme) of the signal, x (t) and connect by a cubic spline to form the upper and lower envelope.

(2) Calculate the mean, m(t) as half of the between the upper and lower envelopes.

(3) Subtract the local mean from the signal, d(t) as an IMF, d(t)=x(t)-m(t).

(4) Repeat the process of iteration on the residual m(t) until the residual is too small and represent the trend.

Experiment Design

The Polyvinyl chloride (PVC) pipe was used in this project with length 6 m and a diameter of 2". PVC pipe widely uses in gas and water distribution system because of their durability, low cost, chemical resistance and easy to handle. The setup of the experiment was shown in Fig. 1.
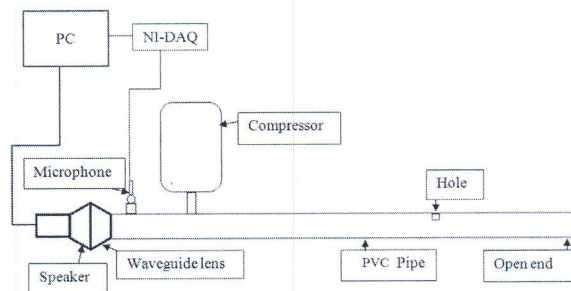

Fig. 1. Basic experiment design for PVC pipeline.

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 in 4 m from the front pipe 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 0.01 s Hamming chirp signal was excited in the pipeline with 20-600 Hz. The low frequency acoustic signal give more advantage because they can propagate in short long distance pipeline compared to high frequency which is easy to attenuate [15]. One second of time response signal, sampled at 20 kHz were acquired in each data. The speed of sound propagation in the pipeline is about 350 m/s. 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 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.

Results and Discussion

The experiment conducted in leak and no leak conditions in order to show the difference in the time-frequency analysis. Fig. 2(a) shows the original signal convert to distance using Equa. 2. There will be a reflection of the Hamming chirp signal because of the natural phenomenon happened in the pipeline. Because of the reflection, the signal come back after 6 m in the pipeline as shown in Fig. 2(b). The excitation signal was seen in the 0.01 s (until 2 m after convert to distance) and without leak, the signal shows no any disturbance even in time-domain analysis.
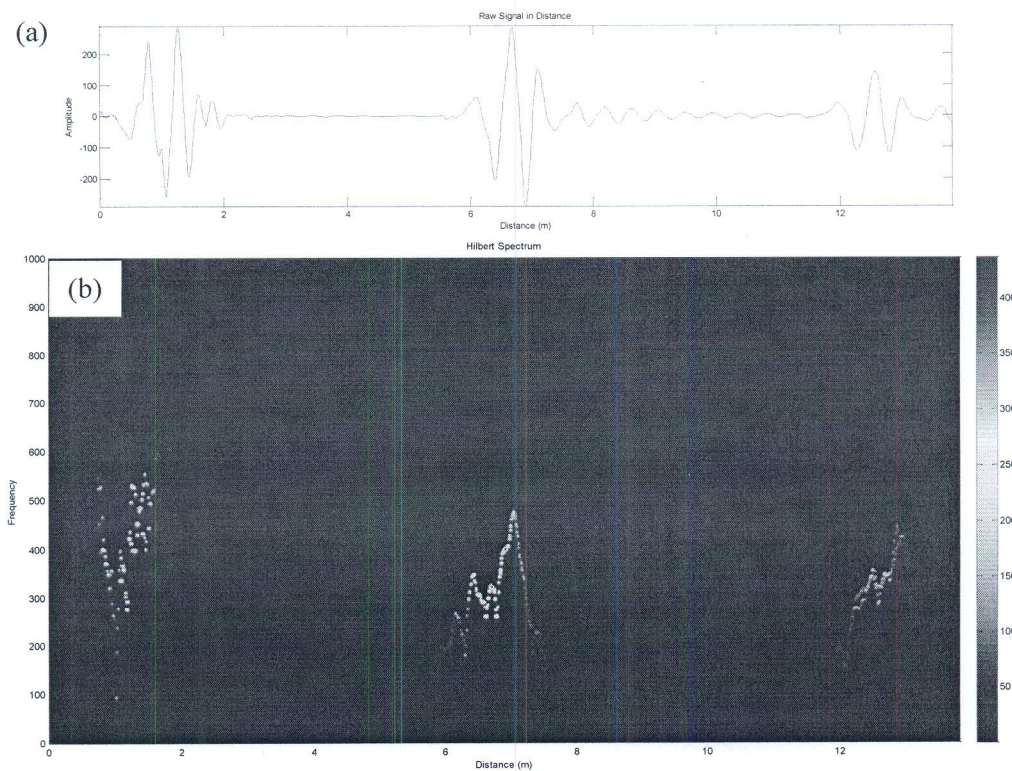

Fig. 2. (a) Raw data for no leak condition after injection Hamming chirp signal. (b). Hilbert spectrum using EMD analysis.

Fig. 3 shows the gas leakage in time domain (a), and Hilbert spectrum (b). It is found that the gas leakage is continuous acoustic signals in the time domain and the frequency range from 20-600 Hz. The acoustic energy concentrates at 200 Hz and shows the leak location at 4.105 m and pipeline outlet at 6.062 m. The real distance of leak is 4 m and pipeline outlet is 6 m. Thus, the leak location error is 2.625 % and pipeline outlet location error is 1.033 %. The experiment conducted 4 times and their leak location error calculated and the result was indicated in Table 1.
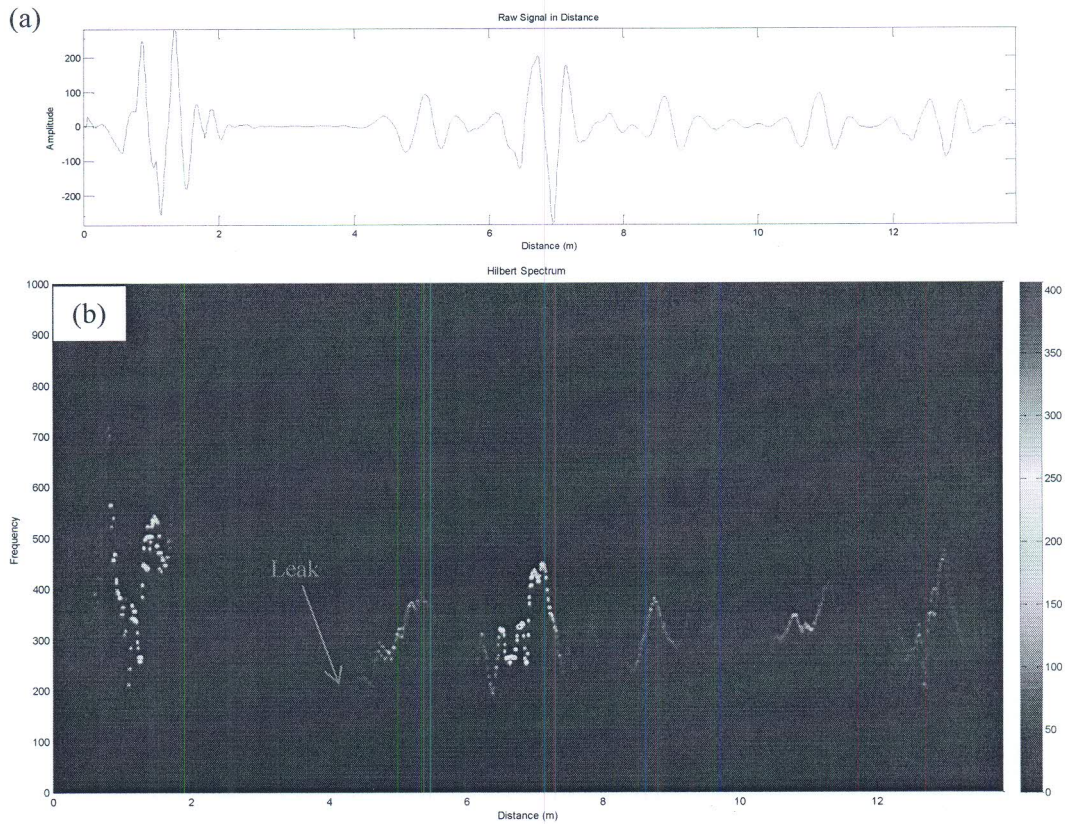

Fig. 3. (a) Raw data for leak condition after injection Hamming chirp signal. (b). Hilbert spectrum using EMD analysis.

Table 1 Result of leak and outlet location error.

Data	Leak A location (m)	Measured distance (m)	Error (%)	Outlet location (m)	Measured distance (m)	Error (%)
1	4.105		2.625	6.062		1.033
2	4.112	4	2.800	6.043	6	0.716
3	4.085		2.125	6.008		0.133
4	4.101		2.525	6.081		1.350

Summary

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, Hilbert Huang Transform shows the acceptable range of error and reliable to do in the laboratory. This experiment is easy to implement and This method also has more accuracy of reflected to the actual frequency components of signals compared to others. The experiment should continue with the addition of junction to validate the method of signal processing and also using long pipeline.

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