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A Study of Ikaz and Normalized Hilbert transform for solving faulty in pipeline distribution system using transmission line modelling

Hanafi.M.Yusop*,M.F.Ghazali, W.H.Azmi, M.F.M.Yusof, M.A.PiRemli M.A.A.Rahim

Advance Structural Integrity and Vibration Research (ASIVR, Faculty of Mechanical Engineering, University Malaysia Pahang, Pekan, Pahang, Malaysia.

m.hanafiyusop@yahoo.com.my*

Abstract. When there are sudden changes in fluid propagation in the pipeline system, pressure transient signal is generated. Due to the rapid pressure and fluctuation flow of the system such as opening and closing of valve rapidly. A few group of researchers had use the pressure transient signal to detect and locate any uncertainties in the system (leak and blockage). Empirical Mode decomposition (EMD) will be as the demonizing method of pressure transient signal before proceeding to be analyzed further by using instantaneous frequency analysis in this research. EMD might be the step of decomposing the signal into intrinsic mode function, but this method have difficulties in selecting a suitable IMF. This paper proposed the uses of Integrated Kurtosis-based Algorithm for z-filter Technique (Ikaz) for that allows automatic selection of suitable and relevant IMF. This work shows the artificial pressure transient signal generates using transmission line modelling (TLM) in order to test the effectiveness of Ikaz as the autonomous selection of IMF. This paper implements the Normalize Hilbert Transform (NHT) as the instantaneous frequency analysis. A straight fluid network was designed using TLM fixing with higher resistance at some point that act as a leak and connecting to the pipe feature such as junction, pipefitting or blockage. The analysis results using Ikaz show that the method can be implement as an automatic selection of intrinsic mode function (IMF) with percentage errors below 5%. Thus, Ikaz-kurtosis ratio is recommended to be implemented as automatic selection of intrinsic mode function (IMF) through NHT analysis.

1. Introduction

Water is a common basic need for human's to utilize in their basic life. The biggest problem faced in water being supplied is the Non-revenue water (NRW) which is the lost and accounted for when being pumped. Due to the high level of water loss in distribution network, this is the major problem. This will also cause a difficulty in meeting consumer's demand. Heavy losses makes the water yields no revenue, keeping water tariffs at a reasonable and affordable level. Asian cities commonly face these issues.[1] As recorded, the level of NRW nationwide is 36.63% and based on these number, it is estimated 21.93% is due to physical loss and commercial loss is 14.70%. [2] This is mainly caused by the aging of pipes, corrosion, erosion, excessive pressure of water effecting the operational error and water hammer generated by rapid opening and closing valve.[3]

It is proven crucial, that the loss of water is effecting certain country deeply. Many steps had been taken to reduce NRW. The methods include locating and detecting leaks, this is to reduce NRW. Water audit or commonly known as water balanced. This can help to determine the amount of water loss due to water distribution system. This is carried out by performing a network-wide district by district. Thus, providing an overall image water loss in the distribution system. Continuous monitoring in pipes such as monitoring the pressure of water and flow data, by a closed circuit camera inspection of the interior [4]. Infrared thermal imaging and fiber optics sensor are the other method applied. But these methods are expensive and are needed to be drawback upon.[5]

Signal analysis process technique is to analyze both time in frequency domain such example is implemented for Hilbert-Huang Transform (HHT). HHT was proposed due to ability to detect and capturing the transient occurs in non-stationary signal. HHT is more commonly applied in the past years for analysis for signal process. This is due to the fact that HHT as it is newly developed and quiet powerful method to analyzed non-linear and non-stationary signal [6]. This method have its own disability as it is difficult to choose the suitable the IMF for next data post-processing method which Hilbert Transform (HT). Empirical Mode Decomposition is utilize to help decompose the signal into a monocomponent and through the sifting component a symmetric component is occupied. This is also known as Intrinsic Mode Function(IMF) [7]. The drawback of the approach is the necessity to know a prior the frequency levels of the original signal should be analyzed [8]. In this case however the HHT is not completely automatic and need to be interacted by the user's skill to select a suitable IMF. Thus, the suitable IMF needed to overcome this problem is selected automatically. The mathematical computational technique and statistical value were analyzed by researcher to increase the degree of automation then the interaction of the skilled user is to eliminate and select the IMF that is relevant.

A few recent studies had been approached on measurable quality for automatic selection of relevant and appropriate intrinsic mode function (IMF). Maji et al.[13] variance were proposed and standard deviation as statistical value to differentiate each level of the decomposition of intrinsic mode function (IMF). Via electrodiogram(ECG) a researched had been done in order to detect Artificial Fibrillation(AF) rhythm and normal rhythm. Ricci and Pennacchi [10] thus showing the Merit Index as an indicator that allows the selection of IMF level automatically. These usually utilizes rotary element (gear) signal to test the efficiency of Merit Index in selecting the relevant and appropriate IMF. In the research of vibration signal was captured the from a rolling element (gear) , afterwards the signal were extracted using a hybrid method of Minimum Entropy Deconvolution (MED), Empirical Mode Decomposition and Teiger Energy Operation (TEO) . The IMF which present the highest value of correlation coefficient is selected compared to the original signal. De Souza et al. [5] an approach through the Energy-Based via mutual information (MI) coefficient as a method of selection relevant IMF. By applying the synthetic signal was applied with embedded in white noise and real-world signal. Mutual Information (MI) was also utilized as a method to select the right IMF in biomedical signal process done by Ricci and Pennacchi [10].

This researched proposed Integrated Kurtosis Algorithm for z-notch filter hybrid with the higher order statistical method (Kurtosis) as the automatic selection of intrinsic mode function (IMF). Hence, the approach of the method was adaptive in general and detects very well any changes and uncertainties of the measured signal, therefore Ikaz was chosen[9]Unlike the current variance, standard deviation and kurtosis or more known as statistical analysis. Thus, making the Ikaz method reliable for monitoring purpose where the changes of the signal amplitude and frequency were commonly acquired. The selected IMF signal will be chosen to be analyzed by using Normalized Amplitude Hilbert Transform (NAHT) and the Normalized Hilbert Transform (NHT). Where it will make the difficulties of HHT to be simplified and able to be used easier. [10]

For the automatic selection of IMF, the Ikaz-Kurtosis ratio was selected due to the effectiveness and reliability this was done using artificial pressure transient signal and random signal generated using Matlab to determine the relevant and appropriate to be further analyzed , and the results shows the IMF containing maximum value of Ikaz-kurtosis ratio coefficient are suited. To obtained better IMF a comparison of the effectiveness of kurtosis compared to Ikaz as the automatic selection method. The aim of this paper is focused on the implementation of Ikaz-kurtosis ratio coefficient as an automatic selection of intrinsic mode function via synthetic pressure transient response. Which is produced by using transmission line modelling (TLM)[11]. Computational efficiently, for studying a wide range of wave and diffusion phenomena is what the TLM known for. By adding the white Gaussian noise into each of the signal response, this act as the background noise in order to make the signal response similar to the real one. The synthetic signal response with added background noise generates utilizing TLM resulted in the IMF contain highest value of Ikaz-kurtosis coefficient. This is suitable and appropriate to be further analyzed. Before proceeding, to test the effectiveness using real Pressure transient response, the Ikaz-kurtosis ratio was chosen as it had been proven suitable as an automatic selection method for better and relevant IMF. Therefore, an improvised degree of automation for Hilbert-Huang Transform (HHT) was utilized to detect pipe leakage in live water distribution system using pressure transient signal.

2. Methodology

2.1. Simulated Pressure Transient Signal

For this research, different pipe length was utilized to construct two simulated pipelines, the pipe modal was also were integrated with number of leaks and water pressure to create the variables. A pipe with a leak and without leak were simulated for the first model (Figure 1(a)). Medium high-Density Polyethylene (MDPE) pipe were modeled with a divided section consisting the valve and the junction which in total sums up a 3 section (figure 1(a)). For the first model a total distance of 70 meter with a water pressure of 1 bar is set. The second modal (figure1 (b)) were constructed by using MDPE pipe, consisting 4 divided section accompany by a valve and 2 junctions. In this model, the distance for the water and pressure acting in the pipe is 37 meters and 2 bars respectively and 2 numbers of leak is accounted for. To simulate the signal when the condition of the pipe is flowing without any leaks, for the junction resistance is set to 3000 but for the simulation with leak 30,000,000 were set at the junction. The diameter of each pipes in both models are constant consisting of 60mm respectively.

A simple design was constructed to validate the identification of the approach. Water hammer pulse were created from the opening and closing of the valve (Figure 1) that propagates through the system. Time-varying valve was applied in the system as describe by Beck et al.[12] The geometry, length and diameters were set in the software. In order to simulate the leak feature at the junction, a higher value of resistivity is inserted this will generate pressure that is reflected.[13] By the speed of sound that is created by the pressure wave and the distance of reflected points from one end to the pipe, can determine the pipe outlet and location of leak.

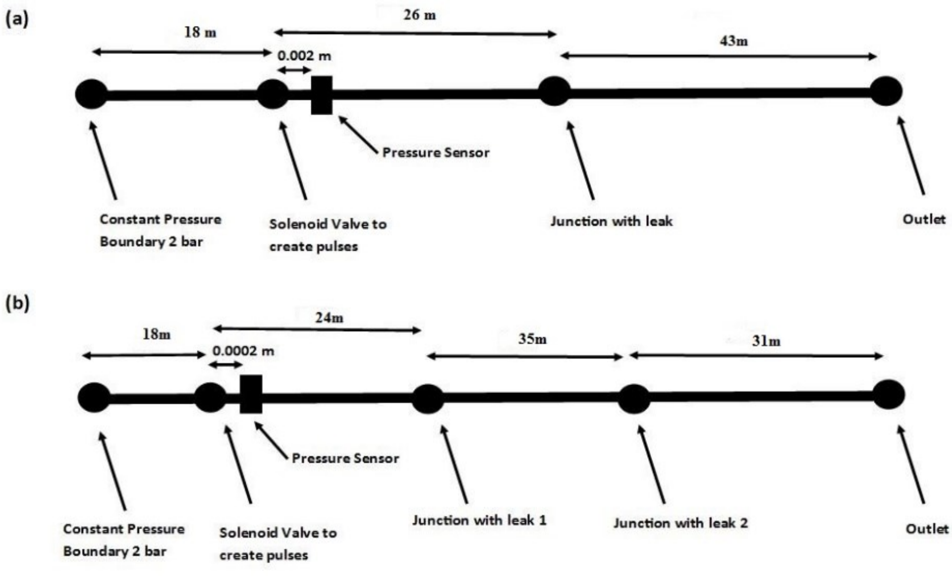

Figure 1. Pipe network model. (a) First model (b) second model.

For the pipeline model's water was used as a medium flow of a simulated fluid. The value of standard temperature and pressure of commonly known as STP were assumed. MDPE and 60mm are the material and diameter used respectively and the speed of sound to be 493 m/s. As seen in Figure 1, the valve and the pressure sensor's distance was set to 0.001 meters. By utilizing a pressure sensor that is located at the valve, a time history signal response of pressure is captured.

2.2 Added White Gaussian noise.

To simulate a real pressure transient signal, TLM software generates a signal response that are added with the white Gaussian noise. The deciding factor to generate white Gaussian noise is the Signal to Noise Ratio (SNR)'s value. If the changes in extrema of the original signal is too strong to be changed by the weak added noise or the added noise is too strong. If utilizing the EMD/EEMD method will propagate a dysfunctional result, which were controlled by the added noise and scarcely accompanied by the original signal [14]. For the SNR between added noise and original signal, the EMD/EEMD method are appropriate to be utilized which the white added noise is approximately 37 dB according to Zhang et al.[15]based on this reference therefore, the SNR value is set to 37 dB. As shown in figure 2 below, the graph shows as a signal response from TLM with added noise. The original response of TLM without noise are represented with the red line and the blue line represented the TLM with added noise. The Hilbert Huang Transform (HHT) and the integrated Kurtosis Algorithm for Z-notch filter technique known as Ikaz as automatic reflection of IMF (intrinsic mode function) were utilize to analyze the signal response of TLM with added noise. Thus resulting the characteristic of the pipe features such as leak, blockage and pipe fitting to be indicated in the analysis.

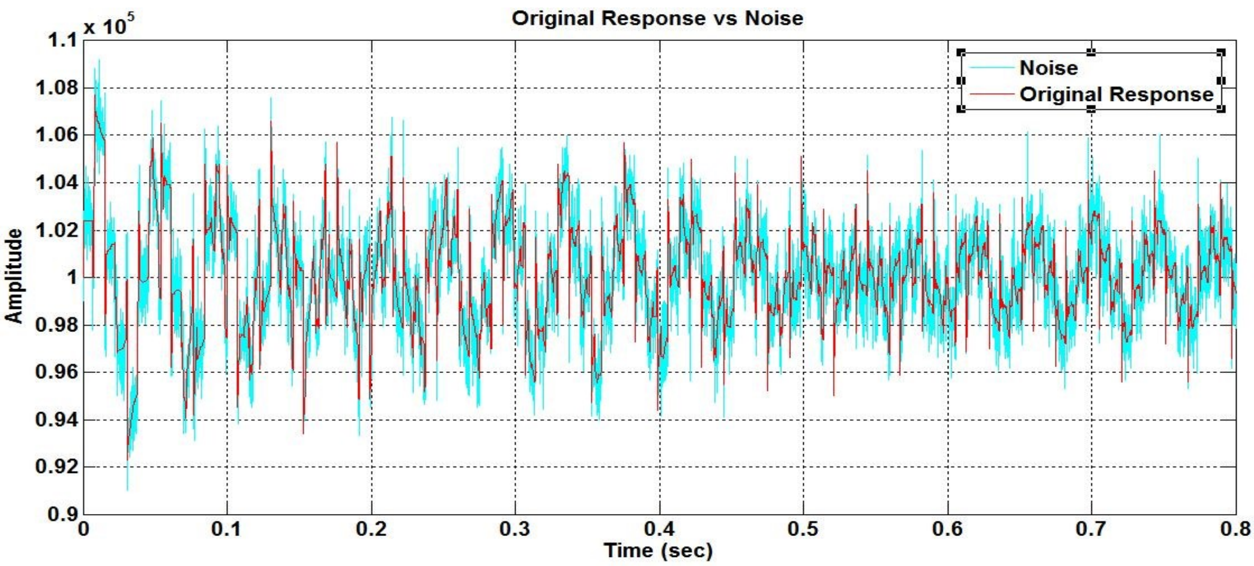

Figure 2. Signal Response with added white Gaussian noise.

3. Results and Discussion

Figure 3 shows the implementation of the first pipe network model being added with noise and the signal response. The 2nd pipe model with the implementation of the signal response and added noise is represented in the Figure 4. Empirical Mode Decomposition (EMD) and Hilbert Transform (HT) are presence in the Hilbert Huang Transformed are utilized to obtain the original signal and frequency.

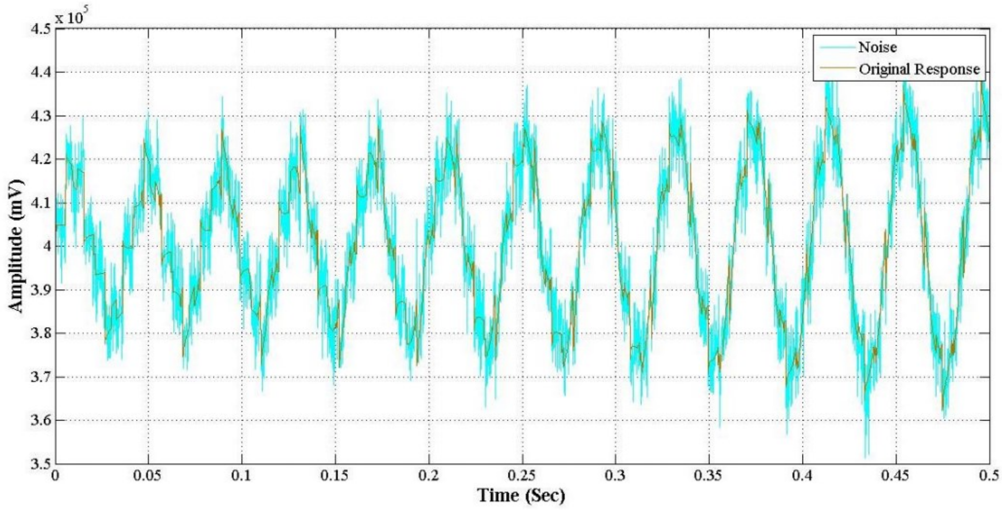

Figure 3. Signal response with added noise for 1st pipeline model response

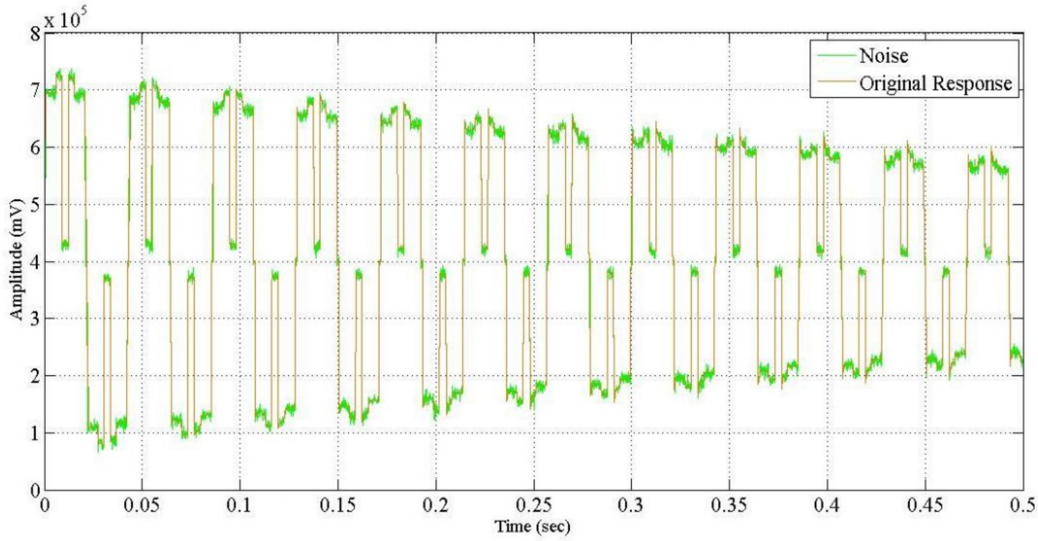

Figure 4. Signal response with added noise for second pipeline model response,

Intrinsic Mode Function (IMF) was composed from the signal response that are analyzed.13 levels of intrinsic mode function (IMF) were composed by EMD from the signal response. The amplitude versus time for the first 12 levels of IMF were represented by Figure 5. The noise signal is represented, by the first level of IMF which consist of a group of higher frequency signal. Due to the presence of noise frequency signals the 1st and 2nd level of IMF was avoided form being analyzed. The remaining and IMF level 7 consist the basic of the network. Based on these reasons, all these IMF were discarded. IMF from level 3-6 were recombined to produce a signal without noise. The suitable level of IMF have to be determined, by implementing Integrated Kurtosis Algorithm for Z-filter technique to kurtosis ratio (Ikaz-Kurtosis). To compute the coefficient of each level, Ikaz-Kurtosis ratio was utilized.

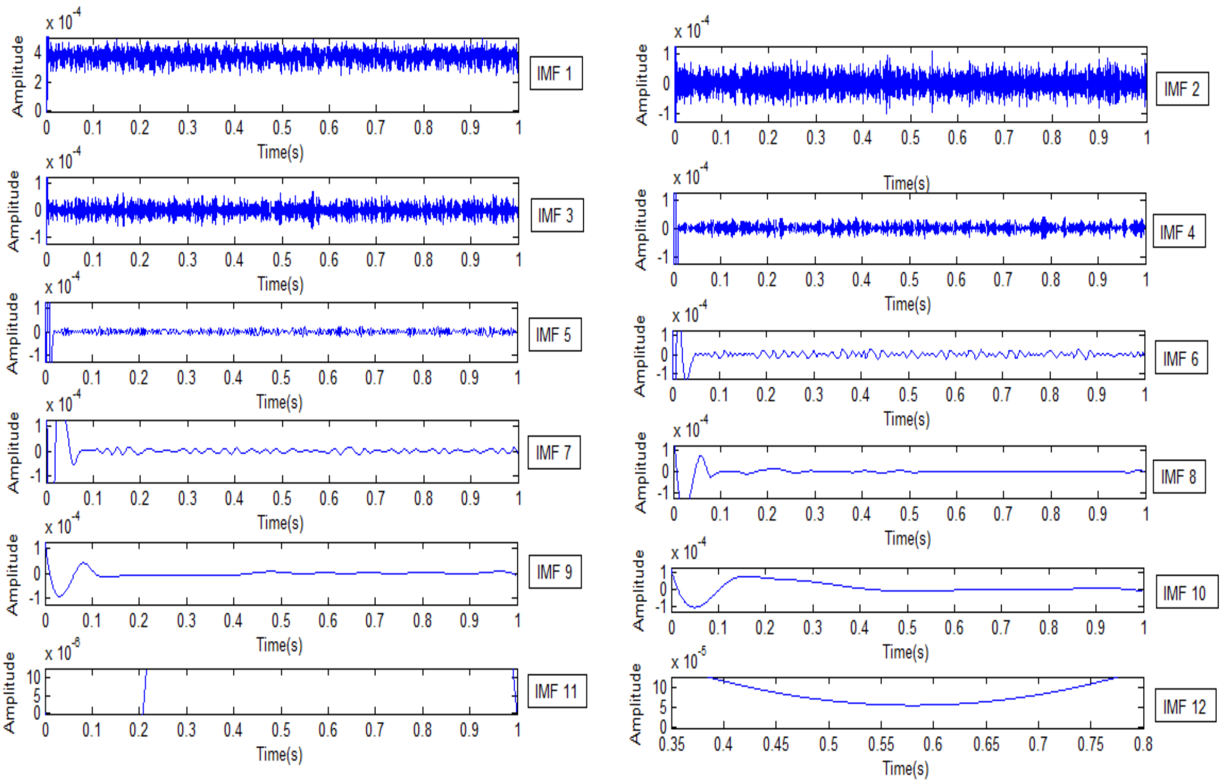

Figure 5. Intrinsic mode function (IMF) from level 1-12

(a) (b)

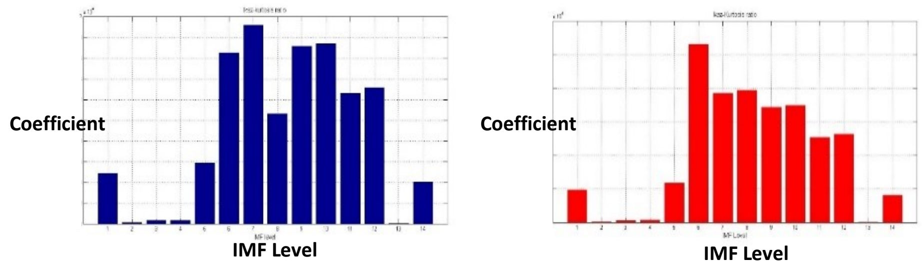

Figure 6. Ikaz-Kurtosis ratio coefficient for the first pipeline model (a) no leak signal b) with leak signal

(a) (b)

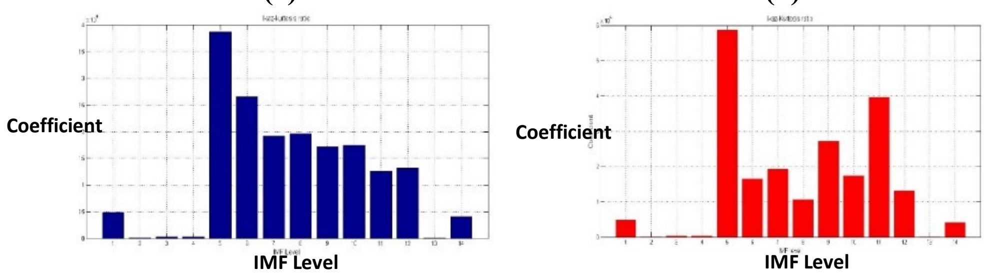

Figure 7. Ikaz-Kurtosis coefficient for the 2nd pipe line model (a) No leak signal (b) leak signal

In Figure 6 (a,b) shows the Ikaz-Kurtosis ratio coefficient of the first model pipe network module during the absence of leak and presence of leak respectively. The same Ikaz-Kurtosis ratio coefficient with the same variable applied were also shown in figure 7 (a,b) but with the second pipe model network.

Based on the two figures mentioned above, the x-axis and y-axis are represented the IMF level and value of Ikaz-Kurtosis ratio coefficient respectively. As the graph shows , we can observe that the most suitable IMF level to be applied through the post-processing and the last step of Hilbert Huang Transform (HHT) analysis or known as Hilbert Transform(HT) are the maximum or highest Ikaz-Kurtosis ratio coefficient. This criteria was specifically chosen, due to the clear and narrow spikes that can be clearly seen by the highest value of Ikaz Kurtosis ratio. Since, the clear and narrow spikes becomes obscure in the lower value of Ikaz-Kurtosis ratio. Therefore, it is rejected since that is the major criteria. The highest value of Ikaz-Kurtosis ratio that were presence in the IMF level of 3-6. The signal without noise were made up of the combination of level 3-6 [16]. Thus, making these levels to be appropriate and relevant to be analyzed. The IMF of level 6 contained the highest Ikaz-kurtosis ratio and level 4 were reserved, but in different figure as illustrated in Figure 6(a,b) respectively. Meanwhile IMF level 5 were shown to have the highest coefficient in the Figure 7 (a), followed by level 6 in figure 7 (b).

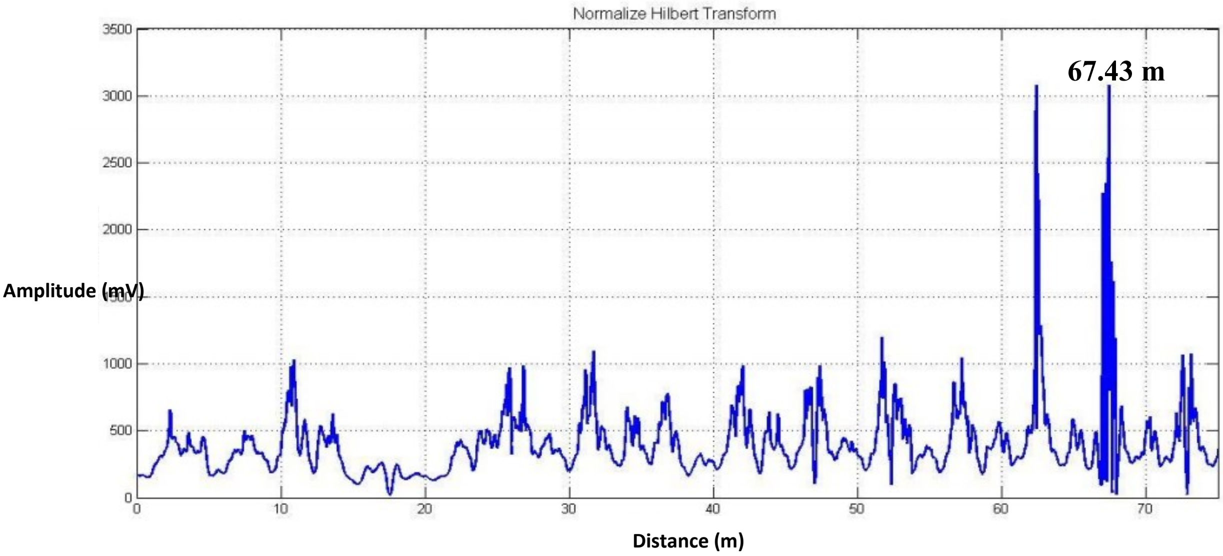

Figure 8a. Instantaneous characteristic of NHT analysis for first pipe network model. for signal without leak

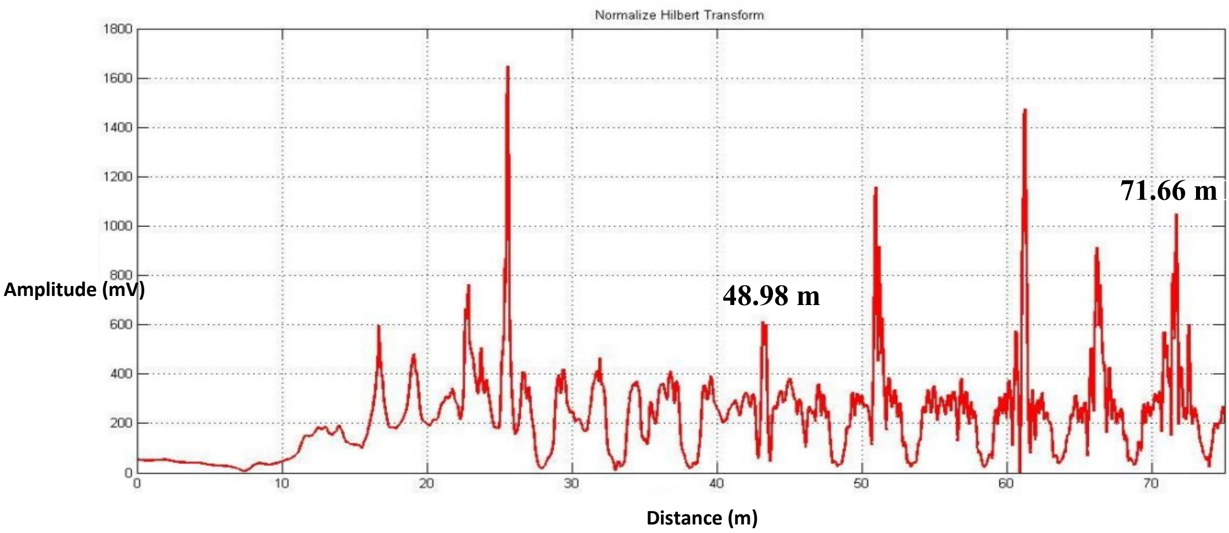

Figure 8b. Instantaneous characteristic of NHT analysis for first pipe network model. for signal with leak

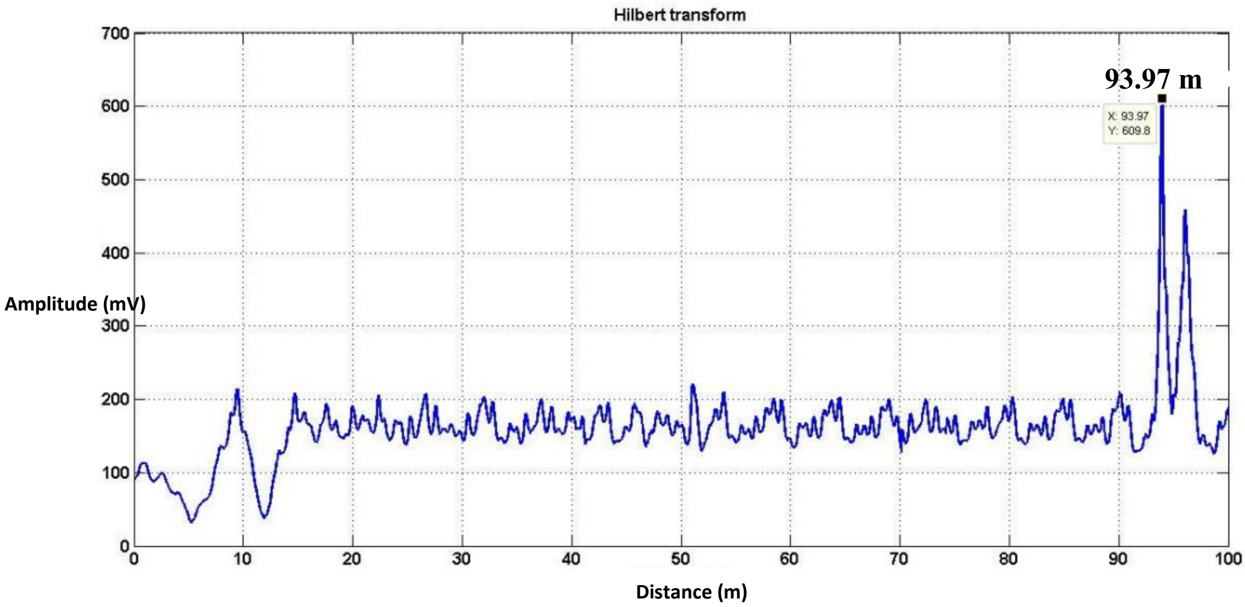

Figure 9a. Instantaneous characteristic of NHT analysis for first pipe network model for signal without leak

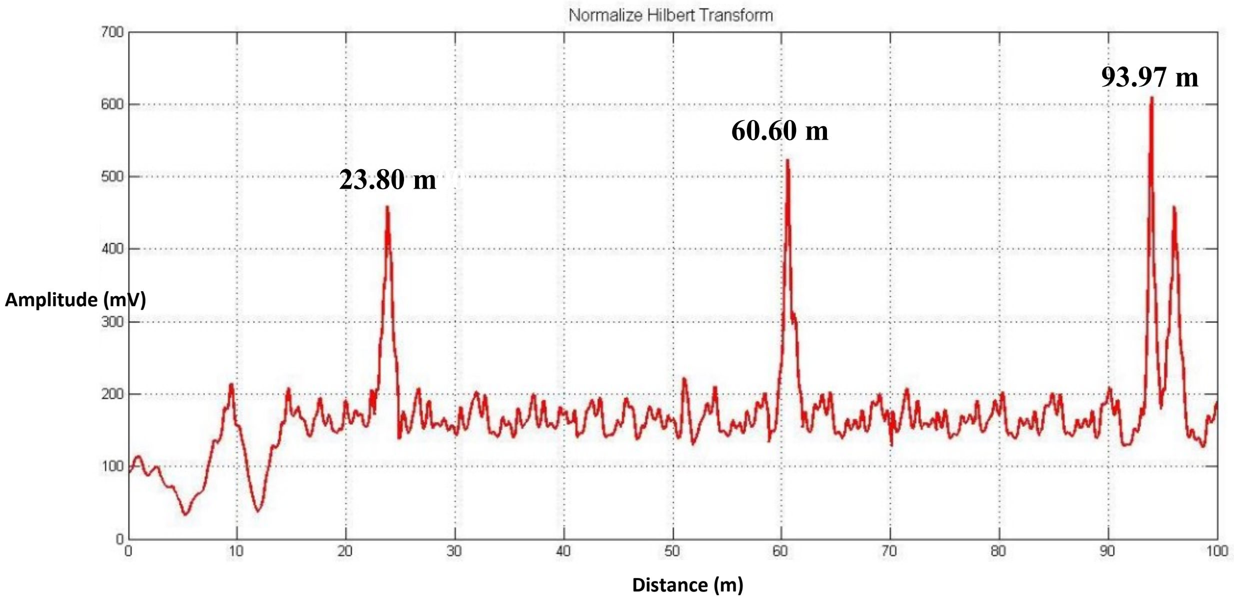

Figure 9b. Instantaneous characteristic of NHT analysis for first pipe network model for signal with leak

The instantaneous characteristic of the signal are shown in the figure 8 and figure 7, being represented with leak and no leak in (a) and (b) respectively. The presence of reflection were highlighted in the instantaneous frequency. The time taken for the wave to travel through the pipe to the reflection point and to be returned in the measurement point are in sync with the peak of the analyzed signal. By multiplying the delayed time corresponding to the peak by the speed of sound in the pipe network (a=493m/s), the distance of reflected point can be calculated and the value is halved to factor in the return journey. The reflection corresponding to the outlet signature is shown in figure 8(a) to be 67.43m and in figure 8(b) as 71.66m. The leak signature corresponded to the reflection seen in figure 8 (b) and figure 8(a) was measured to be none and 25.55m respectively. The signature of leak 2 and leak 1 with the reflection is 60.6m and 23.8m as seen in Figure 9(b). Some errors are bound to occur when the analyse position is compared to the simulated position. The comparison is tabulated in Table 1 below.

Table 1: Comparison between the exact location and experimental location

Water Pressure	Signal Response	Pipe Feature	Simulated Position (m)	IMF contain Maximum Ikaz-Kurtosis ratio Coefficient	Analyse Position (m)	Error %
First Pipeline Model	Leak Data	Leak	26	3	25.55	1.73
		Outlet	69		71.66	3.86
	No Leak Data	Outlet	69	3	67.43	2.27
2nd Pipeline Model	Leak Data	Leak 1	24	3	23.80	0.83
		Leak 2	59		60.60	2.71
		Outlet	90		93.97	4.40
	No Leak Data	Outlet	90	3	93.97	4.40

Table 1, shows the 1st model pipe with leak signature and water pressure of 4 bar, the position of leak is 1.73 % error and the error for position of outlet is at 3.86%. For no leak a 2.27% error of outlet signature position. A water bar of 2bar are applied to the second model pipe the position of signature leak 1 and 2 is 0.83% error and position of outlet signature with 2.71% error. 4.4% of error for outlet position is presence at the no leak signal response. HHT analysis is the final part taken for analysis, to show the position of pipe feature that is leaked and pipe outlet appear. The position is also compared to each original positon and simulated positioned. HHT analysis is able to detect and positioned the transient event occurred in the non-stationary pressure transient signal.

4. Conclusion

This paper discussed, the method of IMF selection through Hilbert Huang Transform (HHT) analysis. The Ikaz-Kurtosis ratio is proven through the result and self-decision method of IMF selection through the HHT analysis had statistically built and analyzed by Ikaz-kurtosis ratio. Utilizing the Ikaz-Kurtosis ratio efficiently, the IMF issue of selection was overcome. Therefore, degree of automation for Hilbert Huang Transform (HHT) was improvised to detect leakage of pipe in live water distribution system using pressure transient signal.

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