

PAPER • OPEN ACCESS

Implementation of I-kaz with Teager-Kaiser energy operator in solving leakage problem using synthetic signal

To cite this article: M.A. PiRemli *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **469** 012094

View the [article online](#) for updates and enhancements.

You may also like

- [An empirical study of modified beat SQT based majority voting fusion method for heart-rate estimation in noisy multimodal cardiovascular signals](#)
Shalini A Rankawat
- [Weighted kurtosis-based VMD and improved frequency-weighted energy operator low-speed bearing-fault diagnosis](#)
Xuewei Song, Hongfeng Wang and Peng Chen
- [Detection of spontaneous seizures in EEGs in multiple experimental mouse models of epilepsy](#)
Lan Wei, Halima Boutouil, Rogério R Gerbatin *et al.*

ECS Toyota Young Investigator Fellowship



For young professionals and scholars pursuing research in batteries, fuel cells and hydrogen, and future sustainable technologies.

At least one \$50,000 fellowship is available annually.
More than \$1.4 million awarded since 2015!



Application deadline: January 31, 2023

Learn more. Apply today!

Implementation of I-kaz with Teager-Kaiser energy operator in solving leakage problem using synthetic signal

M.A. PiRemli¹, M.F.Ghazali¹, W. H. Azmi¹, M.F.M Yusof¹, Hanafi.M.Yusop¹ and M.LAzmi¹

¹Advance Structural Integrity and Vibration Research (ASIVR, Faculty of Mechanical Engineering, University Malaysia Pahang, Pekan, Pahang, Malaysia.

*Corresponding author:aminuddin_pr@yahoo.com

Abstract. Transient event usually happen due to pressure surge inside water pipeline network by either opening or closing valve rapidly or water hammer phenomena. This paper focus on identification of leak signature using Empirical Mode Decomposition (EMD) with the implementation of Ikaz-kurtosis ratio while Teager Kaiser Energy Operator (TKEO) use as instantaneous frequency analysis (IFA). Two synthetic signal with different pipe characteristics was construct using transmission line modelling (TLM). It is show that Ikaz-kurtosis ratio give good result in selecting the intrinsic mode function (IMF) after EMD decomposed the signal into a series of IMFs. TKEO as post processing analysis extract all the information inside the signal that contaminated with noise. Its show that leakage position can be localize with maximum error less 7.3%. Meanwhile, Outlet position recorded 3.4% maximum. This conclude that this method apply for synthetic signal is acceptable for leakage detection.

1. Introduction

Water has been an essential need for human. Water management is very important to ensure every drop of water distributed to the right places. In water distribution system, there must be losses due to inefficiencies in pipeline through physical losses such as leaks as well as apparent losses like theft and metering inaccuracies. This losses term defined as non-revenue water (NRW). NRW is the main problem for water industries across the world. In southeast Asia itself, over 13 million m³ of NRW has been recorded which is contributed to 35% of water loss [1].

According to [2], the nationwide NRW in Malaysia is recorded as 36.63% and researchers are trying to reduce this value. NRW is very synonym to leakage problems in pipeline system. A better service in water distribution system may reduce cost gradually. It is estimated that the total cost to water utilities caused by NRW around the world is worth 141 billion dollars per year [3]. The statistic shows a very huge number and it must solved. Besides, NRW does not only caused financial loss to country, but it is also damaging the environment. Leaks could lead to damage of soil structure that will indirectly cause the slope failure. Other than that, leaks can cause water ponding on the metaled road that which will damages the structure and road components.

Water distribution industries has their strategies to improve the NRW statistics. NRW can reduced by installing NRW management system, leakage monitoring and repair system, targeted meter replacement program, detection and repair leaks in pipe, and hydraulic modelling across the pipeline system. Leak awareness method by using hydraulic model has been used to discover a leak in a particular area within the water network [4]. However, this method does not give any information about its precise



location. Besides that, some companies have applied leakage localization methods that is step testing. This method is an activity that the area subdivided by the systematic closing of valves during the period of minimum night flow. However, this method may cause the infiltration of the ground water [4].

Leakage pinpointing methods that use the leak noise correlator, can precisely determine the position of the leak. This method does not rely upon the personal skills of the operator in interpreting the results [5]. Empirical mode decomposition (EMD) is a method of breaking down a signal without leaving the time domain. The process useful for analyzing natural signals, which are most often non-linear and non-stationary. The signals generated decomposed by using EMD into several components [6]. These components known as Intrinsic Mode Functions (IMFs) are therefore sufficient to describe the signal, even though they are not necessarily orthogonal. However, IMF required an expert to select the right signals. This will limit the uses of IMF in industries.

Few recent studies have approached automatic selection of IMF as to ease the users with lower skill. The uses of variance and standard deviation as statistical value to differentiate each level of the decomposition of intrinsic mode function (IMF) has been proposed by [7]. The research was done using electrocardiogram (ECG) signal in order to detect Artificial Fibrillation (AF) rhythm and normal rhythm. In monitoring rotating machines. The introduction of computation of correlation coefficient value for each level of IMF as quantifiable quality in selecting appropriate IMF level has been proposed in monitoring rotating machine[8]. In the research/study, vibration signal is captured from rolling element (bearing), then the signal is extracted using a hybrid method of Minimum Entropy Deconvolution (MED), Empirical Mode Decomposition (EMD) and Teager Energy Operator (TEO). The selected IMF is the IMF which presents the higher value of correlation coefficient compared to the original signal. Another method of selection of relevant IMF is by using an Energy-Based approach through mutual information (MI) coefficient[9]. The research was done by applying the synthetic signal embedded in white noise and real world signal.

This research proposed the Integrated Kurtosis Algorithm for Z-filter (Ikaz-kurtosis) technique in selecting IMF signals was propose so that it is no longer required experts to choose the correct signals. Ikaz-kurtosis method is capable to indicate both amplitude and frequency difference by simultaneously obtaining the Ikaz-kurtosis representation and Ikaz-kurtosis coefficient [10]. The selected IMF signal analyzed by using Teager-Kaiser Energy Operator (TKEO) before the result of leak location can be know. TKEO is a non-linear operator that can provide an estimate of the instantaneous frequency and amplitude of a signal with AM and FM modulation. The advantage of TKEO is that the calculated energy is derived from instantaneous amplitude and instantaneous frequency of the signal [11].

This research is comparing the effectiveness of Ikaz-kurtosis as the automatic selection of IMF signal. The maximum value of Ikaz-kurtosis coefficient in IMF can be revealed by using artificial pressure transient signal and random signal generated using MATLAB[12]. The aim of the research is to apply the Ikaz-kurtosis ratio coefficient as the automatic selection of IMF using artificial pressure transient signal generated using transmission line modelling (TLM). TLM is a technique for studying a wide range of wave and diffusion phenomena. The White Gaussian noise is add into the signal to imitate the background noise so that the signal is similar to the real pressure transient signal. The signal generated using TLM with the addition of noise will represent the IMF that contains high value of Ikaz-kurtosis coefficient is suitable to analyze. Ikaz-kurtosis ratio is proved to become automatic selection method for better and relevant IMF [13]. Thus, the detection of leakage location can improve by analyzing the correct IMF signal by using TKEO method.

2. Methodology

2.1. Synthetic Signal

This paper discussed the synthetic signal that generate by using Transmission Line Modelling (TLM). TLM can be construct based on our own decision to create the model of the piping system. In TLM, we can either choose the type of pipe, number of pipe and junction, length of every pipe, pipe resistance, and so on. In this paper, two model of pipelines were proposed to test the method the entire

synthetic signal constructed. For both pipeline networks, the parameters for pipe resistance and its pressure of water flow. Meanwhile, for every factor the pipe set to either leak system or without leak system. Both model developed with same pipe characteristics that is using drawn tubing and the material flow is water. The pipe diameter for both system is fix to 60mm of outer diameter in order to make sure the pipe robust with actual test rig. In order to create leak in the system, the resistance of the junction need higher than the value of maximum resistance. As opposite, the without leak system, the resistance set less or equal to reference resistance.

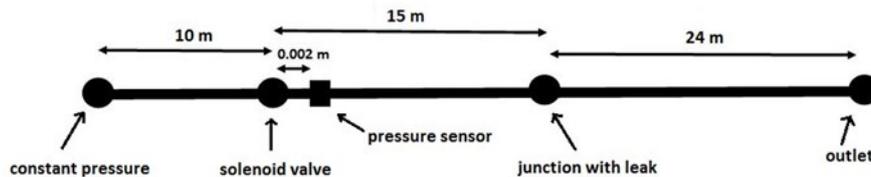


Figure 1. First model of pipeline system.

Figure 1 shows the schematic diagram of the first pipeline network model. The total length of the pipe was 49m that contain four junctions and three pipes. The sensor is set close to the solenoid valve to ensure that at the second junction become the point of analysis. The resistance is set higher than reference resistance at the junction three to create a leak at the junction. The outlet of the piping system is set to be the last junction of the system.

Meanwhile, Figure 2 illustrated the second model of the piping system that slightly different from the previous model. This model designed using five junctions and four pipes with the different length of each pipe. This second model constructed with the total length of 61m in order to make sure it was different from the first model. The location of the sensor same as the previous model that is close to a solenoid valve with the same reason. Moreover, this system contain two-leak position that was at junction four and five.

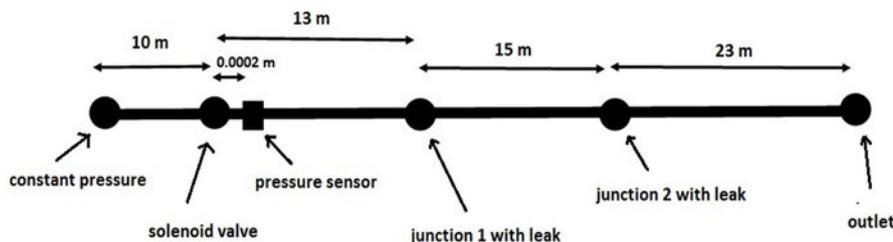


Figure 2. Second model of pipeline system

2.2. White Gaussian Noise

The synthetic data acquired from the TLM software unacceptable if compared to the captured data in real life in the detection process. The reason was that in real life, the captured signal absolutely will with the noise that from many sources for example pump noise, pipe friction, pipe vibration, and surrounding noise. This is because the sensor used on capturing data is so sensitive to the noisy environment.

In order to overcome this problem, white Gaussian noise is added to the synthetic signal created previously. This process is done using MATLAB software with a coding to create white noise. However, the added noise cannot be simply done by entering any level of noise. This is a state in [14] that if the added white noise is too high, decomposition method that either EMD or EEMD will generate a meaningless result and cause faulty in the result obtained. Conversely, if the white noise added too low, it will not bring any changes to the synthetic signal we create before [14]. According to [15], 37dB of white noise were appropriated added into the signal for EMD or EEMD process. In figure 3 show, the

signal obtained from the TLM software without contaminated with noise. Meanwhile, in figure 4 show the synthetic signal with the implementation of white Gaussian noise into it.

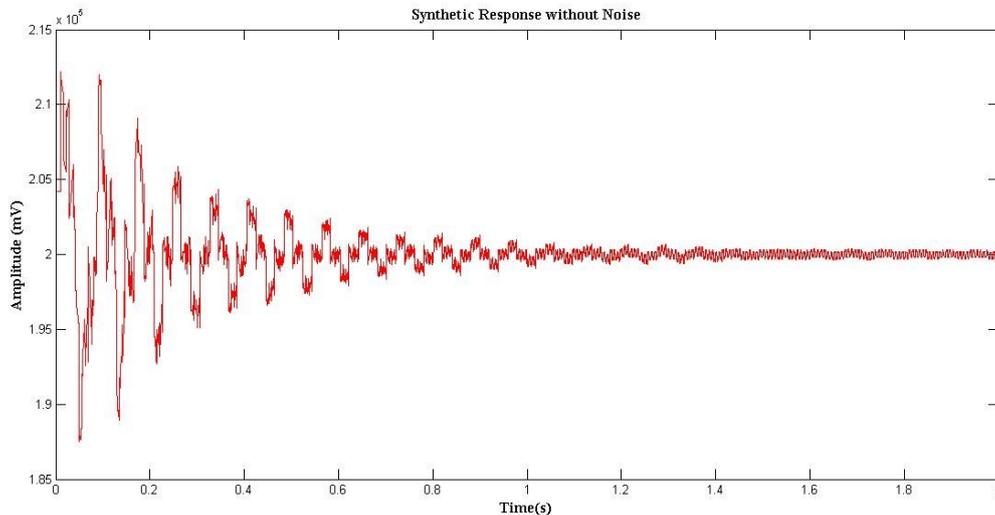


Figure 3: Synthetic response without noise.

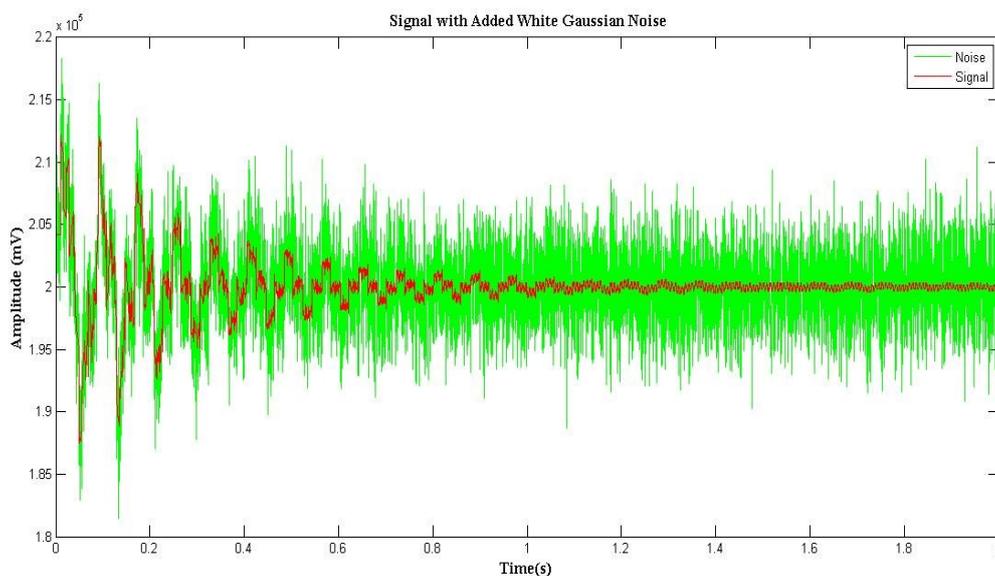


Figure 4. Synthetic signal with added white Gaussian noise.

After the process done, the synthetic data undergoes decomposition process by using EMD. EMD will decompose the noisy signal into several levels of IMFs. The process follows by Ikaz-kurtosis ratio as a tool for automatically selecting the best IMF for instantaneous frequency analysis using Teager-Kaiser Energy Operator (TKEO). The result then displayed in the frequency domain to find the uncertainty inside the data such as a spike. The spike will show the features and leak signature along the pipeline networks.

3. Results and Discussion

Synthetic signal for the first model with added white Gaussian noise shown in figure 5. From the original response of synthetic data, the information of the pipes cannot be discovered. Thus, implementation of EMD function to decompose the signal into their level of amplitude. Meanwhile, in figure 6 show the signal response for second model of pipeline system with added white noise.

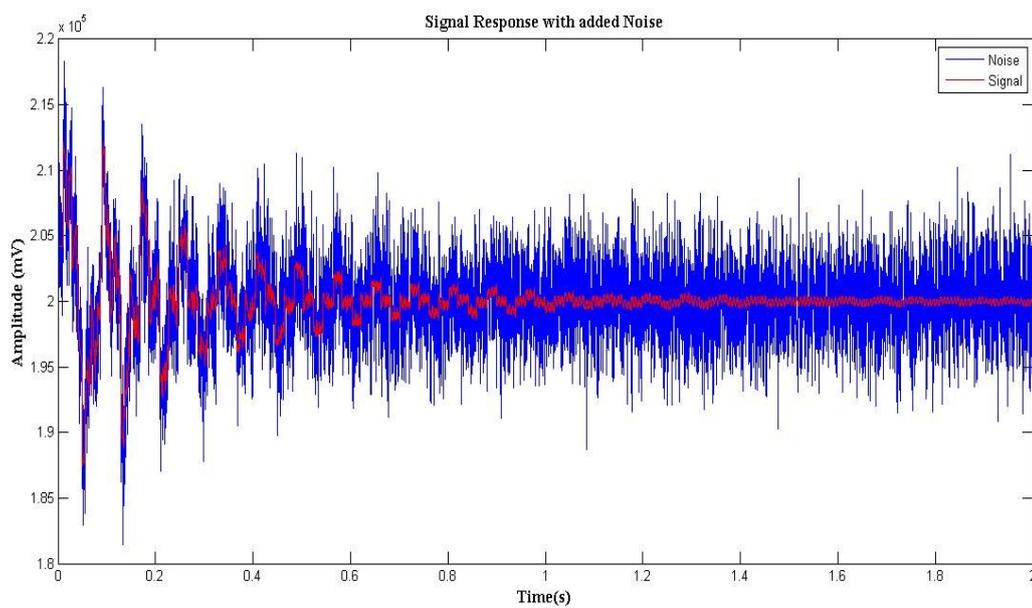


Figure 5. Signal response with added white Gaussian noise for first model.

After all the data of original response for first and second model gathered, the signal firstly undergoes EMD method. This pre-processing method decomposed the signal into 12 component of IMFs based on their amplitude level. The first three level of IMFs from decomposed signal only contained noise the contaminated the signal. The real signal usually will only locate among IMF 4, IMF 5, IMF 6, and IMF 7. Hence, the Ikaz-kurtosis ratio used in order to select the best IMF for further analysis. Ikaz-kurtosis ratio work by selecting the highest valued of Ikaz-kurtosis coefficient between all 12 levels of IMFs. For a further understanding of Ikaz-kurtosis, the researcher in [13] explained specifically on theory and its applications.

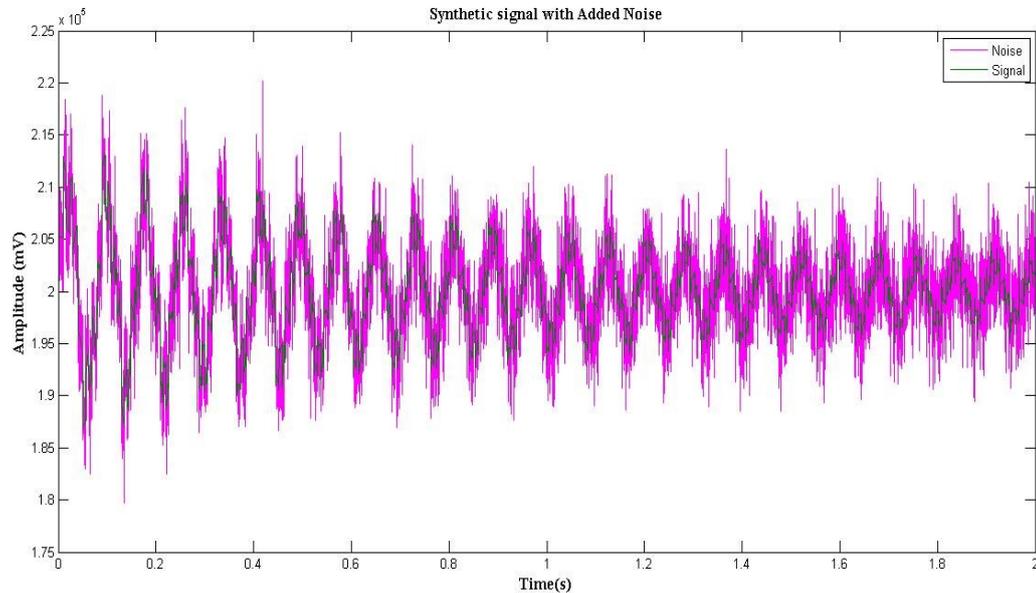


Figure 6. Signal response with added white Gaussian noise for second model.

Figure 7 show the all 12th level of IMFs extracted by EMD process. As clearly see from the figure, the first three level of IMFs contained high amplitude level of signal and it labelled as noise. After the best IMF component selected, TKEO analysis applied to the selected signal in order to analyse the approximation of instantaneous frequency.

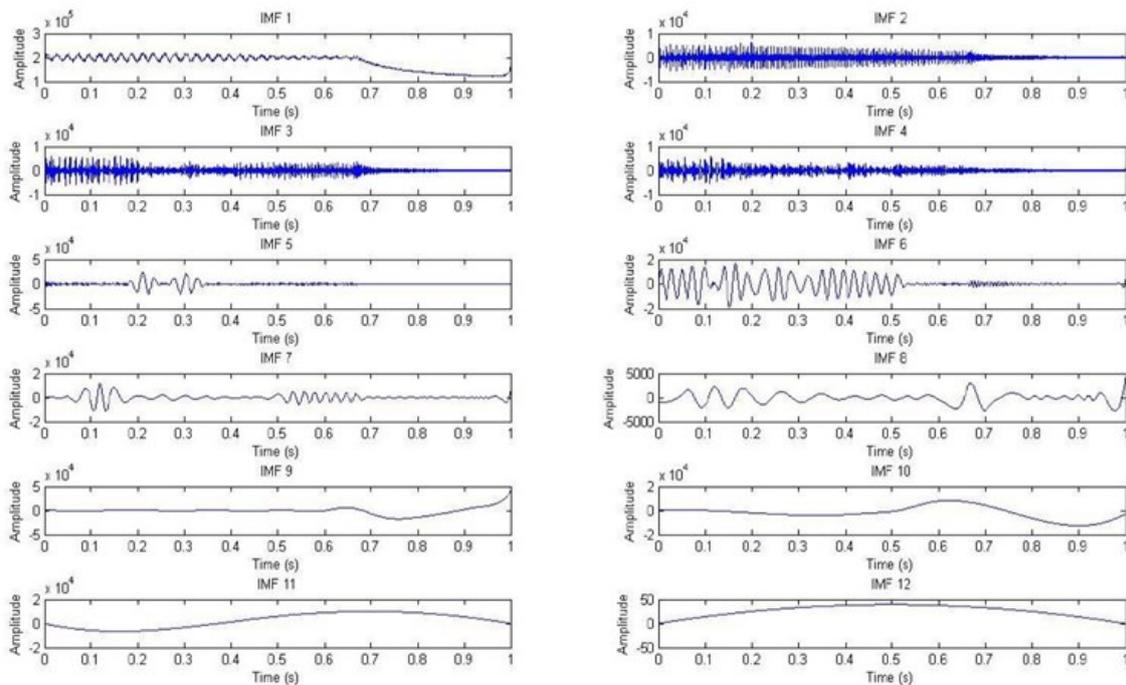


Figure 7. 12 level of IMFs using EMD.

Figure 8 (a) and Figure 8 (b) show the instantaneous frequency estimation using TKEO analysis for first model data with a leak and without leak respectively. The spikes can clearly see in Figure 10(a) instantaneous frequency estimation of TKEO analysis for leak and outlet position. The leak position discovered around 16.10m while the outlet position was at 39.19m. Figure 10(b) for a signal without leak data also point out one spike at a 39.65m distance and can be estimated as outlet position

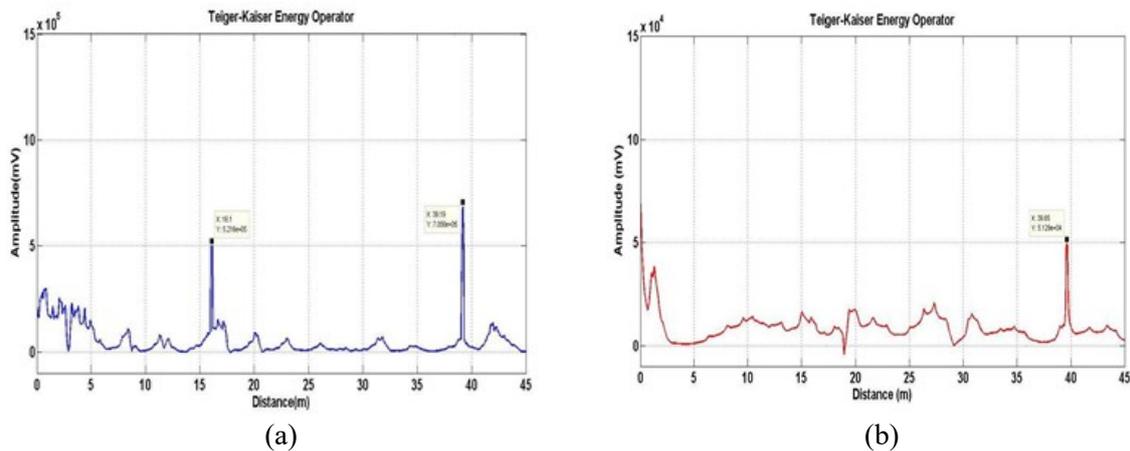


Figure 8. TKEO analysis result for first pipeline system (a) With leak model (b) Without leak model

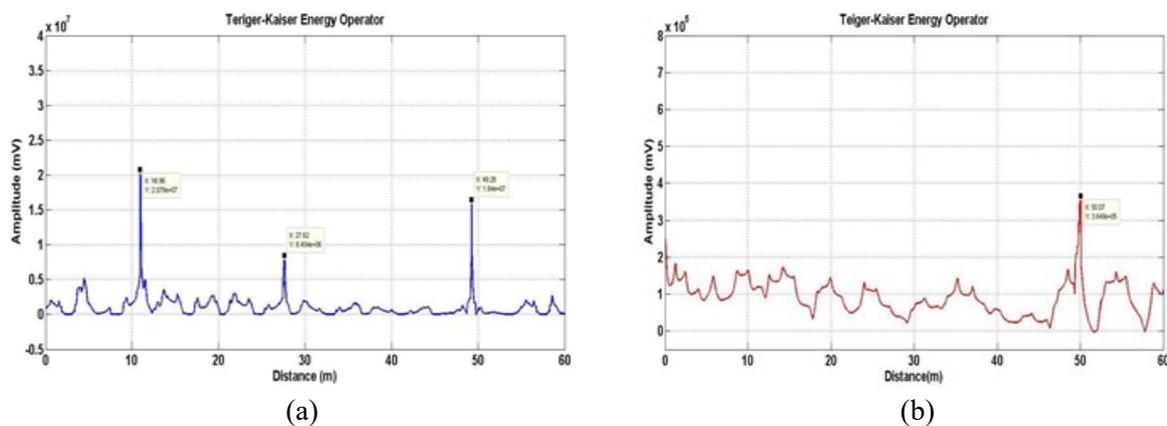


Figure 9. TKEO analysis result for second pipeline system (a) With leak model (b) Without leak model

Figure 9 (a) illustrates the result of TKEO analysis for the second pipeline model for leak system while Figure 9 (b) indicate the result of analysis for without leak system. The second model fabricated by implementing two-leak position at two junctions. In leakage system, the result show three spikes appeared inside the signal that was at 13.96m, 27.62m, and 49.28m. This three position compared to the schematic diagram represented the position of leak1, leak2, and outlet respectively. In Figure 11(b), it is shown on one peak appeared due to the system not contained any leak feature. The signature appeared at 50.07m almost similar to the measured distance of outlet position. So this concludes that all features and leak signatures appeared after the data analysis using TKEO analysis.

Table 1. Comparison between the exact location and experimental location

Water Pressure	Signal Response	Pipe Feature	Exact Location (m)	Experimental Location (m)	Error %
1 st Pipeline Model	Leak Data	Leak Outlet	15	16.1	7.3
	No Leak Data	Outlet	39	39.19	0.5
			39	39.65	1.7
2 nd Pipeline Model		Leak 1	13	13.96	7.3
	Leak Data	Leak 2	28	27.62	1.4
		Outlet	51	49.28	3.4
	No Leak Data	Outlet	51	50.07	1.8

The measured data for leak and outlet position recorded in the Table 1 and compared to experimental location from the TKEO analysis. As clearly stated in the Table 1, leak1 percentage of error show the highest compared to all features that was 7.3% for both model. Outlet for the first model of leak system and no leak system shown 0.5% and 1.7% respectively. This value is very low and assumed as accurate for detecting the features along the pipelines. For second model of leak system, leak2 show 1.4% error compared to its measured position. Outlet features for second model of leak and no leak system indicates 3.4% and 1.8% respectively. Thus, by implementing the EMD as post-processing method with combination of Ikaz-kurtosis and TKEO as instantaneous frequency analysis, all the features leakage can be extract from the contaminated non-linear and non-stationary signal.

4. Conclusion

As a conclusion, this paper applying EMD together with the automatic selection of IMF and Teager-Kaiser Energy Operator (TKEO) analysis as instantaneous frequency estimation show success in detecting the position of leak and outlet from a synthetic transient signal that combined with white Gaussian noise. This method proved to be reliable and suggested to be use for further study to analyse the data for the real live water distribution network.

Acknowledgement

Author want to thank to University Malaysia Pahang from supports the facilities and sources for this research. The acknowledgment also to University Malaysia Pahang for providing internal grant RDU170386 and Ministry of Higher Education (MOHE), Malaysia grant RDU170121.

References

- [1] Frauendorfer, R. and R. Liemberger, *The issues and challenges of reducing non-revenue water*. 2010: Asian Development Bank.
- [2] H.M, S. and A.M. N, *NRW Impact To The Service, Environment And Financial*. 2017.
- [3] Kingdom, B., R. Liemberger, and P. Marin, *The challenge of reducing non-revenue water (NRW) in developing countries. How the private sector can help: A look at performance-based service contracting*. 2006: World Bank Group; Water Supply & Sanitation Sector Board; PPIAF.
- [4] Puust, R., et al., *A review of methods for leakage management in pipe networks*. Urban Water Journal, 2010. 7(1).
- [5] Grunwell, D. and B. Ratcliffe, *Location of underground leaks using the leak noise correlator*, in *WRC Technical Report*. 1981, WRC.

- [6] Ghazali, M., et al. *Leakage Detection in Pipelines Using Ensemble Empirical Mode Decomposition*. in *Proc. Of the Fifth European Workshop on Structural Health Monitoring, Sorrento, Naples, Italy*. 2010.
- [7] Maji, U., M. Mitra, and S. Pal, *Automatic detection of atrial fibrillation using empirical mode decomposition and statistical approach*. *Procedia Technology*, 2013. **10**: p. 45-52.
- [8] Kedadouche, M., M. Thomas, and A. Tahan, *Monitoring machines by using a hybrid method combining MED, EMD, and TKEO*. *Advances in Acoustics and Vibration*, 2014. **2014**.
- [9] de Souza, D.B., J. Chanussot, and A.-C. Favre. *On selecting relevant intrinsic mode functions in empirical mode decomposition: An energy-based approach*. in *Acoustics, Speech and Signal Processing (ICASSP), 2014 IEEE International Conference on*. 2014. IEEE.
- [10] Nuawi, M.Z., et al., *Development of integrated kurtosis-based algorithm for z-filter technique*. *Journal of applied sciences*, 2008. **8**(8): p. 1541-1547.
- [11] Solnik, S., et al., *Teager–Kaiser energy operator signal conditioning improves EMG onset detection*. *European journal of applied physiology*, 2010. **110**(3): p. 489-498.
- [12] Yusop, H.M., et al. *Pipe leak diagnostic using high frequency piezoelectric pressure sensor and automatic selection of intrinsic mode function*. in *IOP Conference Series: Materials Science and Engineering*. 2017. IOP Publishing.
- [13] Yusop, H.M., et al. *The use of transmission line modelling to test the effectiveness of I-kaz as autonomous selection of intrinsic mode function*. in *IOP Conference Series: Materials Science and Engineering*. 2017. IOP Publishing.