Improving Quality of Microtremor Data with Application of Empirical Mode Decomposition Method, Case Study: East Tanjung Karang, Bandar Lampung

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Abstract. Microtremor can be used for determining ground dynamical characteristic. We have measured microtremor data in East Tanjung Karang, Bandar Lampung. Collecting proper data in some urban areas like East Tanjung Karang is a difficult work because it produced data with a lot of transient signal caused by many human activities and industrial work. One of method to removed transient signal is Empirical Decomposite Method (EMD). EMD decompose an input signal (in time series) into several intrinsic mode functions (IMF) and a residual function. We made the first synthetic signal contained frequency with 1, 10, 20, and 30 Hz. EMD method was applied to the signal and obtained some Instrinsic Mode Function (IMF). IMF 1 has some frequency peaks that are 10, 20, and 30 Hz with power spectral density (PSD) amplitude 0.2, 0.9, and 1 W/Hz respectively. The second synthetic signal contained same frequency with the first one but the amplitude was 1, 1, 10, and 50 m. The results in IMF 1 from the second signal still have some peaks but spectral density in 10 Hz increases from 1 W/Hz (before applied EMD) to ±5 W/Hz (after applied EMD, in IMF 1). We applied EMD method also to Y1, Y2, and Y8 microtremor data. We remove IMF 1 or IMF 2 from the original data. The results are the removed IMF 1 data has less spike or transient signal in microtremor time series, but the removed IMF 2 data did not have significant change from the original microtremor. We suggested that higher IMF number, lower the dominant frequency. IMF cannot be related as a single oscillatory source because the result showed that IMF content more than one frequency peak. Removing IMF 1 produced by EMD method can improving quality of micrtremor data because it remove some transient data. This transient can be related to noise in higher frequency that originated locally. it can also decrease maximum standard deviation of HVSR curve. This study revealed revealed that removed IMF 1 data is has less change for both fundamental frequency and amplification factor than removed IMF 2 data in HVSR Curve.

Keywords : EMD, IMF, denoising, HVSR, Bandar Lampung

1. Introduction

Ambient noise measurement has been conducted broadly for determining ground dynamical characteristic [1-4]. Ambient noise is a ground constant vibration that has low amplitude approximately 10^{-4} to 10^{-2} mm. Microseisms is a type of ambient noise which is generated by natural source and has a low frequency (less than 1
Hz). The other type is called microtremor which is generated by living things and has high frequency (more than 1 Hz) [5].

We have measured microtremor data in East Tanjung Karang that is one of sub-district in Bandar Lampung, Capital of Lampung Province. The Horizontal to Vertical Spectral Ratio (HVSR) method can be applied to the microtremor recording for extracting useful information concerning earthquake and geotechnical engineering [6]. Unfortunately, microtremor data that obtained in East Tanjung Karang was so noisy because of heavy traffic and other human activities.

Noise is a term used to indicate the unconsidered vibration by human activity or natural sources such as human footstep, vehicle, train, animal activity, and industrial machinery. To obtain accurate analysis results on microtremor data using the HVSR method, data that does not contain noise or interference is needed [7]. Collecting proper data in some urban areas like East Tanjung Karang is a difficult work because it produced data with a lot of transient signal caused by many human activities and industrial work. Basically, this transient signal can be removed manually by selecting a window containing a relatively statistical signal, or we can use an automated method, for example by using the Short Term Averaging / Long Term Averaging (STA / LTA) method. The other automated method that can overcome this problem is the Empirical Decomposite Method (EMD).

EMD decompose an input signal (in time series) into several intrinsic mode functions (IMF) and a residual function. [8]. EMD has been used to denoising microtremor in metropolitan Beijing area [9]. In this study, application of EMD method to both synthetic signal and microtremor data obtained in East Tanjung Karang was reviewed. Investigation of application EMD method to improve quality of HVSR curve obtained by HVSR method was conducted. Some suggestions was proposed based on characteristics of EMD application.

2. Method

2.1 Empirical Mode Decomposition (EMD)

EMD is an adaptive signal processing method originally was proposed by N. E. Huang [10]. EMD can provide a solution to the shortcomings of Fourier analysis which cannot describe the short time changes in frequency. EMD break down a signal \( x(t) \) into several number series of intrinsic mode functions \( c_i(t) \), \( i = 1,2, \ldots, N \) as

\[
x(t) = \sum_{i=1}^{N} c_i(t) + r_N(t)
\]

with \( i = 1,2, \ldots, N \). The sifting process is applied to process the decomposition [10]. This process has resulted in some IMFs \( c_i(t) \) that has conditions satisfies: (1) the number of extrema and the number of zero crossings either equal to each other or differ at most by one, and (2) at any point, the local average is zero. The residue of the decomposition process, \( r_N(t) \), normally is a constant or has only one frequency value (monotonic).

2.2 Horizontal to Vertical Spectral Ratio

Horizontal to Vertical Spectral Ratio (HVSR) Method originally was introduced by Nakamura [6] for knowing amplification responses that describes the nature of sediment layer. This method compares the horizontal to vertical spectral for each time window of the 3-channel-seismometer recording, North-South & East-West channel as horizontal and Up-Down channel as vertical. Each time window produces one H/V ratio. The average H/V most-dominant curve can be associated with fundamental frequencies to indicate the amplification. Equation for obtain ratio in HVSR method can be written as

\[
HVSR = T_{vec} = \frac{S_{HS}}{S_{VS}} = \sqrt{\left(\frac{S_{NS}}{S_{VS}}\right)^2 + \left(\frac{S_{EW}}{S_{VS}}\right)^2} \frac{S_{VS}}{S_{V}}
\]
with $S_{HS}$ is horizontal spectral in surface, $S_{VS}$ is vertical spectral in surface, $S_{NS}$ is horizontal spectral from North-South channel, $S_{EW}$ is horizontal spectral from East-West channel, and $S_{V}$ is d vertical spectral from Up-Down channel.

3. Results and Discussion

3.1 Applied EMD method to synthesis signal

Synthesis signal were made from sinusoidal waves superposition. The superposition consists of some waves with 1, 10, 20, and 30 Hz in frequency. Each waves was made by general wave equation solution

$$y(t) = A \cos 2\pi ft$$

With $y$ is wave oscillation in m, $A$ is wave amplitude in m, $f$ is wave frequency in Hz and $t$ is oscillation time in second. All of amplitude wave value was set in 1 meter. Some IMFs were produced after EMD was applied to the waves. IMF initially was in time domain then the FFT method was applied to IMF for transforming the series in frequency domain. The results in frequency domain can be seen in Figure 1.

IMF 1 has some frequency peaks that are 10, 20, and 30 Hz with power spectral density (PSD) amplitude 0.2, 0.9, and 1 W/Hz respectively. The highest peak in IMF 2 is in 10 Hz with PSD amplitude 0.8 W/Hz. Another peak of IMF 2 is in 20 Hz. If the results are seen further we have a trend that higher IMF number, more lower the frequency.

IMF cannot be related as a single oscillatory source because the result showed that IMF content more than one frequency peak. To know whether the IMF depends on the original wave amplitude, then we varied amplitude value. Frequency content was the same as the first that was 1, 10, 20, and 30 Hz but the amplitude was 1, 1, 10, and 50 m. After EMD was applied to the signal, the results can be seen in Figure 2.

The extreme difference amplitude cannot produce IMF 1 that has less number of spectral peaks. On the contrary, power spectral density in 10 Hz increases from 1 W/Hz (in original) to ±5 W/Hz (in IMF 1). In the higher number of IMF, broad frequency band was appeared. In IMF 3, the broad frequency band has higher PSD value than IMF 2.

We also want to know what if the spectral produced from IMF if the signal has dense frequency peaks. We applied EMD method to signal made from superposition some wave having 1, 2, 3, 4, and 5 Hz. The results can be seen in Figure 3. IMF 1 spectral show that denser the original signal produced more spectral peaks. We suggest that EMD method cannot decompose frequencies that close each other. The frequency peaks in 4 Hz and 5 Hz have same PSD value that is 1 W/Hz. In the lower frequency peaks, 1 Hz, have higher PSD value than frequency peaks in 2 Hz.

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**Figure 1.** (a) The decomposition of uniform amplitude synthesis signal consisted of some IMFs, (b) the spectral of uniform amplitude synthesis signal, (c) spectral of IMF 1, (d) spectral of IMF 2, (e) spectral of IMF 3, (f) spectral of IMF 4
Figure 2. (a) the spectral of non-uniform amplitude synthesis signal, (b) spectral of IMF 1, (c) spectral of IMF 2, (d) spectral of IMF 3, (e) spectral of IMF 4

Figure 3. (a) The decomposition of denser uniform amplitude synthesis signal consisted of some IMFs, (b) the spectral of denser uniform amplitude synthesis signal, (c) spectral of IMF 1, (d) spectral of IMF 2, (e) spectral of IMF 3, (f) spectral of IMF 4
3.2 Applied EMD to Microtremor Data

Microtremor data used was obtained in East Tanjung Karang. This sub-district is located in the city of Bandar Lampung which is the capital of Lampung province. As a capital, the human activity is so high. This caused a lot of noise in the microtremor recording in East Tanjung Karang. The data have so many noises that its source from footstep of pedestrian, vehicle, motorcycle, and train.

EMD method was applied to Y1, Y2, and Y8 microtremor data. The results are some IMFs and a residual from the microtremor data. We remove IMF 1 or IMF 2 from the original data. We did not remove IMF 3 and so on from the original data, because that IMFs content frequency range desired. Comparative picture can be seen in Figure 4. Removed IMF 1 data has less spike data or transient data. However, removed IMF 2 data did not have significant change from the original data. IMF 1 has the highest frequency than others. We suggest that IMF1 originates locally and contains the transient noise. Transient noise sources do not contain much useful geological or engineering information.

Spectral of removed IMF 1 and IMF 2 was investigated then those were compared to the original. The compared spectral of the original and removed IMF 1 and IMF 2 can be seen in Figure 5. Red graphic denotes the original data whereas blue one denotes removed IMF data. After removing IMF 1, the amplitude in frequency range greater than 10 Hz was decrease but after removing IMF 2, the amplitude in frequency range 7 – 10 Hz was decrease.

![Figure 4](image-url)

*Figure 4.* (a) time series of original Y1 data, (b) time series of original data after removing IMF 1, (c) time series of original data after removing IMF 2. Transparent green bar shows the transient or spike data before and after removing the IMFs.
3.3 Improvement in HVSR Method

Removed IMF 1 and IMF 2 data in Y1, Y2, and Y8 were analyzed by HVSR method. Window length used was 10 s, Konno-Ohmachi smoothing constant was 30. Windows selection has been done manually. The anti-triggering STA/LTA method was not used because IMF 1 can remove transient data. If we select window recklessly with STA/LTA, some long transient data can be considered for further processing. Long transient data probably produced by a train or vehicle. The output is HVSR curve that can be seen in Figure 6.

HVSR curve of Y1 original data has two peaks in $f_0 = \pm 0.8$ Hz and $f_1 = \pm 6$ Hz. In HVSR curve of removed IMF 1 data, $f_1$ peaks amplitude was decrease. Standard deviation in removed IMF 1 data was also decrease. There is no significant effect in frequency range 4-10 Hz caused both IMF 1 and IMF 2 after those were removed from the original data.

Removing IMF 1 produced by EMD method can remove some transient data as seen in Figure 4. This transient can be related to noise in higher frequency. The objective of selection window in HVSR curve is to keep the most stationary parts of microtremor data. Removing IMF 1 can also decrease maximum standard deviation of HVSR curve as seen in Figure 6b.

However, removing IMF 1 or IMF 2 data has effect to the dominant frequency and amplification factor. We can see in Table 1, both dominant frequency and amplification factor is decrease. Removed IMF 1 data is has less change for both fundamental frequency and amplification factor than removed IMF 2 data.

| HVSR Curve          | $f_0$ | $A_o$ | % change $f_0$ | % change $A_o$ |
|---------------------|-------|-------|----------------|----------------|
| Y1                  | 0.9   | 4.8   |                |                |
| Y1-removed IMF 1    | 0.6   | 3.5   | 27.8           | 27.1           |
| Y1-removed IMF 2    | 0.6   | 4.4   | 25.6           | 11.4           |
| Y2                  | 0.8   | 5.5   |                |                |
| Y2-removed IMF 1    | 0.8   | 4.5   | 4.60           | 17.1           |
| Y2-removed IMF 2    | 0.8   | 3.8   | 4.60           | 22.3           |
| Y3                  | 0.6   | 5.7   |                |                |
| Y8-removed IMF 1    | 0.6   | 3.8   | 0.00           | 17.5           |
| Y8-removed IMF 2    | 0.7   | 3.9   | 6.0            | 21.9           |
Figure 6 (a) HVSR curve of Y1, (b) HVSR curve of Y1’s removed IMF 1, (c) HVSR curve of Y1’s removed IMF 2, (d) HVSR curve of Y2, (e) HVSR curve of Y2’s removed IMF 1, (f) HVSR curve of Y2’s removed IMF 2, (g) HVSR curve of Y8, (h) HVSR curve of Y8’s removed IMF 1, (i) HVSR curve of Y8’s removed IMF 2

4. Conclusion

This study reviewed the application of some synthetic signals and microtremor data in East Tanjung Karang. EMD produced some IMFs and residual time series. We concluded that higher IMF number, lower the dominant frequency. IMF cannot be related as a single oscillatory source because the result showed that IMF content more than one frequency peak. EMD cannot decompose frequencies of synthetic signal that have some frequencies close each other in value.

Removing IMF 1 produced by EMD method can improving quality of microtremor data because it remove some transient data. This transient can be related to noise in higher frequency that originated locally. It can also decrease maximum standard deviation of HVSR curve.
After doing HVSR method to removed IMF 1 and IMF 2 data, both dominant frequency and amplification factor is decrease. It also revealed that removed IMF 1 data is has less change for both fundamental frequency and amplification factor than removed IMF 2 data.

Acknowledgements

Authors would like to thank to Institut Teknologi Sumatera for providing the research grant (No. B/302/IT9.C1/PT.01.03/2019) through “Hibah Penelitian ITERA SMART 2019”.

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