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Baseline correction method based on variational mode decomposition

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ABSTRACT

Baseline drift can be caused by ground motion and deflection of instruments and equipment, which leads to the inconsistency between velocity and displacement obtained by direct integration and the actual situation. At present, there have been many related studies, but it is still a difficult problem to carry out automatic baseline correction and directly integrate velocity and displacement (especially permanent displacement). In this paper, a variational mode decomposition (VMD) based method is proposed for baseline correction. This method mainly utilizes the feature that the low frequency component of intrinsic mode function (IMF) component decomposed by VMD contains a linear trend term to carry out baseline correction. The proposed method is verified by the strong motion records of the Tohoku earthquake. The results show that the proposed method is simple and easy to use, which can not only correct the baseline but also maintain the permanent displacement component in the records.

CONTENTS

The technology of digital strong motion accelerometers has advanced quickly in recent decades. In the United States, Japan, and other regions, a huge number of digital strong motion accelerometers of various models have been deployed, obtaining a great number of valuable strong motion records. During an earthquake, the strong motion instrument records not only pure seismic ground motion information, but also complex noises, such as low-frequency noise, which causes the acceleration time history baseline to drift. The elimination of abnormal sudden changes, overall deviations, or gradual drifts of a certain tendency in the acceleration value caused by various reasons in the record is referred to as baseline correction of strong vibration acceleration record. Researchers have conducted a large amount of research in response to the problem of baseline correction. Graizer (1979) proposed a method for fitting the integrated velocity trace with a series of stepwise higher-order polynomials. Iwan et al. (1985) proposed a correction method that approximates a complex baseline offset set by using two offset sets divided by three-time constants. This method is applicable to any recording and meets the physical constraint that the speed oscillates near zero, but it necessitates the use of a custom time constant. Chiu (1997) uses the high-pass filtering method for preprocessing acceleration records to perform baseline correction, but the high-pass filtering method removes not only the baseline error, but also the low-frequency components of the signal, including permanent displacement. Permanent displacement, on the other hand, has special engineering and seismic significance. Boore (2009) discussed and proposed a Monte Carlo-based baseline correction scheme, which used a noise model to model baseline changes. The majority of these methods are based on the assumption that the change in the acceleration baseline occurs within a finite time interval t_1~ t_2. None of these methods, however, can recover low-frequency pulses and are difficult to automate. As a result, this paper proposes a VMD-based baseline correction method.

$$u_k = A_k(t)\cos(\phi_k(t))$$

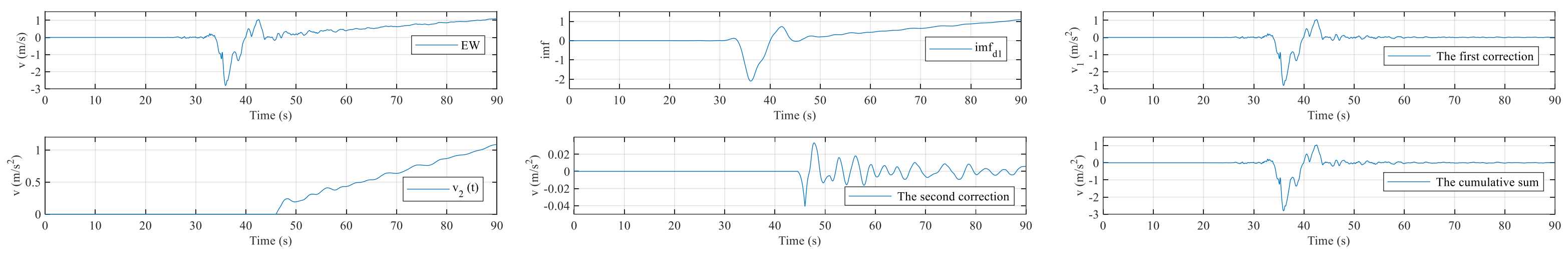
$$\min_{\{u_k\},\{\omega_k\}} \left\{ \sum_k \left\| \partial_t \left[\left(\delta(t) + \frac{j}{\pi t}\right) * u_k(t) \right] e^{-j\omega_k t} \right\|_2^2 \right\} \quad s.t. \quad \sum_k u_k = f(t)$$

$$L(\{u_k\},\{\omega_k\},\lambda) := \alpha \sum_k \left\| \partial_t [(\delta(t) + \frac{j}{\pi t}) * u_k(t)] e^{-j\omega_k t} \right\|_2^2 + \left\| f(t) - \sum_k u_k(t) \right\|_2^2 + \left\langle \lambda(t), f(t) - \sum_k u_k(t) \right\rangle$$

$$u_k^{n+1} = \arg\min_{u_k \in X} \left\{ \alpha \left\| \partial_t \left[(\delta(t) + \frac{j}{\pi t}) * u_k(t) \right] e^{-j\omega_k t} \right\|_2^2 + \left\| f(t) - \sum_i u_i(t) + \frac{\lambda(t)}{2} \right\|_2^2 \right\}$$

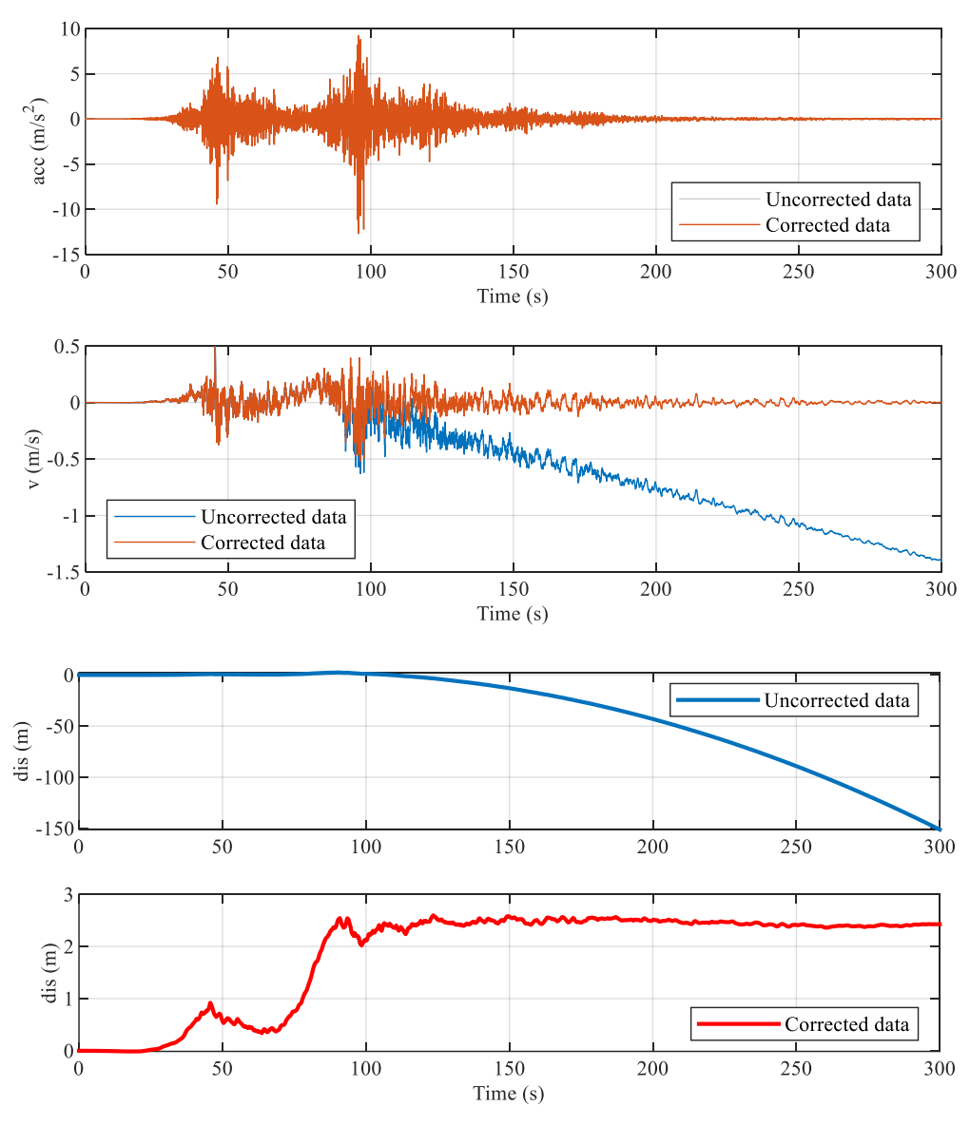
The low-frequency component of the IMF component obtained by VMD decomposition is primarily used in this paper to perform baseline correction. The signal x(t) is made up of all IMF components, and the low-frequency component contains a linear trend term. This feature is used to iteratively correct the baseline offset error. Using the velocity time history of the station TCU068 during the 1999 Chi-Chi earthquake as an example, the specific steps of applying the baseline correction method proposed in this paper are as follows:

Step 1: Decompose the velocity time history curve using VMD to obtain *n* IMF components. Use the energy entropy (maximum entropy) as the filter condition to extract the low-frequency components IMFd1 in all IMF, and determine when the right end of IMFd1 (the last one) passes through the zero point, the remaining (*n-1*) IMF components and data before the right end of IMFd1 passes through the zero point are added together to form the record after the first correction.



Step 2: Take the data after the zero-crossing point at the rightmost end of IMFd1 as the new record to be corrected, repeat step 1 to obtain the record after the second correction, and compare the record after the second correction to the record after the first correction. To obtain a new corrected record, add (after the right end has been aligned). Step 3: Similarly, use the data after the zero-crossing point at the rightmost end of IMFd1 in step 2 as the new record to be corrected, and repeat the iterative process of step 1 until the new record to be corrected is a monotonic curve or a constant term, at which point the iteration is terminated. Step 4: Add the corrected records from each iteration to form the final corrected record. The final record to be corrected can be discarded because it is a monotonic curve or a constant term.

The propose method is a fully automated baseline correction method. Differentiation or integration of the corrected speed time history can be used to obtain the acceleration and displacement time history. Fig. shows the result of baseline correction of the acceleration time history recorded at the station MYG004 during the 2011 Tohoku earthquake.



CONCLUSION

This paper proposes a baseline correction method based on VMD. When compared to the traditional baseline correction method, this method is completely automatic and does not require any parameters to be set in advance. Simultaneously, this method has demonstrated great potential in identifying velocity pulses in near-field seismic records. Finally, this paper uses actual strong earthquake records as an example to confirm the method's effectiveness and accuracy. This method can not only correct the baseline but also maintain the permanent displacement component in the records.

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