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Reach of detecting Cycle-slip based on EMD and Wavelet transform

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Abstract. The Cycle-slip detection is an important step for high precision navigation and positioning. Based on the characteristics of Cycle-slip, it can be regarded as a singular value in carrier phase and then a novel method is proposed for Cycle-slip detection. The experiment results show that the novel method is very suitable for the Cycle-slip detection, and the minimum scale of Cycle-slip that can be detected is 1 cycle.

1. Introduction

The detection of Cycle-slip is a key step in the process of carrier phase data. Cycle-slip destroys the consistency of observations, and it is an important error source [1-4]. Therefore, how to effectively detect Cycle-slip is a hot issue in the GPS scientific research.

At present, the common methods to detect Cycle-slip mainly include dual-frequency P code method, high order difference method, polynomial fitting method, etc. The dual-frequency P code method need to use other methods to determine whether the Cycle-slip is caused by the observation values in L1 or L2. High order difference method and polynomial fitting method are greatly affected by the sampling rate of the observed data, and they can not detect small Cycle-slip [5-6].

It can be seen from the literature that in the case of no Cycle-slip, the secondary difference sequence is mainly caused by the pseudorange observations noise and shows the characteristic of random error. Based on the characteristic, this paper proposes a suitable Cycle-slip detection algorithm.

2. Concept and characteristics of Cycle-slip

Carrier phase observations are made up with the $Fr(\varphi)$ (the fractional part) and $In(\varphi)$ (the integer part). It can be expressed as:

$$\varphi_i = In(\varphi) + Fr(\varphi) + \Delta N \tag{1}$$

$Fr(\varphi)$ is the part less than 1 cycle in the phase difference between the reference signal produced by the receiver and the carrier signal from the satellite, these observations can be considered accurate. $In(\varphi)$ is the counts of the whole cycle of the carrier phase recorded from the time t when received the satellite signal to the current time.

When the receiver is tracking satellite signals continuously, the counter of the receiver is interrupted during the accumulative work due to some reasons, such as signal being blocked, radio interference, etc. These reasons will cause whole cycle jumps in the Carrier phase observations, but the part less than 1 cycle remains unchanged. This phenomenon is called Cycle-slip.

As a function of time, the carrier phase observations is a smooth curve that changes with time when there is no Cycle-slip. However, once the Cycle-slip occurs, the smoothness is damaged, and the sequence of subsequent phase observations values will jump by the same amount from the beginning of the occur epoch.

3. Detection principle and method

3.1. EMD fundamentals

EMD is a time domain decomposition method for signals proposed by Norden E. Huang in 1998. This method overcomes the shortcoming that the traditional Fourier spectrum analysis can only deal with linear and stationary signals, and it is suitable for the analysis of non-linear and non-stationary time series. EMD can decompose complex signals into a series of IMFs with different scales. Each IMF needs to meet the following two conditions:

In the whole time range, the number of local extreme points and zero points must be equal or at most one difference;

At any time point, the mean value of the upper envelope formed by local maximum and the lower envelope formed by local minimum is zero.

The core of the EMD is the screening process to generate IMFs [7-9]:

Assuming that the original signal is $x(t)$, and find all local maximum points and local minimum points, then fit local maximum points and local minimum points as upper envelope and lower envelope respectively by cubic spline function.

Figure out the mean value m_1 of the upper envelope and the lower envelope, calculate the difference $h_1 = x(t) - m_1$ between the signal $x(t)$ and m_1, and determine whether h_1 meets the conditions of IMF. If h_1 meets, then the first IMF component is denoted as $c_1 = h_1$; if h_1 not meets the conditions, it will be regarded as the original signal, and repeat step 1 for k times until h_{1k} meets the IMF conditions, then, h_{1k} is the first IMF component and denoted as $c_1 = h_{1k}$, where is the highest frequency component of the signal.

Separate c_1 from $x(t)$,obtain $r_1 = x(t) - c_1$, regard r_1 as the original signal, repeating the previous process, we will get other IMF components of the signal, When the signal r_n can no longer be decomposed, the decomposition process stopped and the following formula is obtained:

$$x(t) = \sum_{i=1}^{n} c_i + r_n \tag{2}$$

r_n represents the final residual term; c_1 , c_2 ,..., c_n represents the IMF components respectively, whose frequency ranges from high to low.

3.2. Principle of Wavelet singularity detection

The main feature of signal mutation is that there are local changes in time and space. According to the speed of signal change and the proper decomposition scale, good local analysis of wavelet analysis can be fully developed, so as to solve the problem of signal mutation point detection conveniently [10]. The general method to detect the discontinuity point by wavelet analysis is to conduct multi-scale analysis of the signal, when the discontinuity point occurs, the coefficients of the wavelet transform have the maximum modulus, so the time point can be determined by detecting the maximum modulus point.

3.3. The method of detecting Cycle-slip

The singular components of the signal are generally divided into two types:

1) The signal jumps in the amplitude of a certain epoch, resulting in the signal discontinuity, this is the first kind of discontinuity point.

2) The signal is smooth on the surface and the amplitude does not jump, but the first derivative of the signal changes and the first derivative is discontinuous, which is called the second kind of discontinuity point.

According to the characteristics of Cycle-slip, it can be regarded as the first kind of discontinuity point. Firstly, the secondary difference sequence is constructed by differencing the combined observation value of the carrier-phase and pseudorange. Secondly, based on the Empirical Mode Decomposition (EMD), the difference sequence is decomposed into a number of intrinsic mode functions (IMFs) components, and Wavelet transform is carried out on the IMFs, the location of Cycle-slip can be detected by ascertaining the point of modulus maximal value of the wavelet coefficients.

4. Verification of measured data

The algorithm is validated by taking a set of pseudorange and carrier phase measurement data collected by the receiver as an example. Experimental data were selected from the measured data with a sampling rate of 1Hz at Guilin monitoring station on May 18, 2018. The difference sequence without Cycle-slip is shown in figure 1.

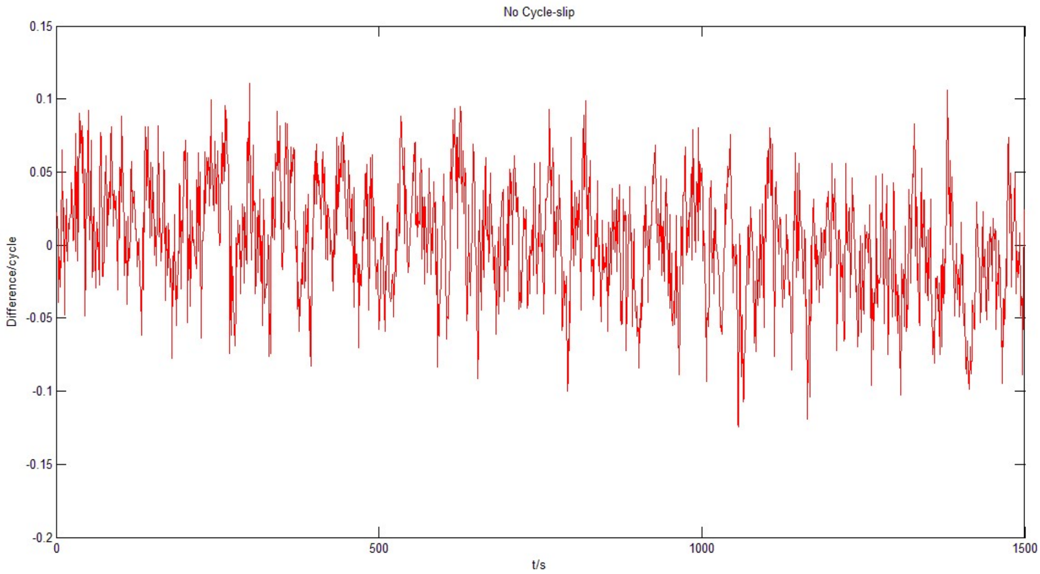

Figure 1. The secondary difference sequence without Cycle-slip

In order to verify the algorithm in this paper, the simulated Cycle-slip is added to the original carrier phase observations. For analyzing the applicability of the algorithm under different conditions, different scales of Cycle-slip were added at different epochs. In this case, the 1 cycle and the 2 cycles were inserted in the 500 epoch and 1000 epoch respectively.

From the figure 2, the secondary difference sequence has a mutation at the 1000 epoch, and the mutation is obvious, while there is no mutation at the 500 epoch, which shows that the secondary difference sequence can only detect the Cycle-slip of more than 2 cycles, but is not sensitive to the small Cycle-slip of 1 cycle.

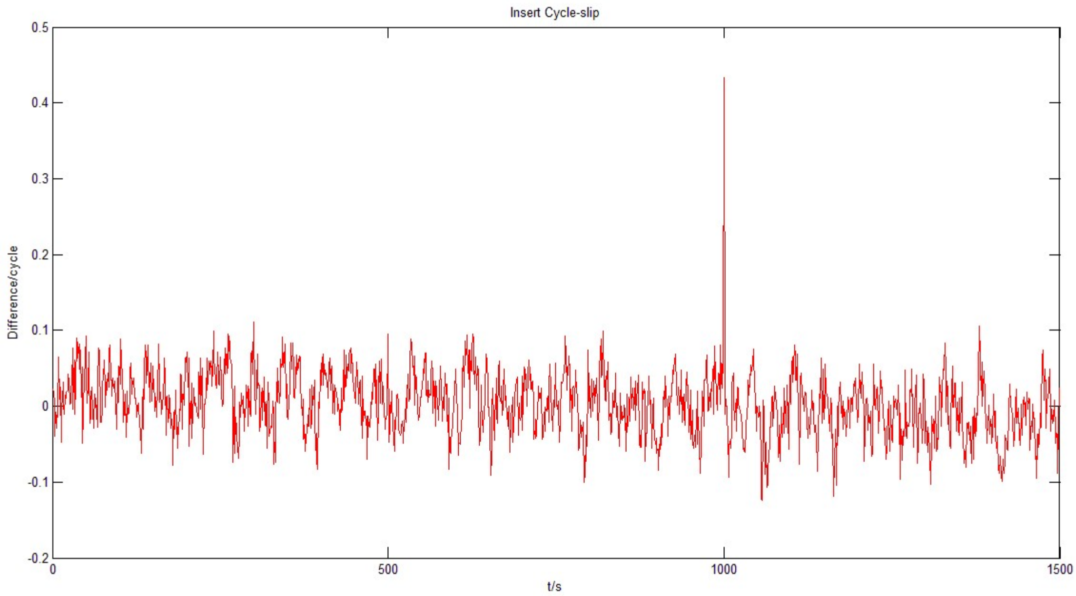

Figure 2. The secondary difference sequence with the simulated Cycle-slip

Based on EMD, the difference sequence is decomposed into a number of IMFs components, as can be seen from the figure 3.

From the figure 4, Wavelet transform is carried out on the IMFs, at the break point of difference sequence, the wavelet coefficient appears obvious modulus maximum point, so the wavelet transform can accurately locate the epoch of the Cycle-slip. In addition, the larger the Cycle-slip, the larger the modulus of the wavelet transform, the more obvious the detection effect of the wavelet transform.

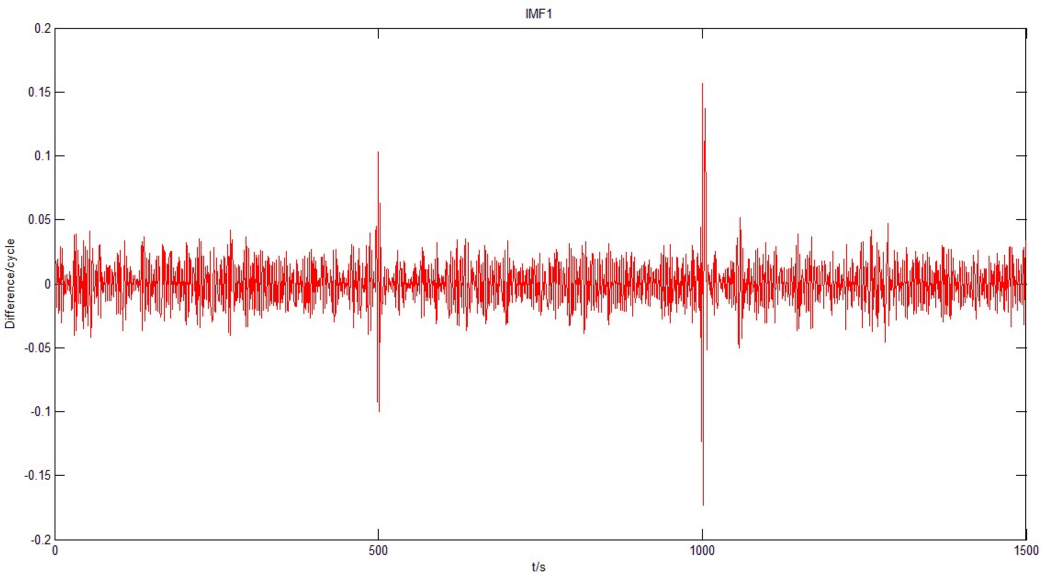

Figure 3. The first IMF

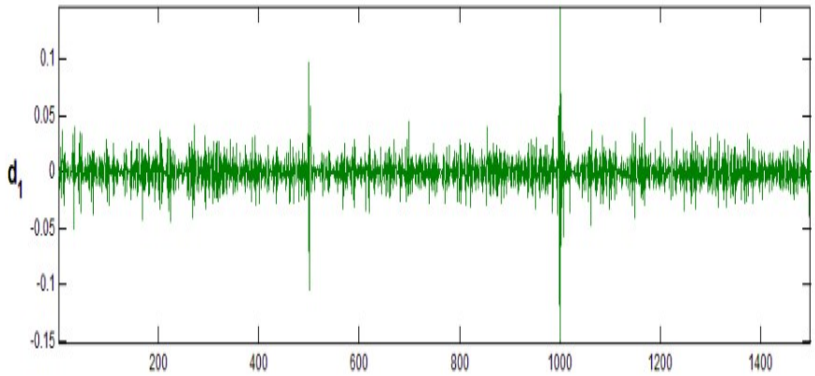

Figure 4. Wave transform of the first IMF

5. Conclusion

In view of the problem of detecting the Cycle-slip, a method combining EMD and Wavelet transform is proposed. The experimental results show that the algorithm can accurately detect the Cycle-slip of 1 cycle. To some extent, the shortcomings of traditional methods were been solved.

References

[1] MIAO Y, SUN Z, WU S. Error analysis and cycle-slip detection research on satellite-borne GPS observation [J]. Journal of Aerospace Engineering, 2011, 24 (1):95-101.

[2] ZHANG X H, L1 X X. Instantaneous re-initialization in real-time kinematic PPP with cycle slip fixing [J]. GPS Solutions, 2012, 16 (3):315-327.

[3] FENG S, OCHIENG W, MOORE T, et a1. Carrier phase-based integrity monitoring for high-accuracy positioning [J]. GPS Solutions, 2009, 13 (1): 13-22.

[4] BANVILLE S, LANGLEY R B. Mitigating the impact of ionospheric cycle slips in GNSS observations [J]. Journal of Geodesy, 2013, 87 (2): 179-193.

[5] LIU Z Z. A new automated cycle-slip detection and repair method for a single dual-frequency GPS receiver[J]. Journal of Geodesy, 2011, 85 (3):171-183

[6] SHARMA, S, DASHORA N, GALAV P, et a1. Cycle slip detection, correction, and phase leveling of RINEX formatted GPS observables [J]. Current Science, 2011, 100 (2): 205-212.

[7] HUANG N E, SHEN Z, LONG S R, et a1. The empirical mode decomposition and the Hilbert Spectrum for nonlin-ear and non-stationary time series analysis [J]. Proc. R. Soc. Lond. A, 1998:903-995.

[8] XING H Y, XURQ, WANG CH S. Pulse signal feature research based on empirical mode decomposition[J]. Chinese Journal of Scientific Instrument, 2009, 30 (3): 596-602.

[9] DU CH Y, ZHANG Y F, YANG P, et al. Approaches for the end effect restraint of empirical mode decomposition algorithm [J]. Chinese Journal of Scientific Instrument, 2009, 30 (1):55-60.

[10] Mallat S, Hwang W L. Singularity detection and processing with wavelets[J]. IEEE Trans On Information Theory,1992,38 (2): 617-643.