Chapter 13
Research on Receiver Clock Jump Detection and Processing in Precise Point Positioning

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Abstract The Melbourne-Wubbena (*MW*) and Geometry-Free (*GF*) combinations of observations are generally used to detect cycle slips in Precise Point Positioning (PPP). This article describes the GNSS receiver clock jump phenomenon, and analyzes its impact on *MW* and *GF* combined observations from the observation model. The experiment confirms that receiver clock jump will not affect *GF* combination observations, but will lead to a misjudgment of *MW* cycle slip detection; and changes are same for all satellites. This essay proposes a new method that uses satellite differenced *MW* together with the undifferenced *MW* and *GF* combinations to detect the clock jump in PPP; in the processing, clock jump is estimated with the coordinate parameters together. The experimental results show that this method can detect and estimate receiver clock jump, avoid unnecessary re-initialization and help to improve the positioning accuracy, effectively.

Keywords GNSS receiver · PPP · Clock jump · Cycle slip

13.1 Introduction

Using Single GNSS receiver's observation data, the users can achieve high accuracy positioning both real time and afterwards with precise satellite ephemeris and clock correction product at any position of the global scope, which is called

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the precise point positioning (PPP). PPP has more advantages compared with relative positioning mode, such as: supply more available observations and preserve the original observation information; get the receive station coordinates directly, at the same time, estimated coordinates of each station are uncorrelated, which is easy for quality control [1]. After the satellite signal is captured by GNSS receiver, as long as the tracking is not interrupted, the receiver will automatically give the carrier phase changes during tracking. High-precision positioning results will be obtained using continuous phase observations. Therefore, in PPP solution, it is very necessary to pretreat the observations before coordinate estimated. The quality of pretreatment will directly determine the positioning accuracy and reliability. A lot of methods have been proposed for cycle slip and gross error detection up till now, such as: differential method, Doppler frequency shift method, Kalman filtering method and so on [2]. Among all these, the turbo-edit algorithm proposed by Blewitt is most widely used in PPP, which uses the *MW* and *GF* combined observations to detect cycle slip [3].

Generally, GNSS receiver's internal time scale takes quartz clock, whose day frequency stability is around 10^{-11}. In the start of GNSS observation, the receiver is set to synchronize with the GNSS time, but the synchronization is not so rigorous due to the limit of quartz clock's accuracy. Moreover, with the measurement carried out, the receiver clock will shift gradually [4]. In order to maintain sync with the GNSS time, most receivers will insert periodically clock jump to control the receiver clock keeping within a certain range of accuracy. Receiver clock jump has an effect on observations similar to cycle slip. At present, the receiver clock jump is usually detected and repaired PPP data processing. This essay proposes a new method that uses satellite differenced *MW* together with the undifferenced *MW* and *GF* combinations to detect the clock jump in PPP; in the processing, clock jump is estimated with the coordinate parameters together.

13.2 GNSS Receiver Clock Jump

There are mainly two kinds of receiver clock jumps: millisecond jump and every second jump. Millisecond jump is to correct the receiver by inserting 1 ms clock correction periodically; while every second jump is to correct the receiver clock every second, and the correction is very small (usually superior to the microsecond range). Generally speaking, millisecond jump has little influence on GNSS observation, so milliseconds jump is mostly considered during clock jump detection [5]. The clock jump will lead to pseudorange or phase observations jumping at all frequencies for all observed satellites which are similar to cycle slip. However the two kinds of data step is different essentially, because the clock jump will not change satellite ambiguity but cause a systematic bias for all satellites. Data step caused by clock jump can roughly divided into two categories: The phase step from clock jump divided into two classes roughly: one is that pseudorange and phase jump together; the other is pseudorange jumps and phase keeps continuation [6].

MW is phase position Wide-lane and pseudorange Narrow lane combined:

$$M_w = L_w - P_n,\ P_n = \frac{f_1 P_1 + f_2 P_2}{f_1 + f_2} \tag{13.1}$$

GF combination is L_1L_2 combination:

$$L_I = L_1 - L_2,\ N_I = N_1 - N_2 = \frac{\lambda_1\lambda_2}{\lambda_m\lambda_n}(N_w - N_c) \tag{13.2}$$

where f_k represents the frequency of k wave range; λ_k represents the wavelength; L_k is phase observation, P_k is pseudorange observation and N_k is ambiguity; λ_w is wide-lane wavelength, λ_n is narrow lane wavelength.

From the above equations, it can be seen that *MW* combination can reflect the variety of wide-lane integer ambiguity well, but it can't detect the cycles slip when there are same cycles slips at both frequencies, and *GF* combination is sensitive to cycle slip, but not useful for some specific cycle slip combination. Priori information such as satellite orbits or station coordinates are not needed when using the two combinations to detect cycle slip, at the same time, there is no need to do any difference between the stations or the satellites; so it can be used for any length of baseline, especially suitable for PPP [3].

When the clock jump happens both for pseudorange and phase observations, the *MW* and *GF* combination will not be influenced, and the systematic bias caused by clock jump can be absorbed in receiver clock in parameter estimation, which will not affect the positioning solver results. However, when the clock jump just happens for pseudorange observations, it will not affect the *GF* combination, but will influence the *MW* combination badly. When this happens, the clock jump is easy to be mistaken for cycle slip. This may lead to ambiguity resetting of all satellites and reinitialize of PPP solution. The solving accuracy and continuity will be seriously affected [6].

13.3 Detect and Processing of Receiver Clock Jump in PPP

The clock jump happens just for pseudorange observations will cause misjudgment of *MW* combination and appear an illusion that there are cycle slips for all satellites. So when detecting cycle slips, the interference of the receiver clock must be excluded. Because the interference of clock jump is the same for all satellites, it can be eliminated by inter-satellite differential. The single differential combination observation between satellite i and satellite j is:

$$\Delta M_w^{ij} = \left(L_w^i - L_w^j\right) - \left(P_n^i - P_n^j\right) \tag{13.3}$$

The single differential MW combination can eliminate the impact of receiver clock jump on pseudorange observation, and avoid the misjudgment of cycle slip detecting. But only using the single differential MW combination may cause some other weak points as follows: (1) the processing can be complicated when reference satellite changes; (2) when cycle slip happens, it is needed to judge whether it happens at the reference satellite or the no reference satellite, which may lead to misjudgment. In this paper, we propose a new method: single differential MW is used to assist the undifferenced MW and GF combinations to detect the cycle slip in PPP. The procedure is as follows: (Fig. 13.1).

After detecting the clock jump, the general processing approach is to correct it on the observations directly. However this method not only changes the original observations, but also when the value of receiver clock jump changes (not completely 1 ms), it may cause the positioning results appear deviation. The mathematical model of PPP is as follows [1]:

$$\begin{cases} P_i^j = \rho^j - cdt + dI^j - dT^j + \varepsilon_{i,P}^j \\ \lambda_i \Phi_i^j = \rho^j - cdt - N_i^j \lambda_i - dI^j - dT^j + \varepsilon_{i,\varphi}^j \end{cases} \tag{13.4}$$

where P, Φ represent the code and phase measurements of the receiver transmitter, respectively; ρ, c, dt, dI, dT are the corresponding distance, light speed receiver and transmitter clock errors, slant total electron content (STEC), and slant tropospheric delay, respectively; λ represents the wavelength of carrier observations, and N represents carrier phase ambiguity in cycles.

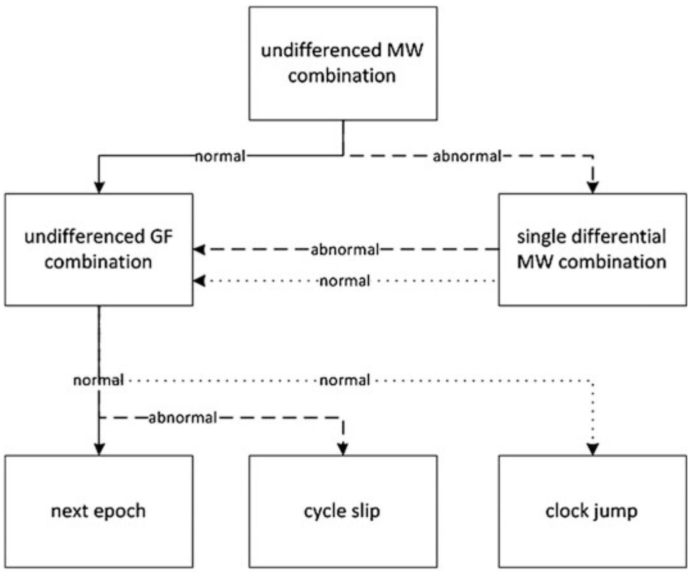

Fig. 13.1 Cycle slip and clock jump detection flowchart

Because the receiver clock jump is the same for pseudorange observations of all satellites, we can add a clock jump parameter for the pseudorange equation, and then the mathematical model turns to be:

$$\begin{cases} P_i^j = \rho^j - cdt + J_{clk} + dI^j - dT^j + \varepsilon_{i,P}^j \\ \lambda_i \Phi_i^j = \rho^j - cdt - N_i^j \lambda_i - dI^j - dT^j + \varepsilon_{i,\varphi}^j \end{cases} \quad (13.5)$$

where J_{clk} represent receiver clock jump. When receiver clock jump is detected, the parameter is reset, or it will be estimated as a same parameter between the epochs.

13.4 Experimental and Analysis

In this experiment, observation data used are from BeiDou Experimental Tracking Stations (BETS) network [7]. The network is built from early 2011 by Wuhan University, and the reference stations mostly lay in Asia-Pacific region. The BETS tracking network is equipped with receiver named UR240-CORS. The kind of receiver is independently developed by China, and can capture dual-band BeiDou/GPS signal, but the data appear frequently clock jump phenomenon. Because temporary no public institutions can provide precise ephemeris and clock products for BeiDou satellites, only GPS data are used in PPP processing and the precision ephemeris and clock products for GPS satellites are provided by IGS. Data processing is based on Passion software which is developed by the author. Figure 13.2 shows the positioning results of lasa station at DOY126, 2012. The data is simulation dynamic and processed by two different algorithms: the new clock jump parameter model and the traditional PPP model.

It can be seen from Fig. 13.3: the receiver clock jump often occurs, and the frequency is approximately 1 h. The traditional PPP algorithm always mistaken clock jump for cycle slip, and reinitialize. This causes poor positioning results; the 3D deviation RMS of full arcs is 0.309, 0.435 and 1.142 m for N, E, and U directions, respectively. The PPP model considering the clock jump parameters can effectively detect, estimated the clock jump, so that the clock jump does not have a negative impact on the positioning results. The 3D deviation RMS of full arcs is 0.038, 0.075, 0.089 m, and the statistical results after the convergence is 0.015, 0.018 and 0.047 m, respectively (Fig. 13.4).

13.5 Summary

This essay proposes a new method that uses satellite differenced *MW* together with the undifferenced *MW* and *GF* combinations to detect the clock jump in PPP; in the processing, clock jump is estimated with the coordinate parameters together.

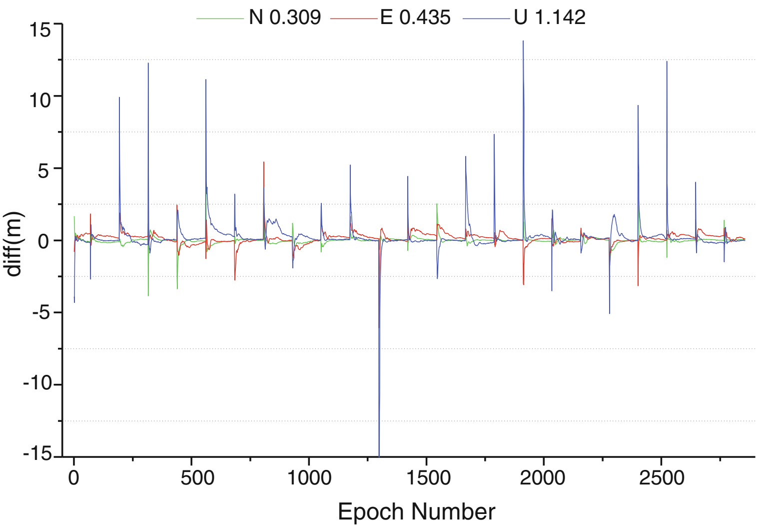

Fig. 13.2 Traditional algorithm solving results

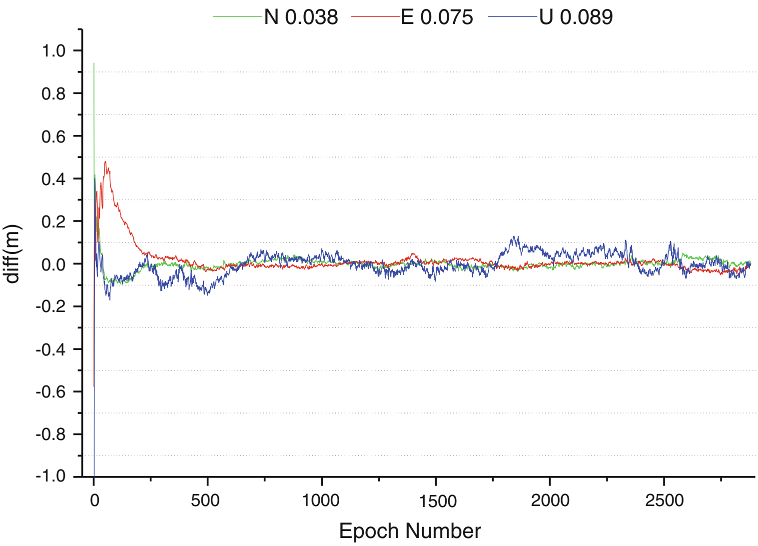

Fig. 13.3 New algorithm solving results

The new algorithm is validated analysis by measured data of lasa station which is equipped with UR240-CORS receiver. The experimental results show that this method can detect and estimate receiver clock jump, avoid unnecessary reinitialize

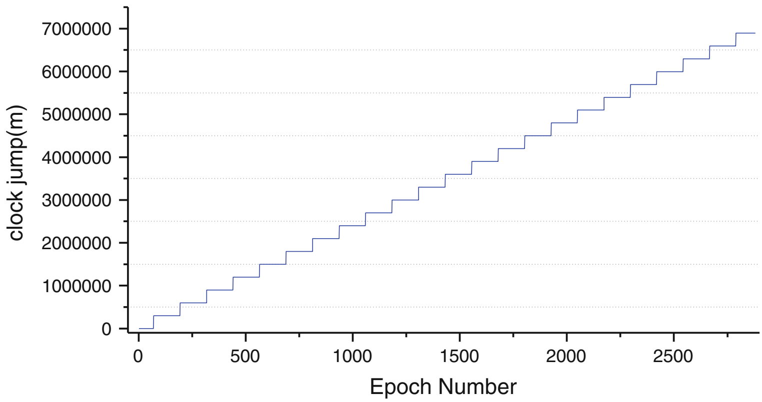

Fig. 13.4 Estimated receiver clock parameter

and help to improve the positioning accuracy effectively. The positioning accuracy is increased from 3D RMS 0.309, 0.435 and 1.142 m to 0.038, 0.075, 0.089 m for N, E, and U directions, respectively.

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