The research on continuous carrier phase time transfer method based on parameter transfer

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Abstract. The method of continuous GNSS carrier phase time transfer is studied in detail, and the cause of jump in carrier phase time transfer results is analyzed. The relationship between multi-day data arc jump and daily jump is deduced in theory, and the correctness of the deduced result is verified by the calculation result of actual measured data. Solution is given to daily jump in carrier phase time transfer. Since the time transfer reference signal is a continuously running high-precision atomic clock signal, a continuous PPP time transfer method based on clock difference parameter transfer is proposed. The method proposed in this paper is validated and analyzed with the actual measured data, and compared with the traditional GNSS carrier phase time transfer solution. The results show that the method given in this paper can solve the problem of daily jump jump to a certain extent, effectively improve the continuity, availability and reliability of time transfer results, and also improve the frequency stability of time transfer results.

1. Introduction
At present, the technology of GNSS carrier phase time transfer has become the main long-distance high-precision time transfer method, has been used for by the main time laboratory in high-precision time transfer, and has been used calculated by BIPM (Bureau International Des Poids et Mesures) UTC. The jump usually exists in GNSS carrier phase time transfer results, which leads to the discontinuous of time transfer result, sometimes the jump can reach several nanoseconds, or even larger, which directly affects the accuracy of GNSS carrier phase time transfer, and even causes the distortion of the results.

The continuous time series is needed in high-precision time transfer and high-precision timing, and the existence of jump is not conducive to observe the real operation state of atomic clock for long time. Therefore, it is necessary to research the continuity maintenance method of GNSS carrier phase time transfer. For solving this problem, the jump is classified according to the different causes, and theoretically deduces and analyzes the relationship between multi-day data arc jump and daily jump. For the day boundary discontinuity in GNSS carrier phase time transfer, the continuous PPP time transfer methods based on parameters and overlapping data are proposed. The effectiveness of the proposed method is verified by experiments based on the actual data.

2. The jump analyze
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The PPP model is used in GNSS carrier phase time transfer usually, the non-ionosphere observation equation is used, the formula (1) and (2) give the observe equation, the detailed derivation process will not be repeated here, and can refer to the relevant literature.

\[
\Phi^j = \rho^j + c \cdot \delta t^j - c \cdot \delta t^j + \lambda \cdot N^j + T^j + \epsilon^j_{\Phi}
\]

\[
\tilde{P}^j = \rho^j + c \cdot \delta t^j - c \cdot \delta t^j + T^j + \epsilon^j_P
\]

Where, \(j\) is satellite number, \(c\) is velocity of light, \(\delta t^j, \delta t^j\) are relative clock difference of receiver clock and satellite clock to system reference time, \(\lambda\) is the distance between satellite and receiver, \(\lambda\) is wavelength, \(N^j\) is integer ambiguity, \(T^j\) is troposphere error, \(\epsilon^j_{\Phi}, \epsilon^j_P\) are observe noise.

It is known from formula (1) and (2) that the receiver clock error parameter and ambiguity parameter are related one by one, the error in receiver clock error parameter will be absorbed by the ambiguity parameter, therefore, it is impossible to obtain the receiver error directly from carrier phase observation, and pseudo range measurements must be combined to solve the problem. The magnitude of the jump depends on the pseudo range observation and carrier phase observation noise, because the pseudo range observation noise is obviously larger than the carrier phase observation noise, the discontinuous of time transfer results is mainly influenced by pseudo range observation noise. Usually, the pseudo range observation noise is affected by instrument error and multipath error, the noise is not pure white noise, its error will be directly absorbed by receiver clock differential solution, and cause the jump.

2.1. Classification of jump

The jump in GNSS carrier phase time transfer is divided into daily jump and jump caused by abnormal observation data.

The daily jump is caused by manmade calculation in the unit of days, the main reason for the daily jump is that the influence of the initial conditions, troposphere, multipath and other errors is not exactly the same every day, due to the difference of the average observation noise of pseudo range and carrier phase in the two adjacent days, the estimated ambiguity parameters of the two adjacent days are inconsistent, which eventually leads to the jump of the time series of the two adjacent days at the junction of day and day. At the same time, IGS satellite precision clock products are mostly provided on a daily basis, the adjustment and jump of the reference time benchmark of precision clock products will also lead to the discontinuity of time transfer results.

The jump caused by the abnormal observation data is mainly due to the missing or large error of some observation data caused by the change of observation environment and abnormal receiver within on day, which leads to the need to estimate the new ambiguity parameters in the solution, resulting in the inconsistency of the estimated ambiguity parameters before and after the abnormal data, and cause the discontinuity of the time transfer results.

2.2. Multi-day jump analyze

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The PPP time transfer using the overlapping multi-day observation data is usually method for solving the daily jump, this method can reduce the noise of the average pseudo-range observation, and weaken the influence of day boundary discontinuity in multi-day, but this method can not get the continuous time transfer results for the long time, which turns the daily jump into multi-day jump, and there are still jump at the adjacent data arcs.
Suppose that the clock error calculated by PPP method is $t + \Delta$, $t$ is the true time, $\Delta$ is the deviation caused by various uncertainties, the daily jump satisfies the formula (3).

$$BD_{N,N+4}^i = \Delta_{N+4,N+4}^i - \Delta_{N,N}^i$$

(3)

Where, the superscript of $BD$ is the length of data arcs, the subscript $(k, k + 1)$ of $BD$ indicates the jump between the $k$ day and the $k + 1$ day, the subscript $(k, n)$ of $\Delta$ indicate the time deviation between the $k$ day and $d$th day, the average of pseudo range noise and the carrier phase noise of first epoch are the main factor to $\Delta$.

When the length of data are $N$ days, the jump of multi-day can be expressed by formula (4).

$$BD_{N,N+4}^N = \Delta_{N+2N,N}^N - \Delta_{N,N}^N$$

(4)

The multi-day jump $BD_{N,N+1}^N$ can be expressed by the daily $BD_{1,i+1}^1$ in formula (5).

$$BD_{N,N+4}^N = \sum_{i=1}^{N} BD_{1,i+1}^1 + \sum_{i=1}^{N} \sum_{k=1}^{N} BD_{1,i+1}^k + \cdots + \sum_{i=1}^{N} \sum_{k=1}^{N} \sum_{n=1}^{N} BD_{1,i+1}^{kn}$$

(5)

$BD_{1,i+1}^1$ have the same distribution, and the formula (6) can be got.

$$E(BD_{N,N}^N) = \frac{N \cdot E(BD_{1,i+1}^1) + N \cdot E(BD_{1,i+1}^2) + \cdots + N \cdot E(BD_{1,i+1}^N)}{N} = N \cdot E(BD_{1,i+1}^1)$$

(6)

It is known from formula (6) that the size of multi-day jump between multi day arc segment is proportional to the number of days $N$, which is $N$ times of the average value of daily jump.

In order to verify the correctness of the above derived results, using the observation data of NIST and AMC2, PPP solution is carried out with daily data and three-day data arc segments respectively. The time transfer results of two stations are shown in Figure 1, the red curve 1 the figure represents the continuous time transfer algorithm based on overlapping arc segments in this section, and the green curve represent the traditional daily solution.

![Figure 1. Time transfer series of NIST-AMC2](image)

It can be known from Figure 1 that the time transfer result in each arc segment of three-day data arc solution is continuous, which can weaken the influence of daily jump. There is still boundary discontinuity between three-day data arc, it is can be seen in Figure 1 that the jump of three-day data arc solutions is about the sum of three daily data arc solutions, which verifies the correctness of the theoretical derivation of equation (6).

3. **The continuous time transfer method based on parameter transfer**

3.1. **The continuous PPP time transfer method based on clock difference parameter transfer**

In the time laboratory, the reference signals of time transfer equipment are continuously running high performance atomic clock signal, generally, there is no jump, so the continuous PPP time transfer based on clock difference parameter time transfer can be used to eliminate the daily jump. The basic
idea is to store the clock error and its accuracy information obtained in the last epoch of the first day and transfer it to the first epoch of the second day to realize the continuous time transfer. The store and transfer of three dimensional coordinates, receiver clock error and corresponding covariance information at midnight can transfer time information from one day to another.

In order to verify the effectiveness of the continuous time transfer method based on overlapping arcs, the six days data of NIST and IENG stations are used for experimental analysis, the sampling interval of the observation data is 30s, and the satellite orbit and clock error are obtain by interpolation of the precise ephemeris and clock error products published by GFZ. The traditional daily method and the continuous PPP time transfer method based on clock error parameter are adopted respectively. The results of time transfer between stations using the two methods are shown in Figure 2, and the Allan variance curve of stability of time transfer between station using the two methods is shown in Figure 3. The red curve represents the result of continuous PPP time transfer method based on clock error parameter transfer, and the green curve represents the result of traditional daily solution.

![Figure 2. The time transfer series of NIST-IENG](image)

![Figure 3. The frequency stability of time transfer result of NIST-IENG](image)

It is can be seen from Figure 2 and Figure 3 that the continuous PPP time transfer method based on the clock parameters transfer can eliminate the influence of the day boundary and obtain the continuous time transfer results, and this method can improve the short frequency stability of time transfer results.

The continuous PPP time transfer method is simple which based on clock parameter, but the last epoch of \( n - 1 \) day and the first epoch of \( n \) day is not the same time, when the clock error parameters are transferred directly, the influence of the change rate of clock error between the two times is ignored, therefore, this method requires that the station receiver must be equipped with high performance atomic clock, the method is fails when the receiver clock has jump.
3.2. The continuous PPP method based on ambiguity parameter transfer

The main reason of the daily jump is that the average pseudo range observation noise of the adjacent observation arc is different, which makes the ambiguity parameters estimated in the two adjacent days inconsistent. According to the characteristic that the phase ambiguity remains unchanged at the boundary of continuous observation period, the ambiguity parameters of two adjacent days are connected to realize continuous time transfer, and a continuous PPP method based on ambiguity parameter transfer is proposed to weaken the influence of daily jump. The basic idea is to store and transfer the ambiguity parameters and corresponding covariance information of each satellite calculated in the last epoch of \( n - 1 \) day to the first epoch of \( n \) day, and transfer the ambiguity parameters and corresponding covariance information calculated in the last epoch of \( n \) day to the first epoch of \( n + 1 \) day, and so on.

This uses the same data with 3.1 to verify and analyze the proposed method. The traditional daily method and the continuous PPP time transfer method based on ambiguity parameter transfer are used to solve the problem respectively, and the time transfer results between stations are obtained. The results of time transfer between station of two methods are shown in Figure 4, and the stability Allan variance curve of time transfer between stations of two methods is shown in Figure 8. The red curve represents the result of continuous PPP time transfer method based on ambiguity parameter transfer, and the green curve represents the result of traditional daily solution.

![Figure 4. The time transfer series of NIST-IENG](image)

![Figure 5. The frequency stability of time transfer result of NIST-IENG](image)

It can be seen from Figure 4 and Figure 5 that the continuous PPP time transfer method based on ambiguity parameter transfer can weaken the influence of daily jump to time transfer results, and the
series of day adjacent is more smooth, the frequency stability result obtained by continuous method equivalent to that obtained by traditional daily PPP time transfer method.

4. Conclusion
Compared with the traditional method, the continuous PPP time transfer method based on ambiguity parameter transfer can reduce the influence of daily jump by using the feature that the ambiguity parameter remains unchanged at the boundary of continuous time. However, when the satellite signal is out of lock or the observation data are all missing, the ambiguity parameter can’t be transmitted backward, so the method should be reinitialized.

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