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Evaluation of Daily Jump Compensation Methods for GPS Carrier Phase Data

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ABSTRACT

In this paper, we described the timing-offset comparison results between various daily jump compensation methods for GPS carrier phase (CP) measurement data. For the performance comparison, we used about 70 days GPS measurement data obtained from two GPS geodetic receivers which share the reference 1 PPS and RF signals and closely located in each other within a few meters. From the experiment results, the followings were observed. First, daily jumps existed in CP measurements depend on not only the environment but also the receiver which will make a full compensation be very hard or impossible. Second, clock bias can be occurred in the case of using a simple compensation with accumulation of daily jumps but it could be used in a short-period frequency comparison campaign (less than about 7 days) despite of its drawback.

Keywords: daily jump, GPS carrier phase, precise point positioning, timing receiver, offset compensation

1. INTRODUCTION

Carrier phase measurement by using geodetic timing receivers is widely used for providing high precision time and frequency transfer (Overney et al. 1998, Bruyninx & Defraigne 1999). One of the main limitations for providing high precision by using carrier phase (CP) measurement is its discontinuities at the day boundaries called as daily jumps (or day-boundary jumps) which are caused by the non-perfect overlapping of the IGS clock files (usually analyzed by daily batches) and colored noise in the measured code data. In addition to the two main errors, there are various types of input error causing day-boundary jumps. For example, a discontinuity is introduced at the boundary between processing arcs due to a station height error. Satellite orbit errors can have similar effects. Environmental noise (e.g. from multi-path or temperature dependences) may has a larger effect on clock jumps between arcs. Various methods for mitigating or compensating daily jumps such as phase-only method, sliding batch solution (SBS), clock handover and so on are already presented in (Orgiazzi et al. 2005, Dach et al. 2006, Defraigne et al. 2008). However, fully compensation method is not yet presented. For an example, the level of day boundary discontinuities can be reduced to a level of less than 100 ps on average by using SBS through averaging pseudorange data on multi-day periods and overlapping solutions (Guyennon et al. 2007). Therefore, it is highly necessary to give an effort of investigating an efficient method for continuous geodetic time transfer.

In this paper, we present the experiment results performed by using two timing receivers which share the 1 PPS and the RF signals and are closely located. With the same reference signals and close location, the external effects like clock error between the receiver clock and the IGS time (IGST) scale clock, fading and temperature variation are about the same at the two receivers. Therefore, if there are disparities between the daily jump characteristics of the receivers, then they mainly come from the receiver dependent factors giving the chance of deep investigation of the daily jump features. Moreover, we can easily evaluate the amount of the improvement obtained by applying compensation (or mitigation) algorithms and compare the performances of the employed various methods by using the differenced data between the receivers because only background noise should be left in the differenced data at an ideal situation. On the other hand,

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if we use different reference signals in different receivers, then it is very difficult (or maybe impossible) to distinguish where the jumps come from because the jumps could be occurred by the jumps of the input reference signals.

2. DAILY JUMP COMPENSATION ALGORITHM

In order to compensate the daily jumps existed in GPS CP measurements, it is required to estimate both the directions and the magnitudes of the jumps. If there is a calibrated time transfer method like two way satellite time and frequency transfer (TWSTFT), one can more exactly estimate the jumps because one can take advantage of the strong points of each of them by combining the two methods, that is the accuracy for TWSTFT and the stability for GPS carrier-phase (Jinag et al. 2007). However, the cost of establishing the foundation of a TWSTFT is very high so only a few timing laboratories are equipped with the system. Further, full day operation of TWSTFT system is hard (usually most of the experiments are executed just a few hours per day) while carrier phase measurements are continuously operated. Therefore, in this paper, we just investigate several methods for mitigating daily jumps by using code and carrier phase data without a calibrated method.

The flow chart for compensating daily jumps is shown in Fig. 1. The procedure for compensating daily jumps is as follows. At first, the outliers, which are observation points that are distant from other observations (Wikipedia), in the collected data are removed by using so called the modified Z-scores method (Iglewicz & Hoaglin 1993). The modified Z-scores is defined as follow:

$$MZ_i = 0.6745(x_i - \widetilde{x})MAD, \quad i = 0, \ 1, \ \cdots \ N-1 \qquad (1)$$

where x_i is the measured data, $\widetilde{x}$ represents the median value, $MAD = median\{| x_i - \widetilde{x} |\}$, and N is the number of data. The constant 0.6745 is needed because E (MAD) = 0.6745 for large N (Wikipedia). If the input data is estimated to an outlier, then the data is replaced by the median value.

After replacing the outlier data, the daily jumps are calculated by using a moving average or linear fit algorithm. In the calculation of the jump, the data are processed by one-day base because the daily jumps are occurred from the day boundary discontinuity.

Next, the measured original (uncompensated) data are compensated by using the estimated daily jump compensation values. The compensation methods are mainly divided into two cases, that is, compensation by CP-only and with code (P3) measurements. In the case of CP-only compensation, we employed successive jumps to estimate both the direction and the magnitude of current jump. For the CP-only compensation, we use the following two methods:

(i) using 2 successive jumps: the current jump value is calculated by the difference between the last 1-hour (12 points of the 5-minute sampled CP data) mean of the previous day's CP data and the first 1-hour mean of the present day's data;

(ii) using 3 successive jumps: the current jump value is calculated by two differences, the first one is the subtraction of the previous day's last 1-hour mean from the present day's first 1-hour mean, and the second one is that of the post day's first 1-hour mean from the present day's last 1-hour mean. The rule of determining the current jump is as follows: at first, if the signs of the differences are the same then takes the mean of the two differences; secondly, if the signs are opposite then takes the smaller one between the half of the large difference and the small difference values.

In the compensation of using P3 together, the one day averaged P3 data with n-point moving average are employed. The jump directions are entirely determined corresponding to the sign of the differences obtained from subtracting the previous moving averaged values from present ones.

In the other hand, the current jump magnitude is calculated from the combination of the sign and the magnitude of the basic jump value which is already obtained from the CP measurement. If the sign of the basic jump is equal to that of the moving averaged P3 difference then the smaller one between the one-tenth of the moving averaged P3 difference and the basic jump difference, and

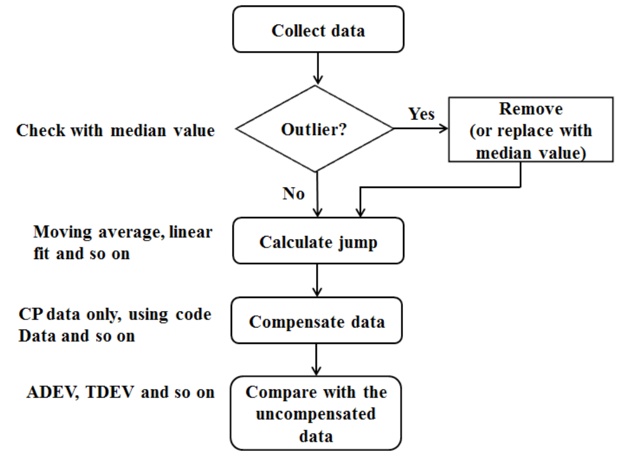

Fig. 1. Flow chart for compensating daily dumps.

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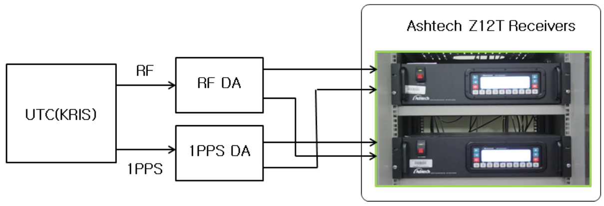


Fig. 2. Block diagram of the experiment setup of the daily jumps using two timing receivers.

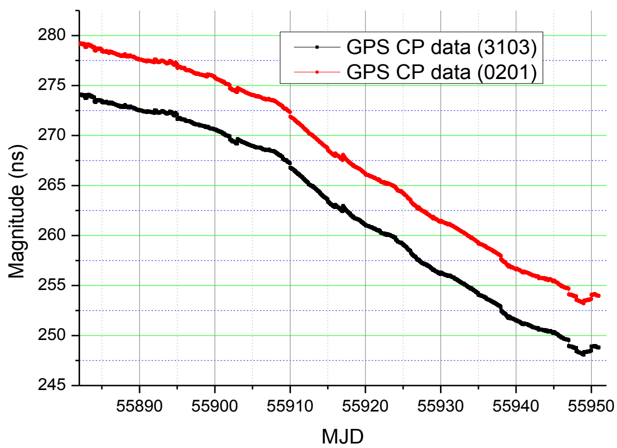


Fig. 3. Measured GPS CP data for the 3103 and 0201 receivers from MJD 55882 to MJD 55951.

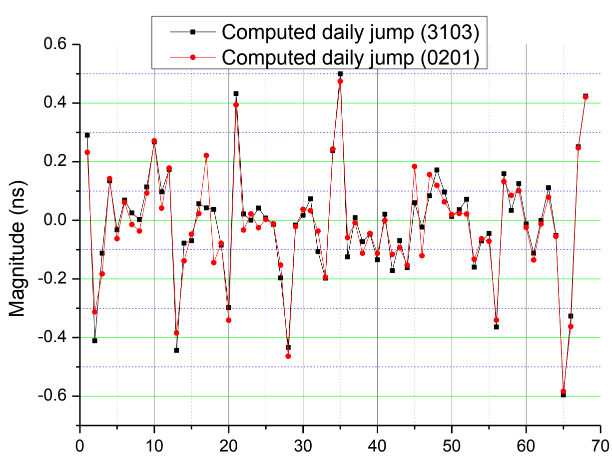


Fig. 4. Estimated daily jumps of the 3103 and 0201 receivers from MJD 55882 to MJD 55951.

if the two signs are opposite in each other then takes the one-tenth of the moving averaged P3 difference as the magnitude of the current jump.

Finally, the frequency and time stabilities of the compensated data are compared to those of the uncompensated (original) data. For the comparison of frequency stability, we use the well-known modified Allan deviation (MDEV), and maximum time interval error (MTIE) is chosen to compare the timing performance.

3. MEASUREMENT SETUP AND RESULTS

3.1 Measurement Setup

Fig. 2 shows a configuration of the experiment where two timing receivers use the same 1 PPS and RF reference signals and are closely located in each other within a few meters. With this kind of experiment situation, the variations of the daily jumps should be similar at the two receivers because the causes of the jumps are almost the same. In order to get CP processed data, we use GIPSY OASIS-II software for the experiment and about 70-day code and phase measurements are obtained.

3.2 Measurement Results

The measured GPS CP data for the receiver #1 (3103) and the receiver #2 (0201) are shown in Fig. 3. The clock phase offset difference between the two receivers is about 5 ns and the fluctuations both of the receivers are very similar with about 0.2 ns variation. The computed daily jump values for the receiver #1 (3103) and the #2 (0201) are shown in Fig. 4. At a glance, the jump patterns (both in the direction and the magnitude) are very similar in each other. In order to

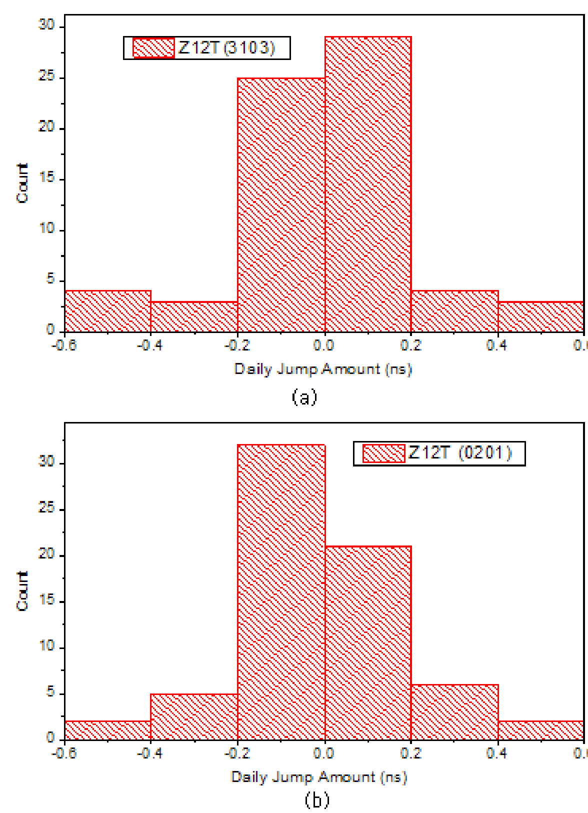


Fig. 5. Histograms of the daily jumps of (a) the 3103 receiver and (b) the 0201 receiver, respectively.

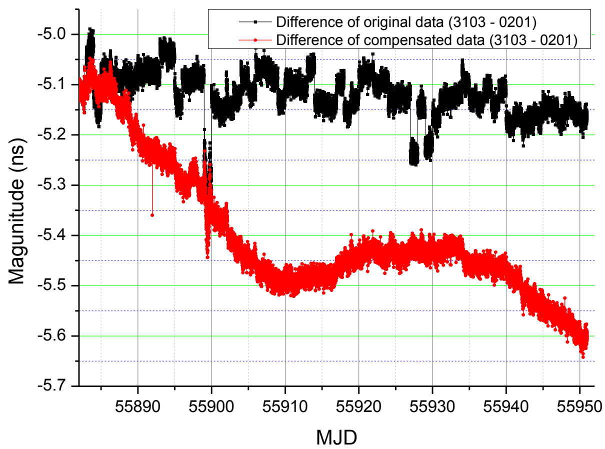


Fig. 6. Differenced data between the two receivers for the uncompensated and the compensated data, respectively.

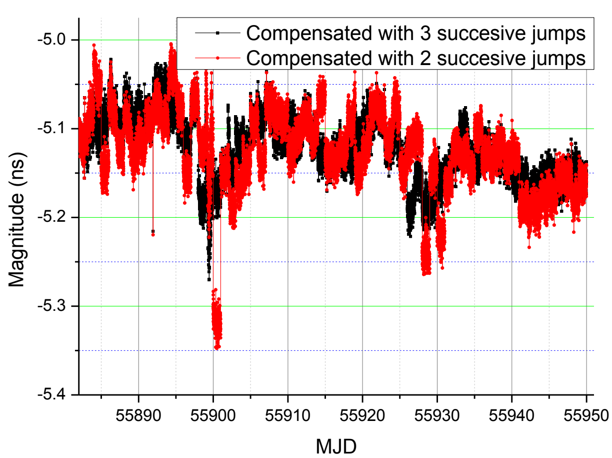


Fig. 7. Compensation results of the differenced data between the two receivers by using 2 and 3 successive CP jumps, respectively.

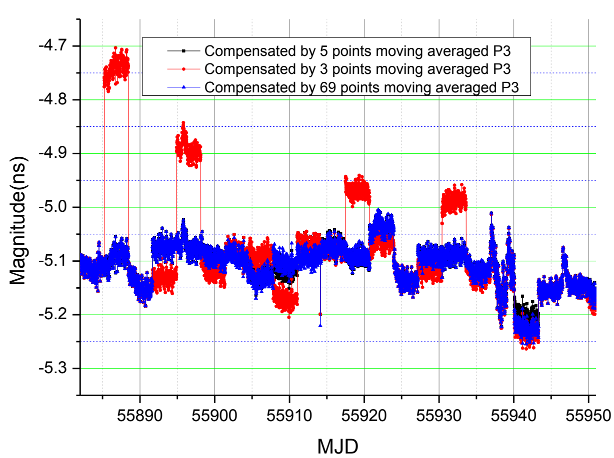
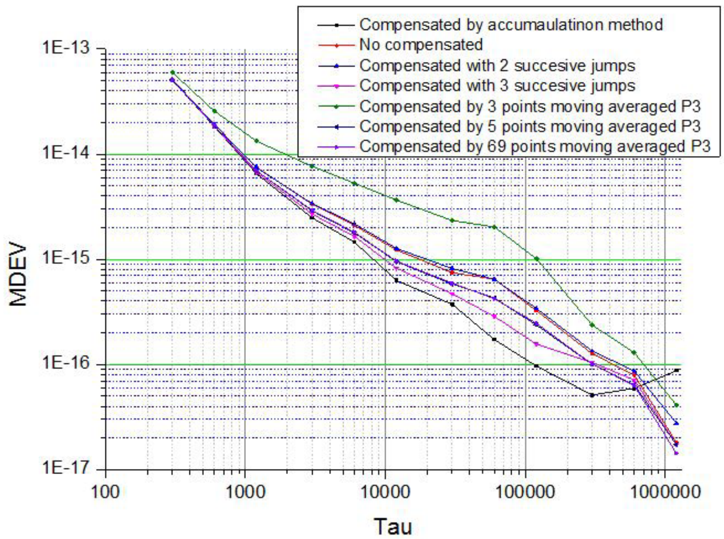


Fig. 8. Compensation results of the differenced data between two receivers by using 3, 5 and 69 points moving averaged P3 data, respectively.

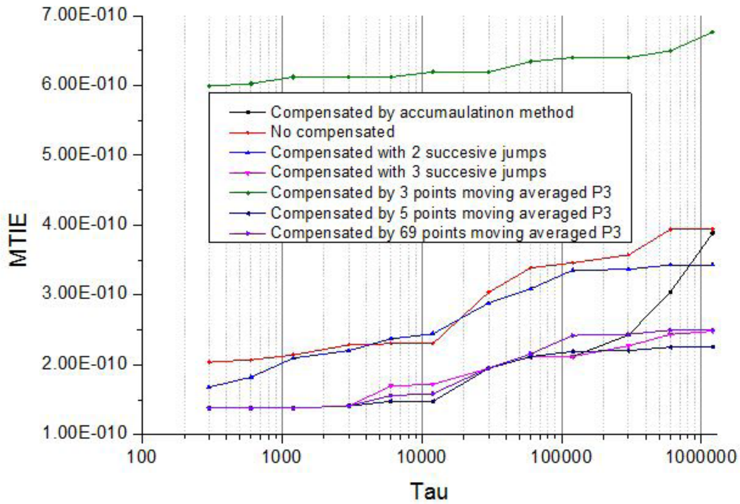
see the characteristic of the jumps somewhat more detail, we provide the histograms of the two receivers in Fig. 5. As we can see from the figure, most of the jumps are existed between -200 ps and 200 ps at the two receivers and look like the Gaussian shapes. However, bilateral symmetry is not the same, that is, the 3103 receiver is a little partial to plus direction while the 0201 receiver is to minus direction. This means that the directions and magnitudes of the jumps between the two receivers are a little different from each other.

Fig. 6 shows the experiment results of the difference data obtained by subtracting the data of the receiver #2 (0201) from those of the receiver #1 (3103) for the uncompensated and the compensated data, respectively. For the compensation, we employ the following steps. At first, the current jump is calculated by using the difference between two successive jumps. Secondly, the current compensation value is calculated by adding current jump to the previous jump. In order to process the steps repeatedly, the previous jump is set to zero at the starting point. Thirdly, the compensated data are obtained by subtracting the current compensation value from the uncompensated data. After the compensation, the current compensation value is set to the previous compensation value. By repeating the steps for all the acquired jumps, we can get the whole compensated data, finally. We call this compensation method as a simple accumulation method. From the figure, it can be noted that the jumps can be smoothly compensated by using the simple accumulation method, but it gives a kind of frequency offset. Therefore, this kind of compensation method may not be recommended in the situation of time comparison since the frequency offset may make deviation of the clock time be so large.

Compensation results of the differenced data between the two receivers by using 2 and 3 successive CP jumps are shown in Fig. 7, respectively. The process of compensation with 2 and 3 successive CP jumps was explained in Section 2. As we can observe in the figure, the jumps are rarely mitigated and large jumps are transferred to the next in the case of using 2 successive jumps while most of the jumps are reduced more or less by using 3 successive jumps. The absolute synchronization error between two clocks is obtained from the code measurement data (Ray & Senior 2005). Therefore, it is expected that the jumps can be somewhat abated with the assistance of P3 data. Compensation results of the differenced data between the two receivers by using 3, 5 and 69 points moving averaged P3 data are shown in Fig. 8, respectively. The process of compensation with P3 was also aforementioned in Section 2. From the figure, it is investigated that compensation effect can be hardly seen in the case of using 3-point moving average and the best reduction effect can be obtained by



(a) MDEV



(b) MTIE

Fig. 9. Stability values of the differenced data between two receivers for the original CP and the compensated data obtained from the 6 compensation methods, (a) MDEV and (b) MTIE, respectively.

using 5-point.

In order to investigate the improvement of the compensation methods, MDEV and MTIE values are depicted in Fig. 9. From the figure, the followings are observed. First, in the view point of the frequency stability, the accumulation method gives the best performance up to 6*105 s observation time but the stability is rapidly degraded from 3*105 s; compensated with 3 successive CP jumps provides good stability in the overall observation intervals; and compensated by 3-point moving averaged P3 shows the worst performance and moreover it severely degrades the stability compared to that of the uncompensated data. Second, in the view point of the timing capability, the accumulation method gives the best performance up to 2*104 s observation time but the performance is rapidly degraded from about 1.2*104 s; compensated by 5-point moving averaged P3 provides good timing performance in the overall observation intervals; and compensated by 3-point moving averaged P3 shows the worst performance and moreover it degrades the performance more than two times compared to that of the uncompensated data. With the observations, we can make the following analogical inference: the simple accumulation method may be employed in a short-period frequency comparison campaign (within about a week) but could not be used in a long-term; and compensation with more than 5-point moving averaged P3 can be recommended for a time comparison campaign.

4. CONCLUSIONS

Various compensating methods of daily jump (day-boundary discontinuity) existed in carrier phase (CP) processed GPS data are investigated with about 70-day CP and code (P3) measurements. The compensation methods can be mainly divided into two cases, namely, CP-only and with code (P3). In the case of CP-only compensation, we employed 2 and 3 successive jumps to estimate the direction and the magnitude of the current jump while one day averaged P3 data with 3, 5 and all (69)-point moving average are employed for the usage of P3 measurement.

In order to investigate the improvement of the compensation methods, MDEV and MTIE values are used. From the compensation results, the followings were observed. First, daily jumps existed in CP measurements depend on not only the environment but also the receiver. Second, in the view point of the frequency stability, the simple accumulation method could be employed for a short-period frequency comparison campaign (less than about a week) because it may provide good frequency stability within that period. Second, in the view point of the timing capability, the compensation with more than 5-point moving averaged P3 provided better timing performance than the others in the overall observation intervals so it could be recommended for a time comparison campaign.

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