Analysis of the influence caused by UPD on GNSS positioning using SDCP measurements

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ABSTRACT

The position service provided by global satellite navigation system (GNSS) has high-precision characteristics, it is widely used in the field of building deformation monitoring. As the baseline between the receivers is short for the above application scope, the common clock source method can be used to eliminate some error items. For common clock SDCP measurement, the uncalibrated phase delay is a major error item. The UPD feature and the usual estimation methods were analyzed and verified by experimental tests in the paper. The experimental results testify that the UPD is a random variable, which varies with the ambient temperature. The UPD can be eliminated by using ARMA filter, and the ARMA filtered SDCP position accuracy can be improved by more than 20% compared to the DDCP positioning result.

Keywords: GNSS, uncalibrated phase delay, common clock source, SDCP

1. INTRODUCTION

The position and timing service provided by the global satellite navigation system has the advantages of high accuracy and all-weather, so it has a wide range of applications in the field of deformation monitoring of large buildings [1, 2]. For the application of building deformation monitoring, scholars have also proposed many positioning algorithms for deformation monitoring [3-6]. In order to improve positioning accuracy, the differential carrier-phase measurements are usually used to weaken the observation errors.

In deformation monitoring applications, the baseline length between receiving antennas is relatively short (generally less than 1km), so the single difference carrier phase(SDCP) measurements, which are obtained by taking between the observations from the two receiving antennas, can effectively eliminate satellite observation errors and signal transmission errors, including: satellite clock error, satellite orbit error, satellite uncalibrated phase delay (UPD) error, ionospheric propagation delay error, tropospheric propagation delay error and so on. The double difference carrier phase (SDCP) measurements, which are obtained by taking between SDCPs, can eliminate the observation errors at the receiver side, including: receiver clock error and receiver UPD. Although the DDCP measurements can eliminate almost all the observation errors, however its observation noise power is 2 times larger than that of SDCP. In addition, the number of DDCP observations is one dimension less than that of SDCP. All of which will limit the improvement of the positioning accuracy of the algorithms using DDCP measurements.

The receiver clock error in the SDCP measurements can be eliminated by adopting the method that all the receivers use the common clock source. Therefore, the UPD is one of the main errors that affect its accuracy for positioning algorithms using the common clock source SDCP measurements. The UPD is mainly caused by the signal transmission delay in the cable and the processing delay of the receiver front end. In previous studies, UPD is generally considered to be a constant value. However, due to environmental changes, UPD is not a constant, but a value that changes with the environment [7], so UPD needs to be dynamically estimated [8-11].

This paper mainly focuses on the analysis of the influence caused by the UPD error that how the positioning accuracy changes for different UPD error levels. Firstly, the common clock source SDCP measurement model is given; then the feature of the UPD is analyzed, and the commonly used estimation methods of UPD are given. In the last, the experiments for both zero baseline and short baseline scenarios are conducted, to analysis the UPD characteristics and verify the impact of the UPD on the positioning accuracy of algorithm using common clock source SDCP.

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2. THE SHORT BASELINE COMMON CLOCK SOURCE SDCP MEASUREMENT MODEL

The single difference between stations refers to take difference between the observations obtained by the two receivers *r* and *q* processing the received signal from the same satellite *s* simultaneously, which can eliminate the satellite-related errors and weaken the transmitting error. According to the equation (1), the short baseline common clock source SDCP measurement can be expressed as

$$\Phi_{qr}^{s} = \Phi_{r}^{s} - \Phi_{q}^{s} = \rho_{qr}^{s} - \lambda_{i} N_{qr}^{s} + U_{qr} + \delta m_{qr}^{s} + \varepsilon_{qr}^{s} \quad (1)$$

where Φ represents the carrier phase observation (m); the superscript *s* represents the satellite number; the subscript *r* represents the receiver number; *ρ* is the geometric distance from the satellite to the receiver (m); *λ* is the wavelength of the carrier (m); *N* is integer carrier ambiguity(cycle); *U r*epresents the uncalibrated phase delay (m); *δm* denotes the multipath error of the carrier phase observation measurement (m); *ε* is the carrier phase measurement noise, which follows zeros mean Gaussian distribution.

3. THE UPD FEATURE ANALYSIS AND COMMON ESTIMATION METHODS

3.1. The UPD feature

The UPD is caused by the propagation delay of the signal in the receiving cable, the signal processing delay of the receiver front end, etc. In addition, due to the change of the ambient temperature, the signal transmission and processing delay will also change [11, 12]. Therefore, UPD is composed of two parts, one part is the initial deviation, this part is a constant value, and the other is the random deviation caused by the environmental temperature change. Thus the UPD at the t_k epoch can be expressed as:

$$U\left(t_k\right) = U_0 + \int_0^{t_k} du\left(f\left(t\right)\right) df\left(t\right) \quad (2)$$

where U_0 is a constant, representing the UPD at the initial starting moment of the receiver. *du*(*x*) represents the UPD rate of change as a function of the ambient temperature; *f*(*x*) is a function of the ambient temperature that varies with time. As the process that ambient temperature changes with time is a a random process, the function *f*(*x*) describes a random process. If the process of UPD change rate *du*(*x*) with ambient temperature follows a normal Gaussian distribution, then the second part on the right side of the equation (2) is a random walk process.

3.2. The UPD estimation based on moving average (MA) filtering

The UPD estimation based on MA filtering can be expressed as:

$$\hat{U}_{rq,k} = \frac{1}{M} \sum_{i=k-M+1}^{k} U_{rq,i} \qquad k \geq M \quad (3)$$

where $U_{rq,i}$ is the difference between UPDs of the receiver *r* and *q* at the *i*-th epoch. *M* represents the filter length. The MA filter is actually a low-pass filter, which can effectively estimate the trend of UPD. Based on the estimation method of the above formula, its estimation accuracy is:

$$\sigma^2\left(\hat{U}_{rq,k}\right) = \frac{1}{M-1} \sum_{i=k-M+1}^{k} \left(U_{rq,i} - \hat{U}_{rq,k}\right)^2 \quad (4)$$

When *k*<*M*, that is there are fewer UPD sequences, the UPD is estimated using the following equation:

$$\hat{U}_{rq,k} = \frac{M-1}{M} U_{rq,k-1} + \frac{1}{M} U_{rq,k} \quad (5)$$

3.3. UPD estimation based on autoregressive moving average (ARMA) filtering

The UPD estimation based on ARMA filtering can be expressed as:

$$\hat{U}_{rq,k} = -\sum_{i=1}^{p} a_i U_{rq,k-i} + \sum_{j=1}^{q} b_j \xi_{k-j} + \xi_k \tag{6}$$

where (p, q) is the order of the ARMA filter. a_i and b_j are constant coefficients respectively. ξ_j is a Gaussian white noise random variable, its mean is zero, and its variance is σ_ξ^2. The order (p, q) of the filter and constant coefficients a_i and b_j can be determined by experience, or by optimized fitting with using the existing UPD sequences. The past white noise ξ_{k-j} already occurred before the current epoch k, which is a determined term by the minus between the observed and predicted value.

4. EXPERIMENTAL TESTS

A number of field experiments including zero and short baselines have been conducted to verify the feature of the UPD and its influence on the positioning accuracy with using SDCP measurements. For the zero-baseline test scenario, the signal from the same receiving antenna is divided into two channels by the power splitter, and then they are connected to the two input ports of the common-clock receiver respectively. As the signal coming from the same antenna, the multipath errors are same for the two divided channels, therefore it is convenient to analyze the characteristics of UPD. For the short baseline test scenario, there are two antennas, and the distance between the two antennas is less than 1 kilometer. In the actual experiments the baseline is about 20 meters long, and the two antennas are placed the roof of a building with a good observation condition, where there were few taller block buildings. In these experiments, a Beidou three-frequency common-clock receiver manufactured by Hunan Xingnan Information Technology Co., Ltd. was used for collecting the observation data.

The UPD changes of Beidou B1, B2, and B3 are shown in Figure 1. It is shown in the figure that the change trends of the three frequency signals' UPDs are same, and all of them are changing with the ambient temperature. And it can be seen that the UPD of the B1 frequency signal has the largest variation range, and the B3 frequency signal's UPD has a smaller variation range.

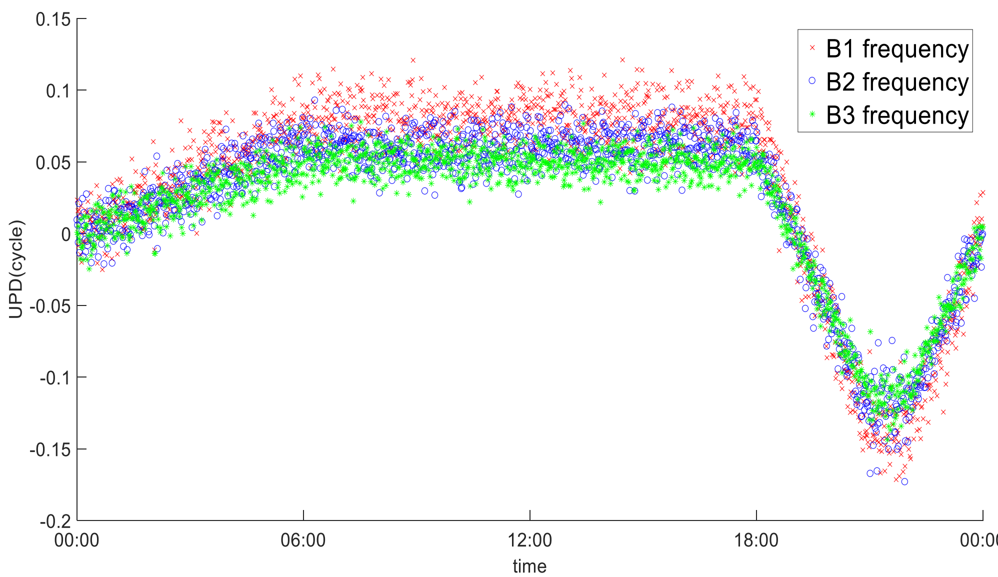

Figure 1. The UPD series variation along with observation time.

In order to analyze the impact of UPD on positioning accuracy, the positioning results with using DDCP, uncalibrated SDCP, constant calibrated (CC) SDCP, MA filtered SDCP and ARMA filtered SDCP are compared. Form all the tests, the MA filtering length is 10 minutes; the orders of the ARMA filter p=2, q=1, and the coefficients a_1=1.784, a_2=-0.784, b_1=-0.485.

The positioning results using different measurements in the zero-baseline scenario are shown in Figure 2. It is shown that the uncalibrated SDCP results are slightly worse than the DDCP results. But the CC SDCP results are worse than the results of uncalibrated SDCP. It is because that the CC method idealizes the UPD as a constant value, which leads to a correction deviation. It is shown in Table 1, the SDCP positioning accuracy has been improved by using MA filtering and ARMA filtering methods. Compared with DDCP results, the MA filtered and ARMA filtered SDCP three-dimensional positioning accuracy are improved by (24%, 25%, 27%), (44%, 45%, 37%) respectively. It is shown that the ARMA filtering has a better effect on the elimination of UPD.

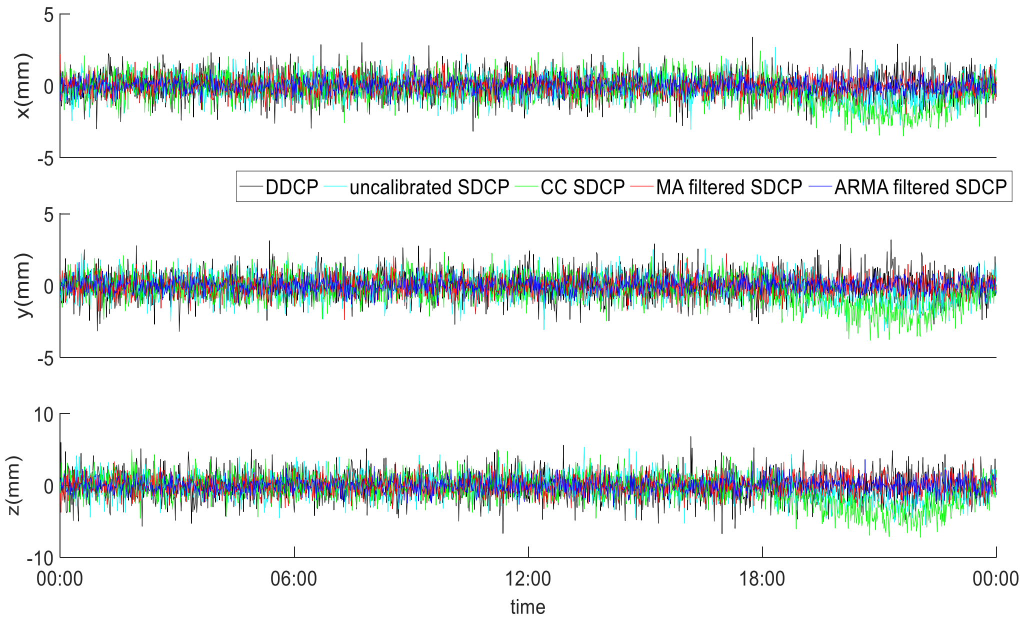

Figure 2. The three-dimensional positioning error int the zero-baseline test.

Table 1. Comparison of baseline solution accuracy in the zero-baseline test.

Measurements	**Root mean square of position results (mm)**			**Improvements (%)**
	x	***y***	***z***	
DDCP	1.29	1.37	2.65	
uncalibrated SDCP	1.33	1.40	2.75	(-3, -2, -4)
CC SDCP	1.41	1.52	3.06	(-9, -10, -15)
MA filtered SDCP	0.98	1.03	1.92	(24, 25, 7)
ARMA filtered SDCP	0.71	0.75	1.65	(44, 45, 37)[a]

Note: [a] The positioning accuracy improvement percentage is 44%, 45% and 3 % with respect to the DDCP model in the *x*, *y* and *z*, respectively.

The positioning results using different measurements in the short baseline scenario are shown in Figure 3. It can be seen that the impact of every UPD processing method on the SDCP positioning performance in the short baseline scenario is similar to the corresponding processing method in the zero-baseline scenario. Compared the results in Table 2 with that in Table 1, the accuracy improvements of the MA and ARMA filtering methods are decreased, their three-dimensional positioning accuracy are improved by (15%, 16%, 12%), (24%, 25%, 20%) compared with the DCP results respectively. It is because that in the short baseline scenario, except UPD error, other measurement error, such as multipath error, also exists. Nevertheless, it can be seen that UPD is still a major error term in SDCP, and the positioning accuracy can be improved by more than 20%, if it is eliminated by using ARMA filtering method.

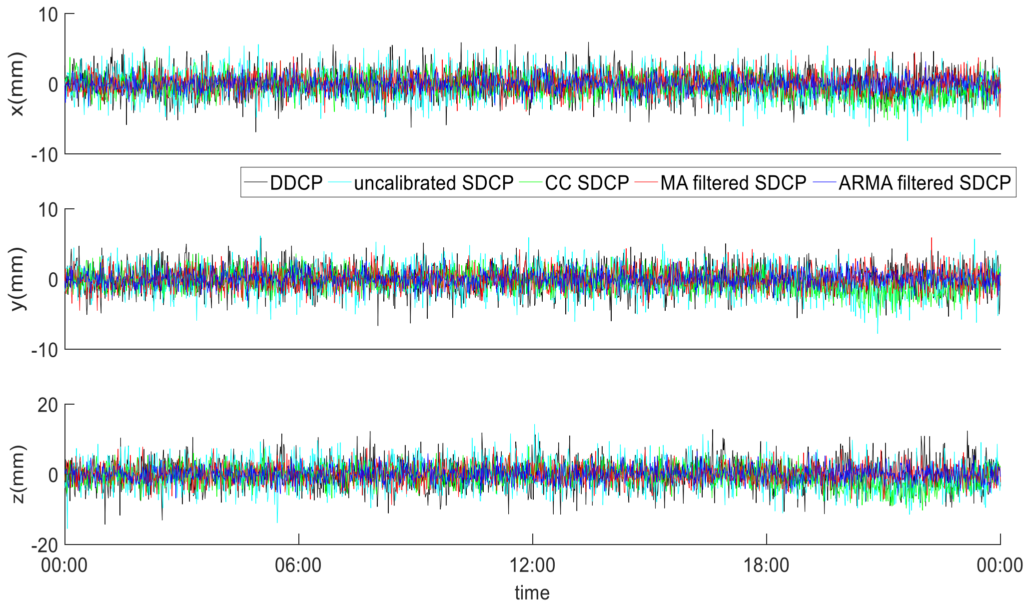

Figure 3. The three-dimensional positioning error int the short-baseline test.

Table 2. Comparison of baseline solution accuracy in the short-baseline test.

Measurements	**Root mean square of position results (mm)**			**Improvements (%)**
	x	***y***	***z***	
DDCP	1.87	1.91	3.34	
uncalibrated SDCP	1.89	1.89	3.41	(-1, 1, -2)
CC SDCP	1.94	2.03	3.43	(-4, -6, -8)
MA filtered SDCP	1.49	1.57	2.79	(15, 16, 12)
ARMA filtered SDCP	1.41	1.44	2.65	(24, 25, 20)

5. CONCLUSIONS

In the high-precision position scopes, the algorithms using SDCP measurements has a larger improvement capacity than that using DDCP measurements. The UPD is the major error source of the SDCP measurement under the common clock condition. It is illustrated from the zero and short baseline experimental tests' results that the UPD is a random variable, which varies with the ambient temperature. The UPD can be eliminated by using ARMA filter, and the ARMA filtered SDCP position accuracy can be improved by more than 20% compared to the DDCP positioning result.

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