위성 클럭 에러 추정 정확도에 따른 정밀 단독 측위 성능 분석

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The Analysis of Performance of Precise Single Positioning according to estimation accuracy of Satellite Clock Error

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요 약

본 논문에서는 관측소 지리적 위치에 의한 대류권 파라미터에 따른 위성 클럭오차 특성을 분석한 것으로 PANDA 소프트웨어를 이용하여 관측소 거리의 간격에 따른 GPS 위성 클럭오차에 따른 정밀단독측위의 성능을 연구하여 결과를 제시하였다. 분석 결과에 의하면 거리의 간격이 200km이하인 경우에는 대류권 파라미터와 위성 시계 오차 파라미터의 관련성이 크며, 최대 0.8ns의 클럭 오차를 발생하였다. 또한 거리의 간격이 500km이상인 경우에는 위성 클럭 오차와 대류권 파라미터의 관련성이 현저하게 감소됨을 알 수 있었다.

ABSTRACT

In this paper, we analyzed the influence of different observation stations distributions on satellite clock offset estimation based on the PANDA software. The result shows that, when the distance between stations is shorter than 200km, the correlation of troposphere parameter and satellite clock offset parameter is strong, the accuracy of satellite clock offset estimation will be up to 0.8ns; when the distance between stations is up to 500km, as the correction of troposphere parameter and satellite clock offset parameter is significantly reduced, and the two kinds of parameters can be distinguished.

키워드

precise point positioning, clock error, troposphere, GSP satellite
정밀단독측위, 클럭 오차, 대류권, GPS 위성

Ⅰ. Introduction

Precise point positioning (PPP) can realize that the high-accuracy orientation anywhere in the world relies on high precision navigation satellite orbit and clock offset product. High-precision post-precise point positioning generally uses the sophisticated product provided by International GNSS Service (IGS), which can reach cm level of static positioning accuracy [1].

At present, for real time PPP technique, broadcast ephemeris and IGU ephemeris supplied by

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IGS could meet the real time demand, however, they could not meet the requirement of accuracy, in which the satellite clock offset is an important constraint. Therefore, for now, in the system of real time precise positioning service, the real time estimation of high-accuracy satellite clock offset is the premise, while the estimated accuracy of satellite clock offset is the key to the accuracy of real time precise positioning.

Generally speaking, satellite clock offset is a scalar without directionality, and the influence of geometric distribution can be omitted when estimating clock offset by using the observed data. This viewpoint is based on a fact that only the pseudorange observed value is employed in clock offset estimation, taking no account of the influence of troposphere remains error. Therefore, there is a sense in which clock offset is not affected by geometric distribution [2].

However, for high-accuracy clock offset estimation, it is needed to employ the observed value of carrier phase and do parameter estimation for the error of troposphere wet component and so on. This kind of parameter is related to the location of observation station, and there is correlation between the parameter of satellite clock offset and that of troposphere. Thus, the distribution of observation stations can affect satellite clock offset estimation.

This paper will use the data observed by IGS tracked station and CORS (continue operation reference station) station, and take advantage of the PANDA (positioning and navigation data analyse) software to analyse the correlation between various distribution of observation stations (different distance between stations) and the accuracy of satellite clock offset estimation.

Ⅱ. Accurate satellite clock offset estimation

In accurate satellite clock offset estimation, usually the un-differenced phase without the influence of ionized stratum and the pseudo range observed value are adopted, and the equation of the observed value error is:.

$$v_{k,\phi}^{j} = \triangle t_k - \triangle t^j + \rho_k^j/c + M(\theta_k^j)\delta\rho_{k,trop}/c + \lambda \cdot N_k^j/c - \lambda\phi_k^j/c + \epsilon_{k,p}^{j} \quad (1)$$

$$v_{k,p}^{j} = \triangle t_k - \triangle t^j + \rho_k^j/c + M(\theta_k^j)\delta\rho_{k,trop}/c - P_k^j/c + \epsilon_{k,p}^{j} \quad (2)$$

In the above equation, k is the mark of observation stations; j is that of satellite; c is the speed of light; $\triangle t_k$ is the receiver clock offset; $\triangle t^j$ is the satellite clock offset; $\delta\rho_{k,trop}$ is the delay parameter of troposphere; $M(\theta_k^j)$ is the projective function; $\epsilon_{k,p}^{j}$、 $\epsilon_{k,p}^{j}$ are the influence of error not modeled; P_k^j、 ϕ_k^j are observed values of pseudorange and phase without the combination of ionized stratum respectivelyλ is the wavelength of the observed value without the combination of ionized stratum;ρ_k^j is the geometrical distance between the location of satellite when transmitting signals and that of receiver when receiving signals.

Since the observed value of GPS is the relative time delay of observation stations and satellite, all of the GPS satellite clock offset discussed in this paper refer to relative clock offset [3].

Actually, in clock offset estimation, the confirmation of vague parameter mainly depends on the pseudo range observed value. Also, the vague parameter can be eliminated with the adoption of carrier wave observed value epoch difference, simplifying clock offset estimation.

Apart from the vague parameter, tropospheric parameter is a major factor affecting accurate clock offset estimation. It can be seen from the observation equation that the design matrix coefficient of troposphere parameter tropospheric mapping functions of the same satellite from different observation stations are approximately equal, making satellite clock offset strongly correlate to tropospheric parameter, the solution is unstable.

III. Analysis

A. Influence of correlation between observation stations space and satellite clock offset

Adopting the data from IGS tracked station and CORS station, the experiment analysed 5 typical kinds of observation stations distribution with different space from 50km~1000km, including 1000km、500km、200km、100km、50km, as showed by Fig. 1 and Fig. 2, and each kind of observation stations distribution employed 4 observation stations. Fig. 1 is the data from CORS station, and the blue station spots stand for 50km observation stations distribution, the green ones for 100km, the red ones for 200km.

In order to analyse the influence of the network of different observation stations space on the estimation of satellite clock offset, this paper uses the 76 days' observed data in 2010 of 5 networks of observation stations distributed diversely in §2 and 68 observation stations (the average distance between observation stations is 2500km) well-distributed globally. Based on the PANDA software developed independently by Wuhan University, Fig. 1 estimates and analyses the GPS satellite clock offset, sampling interval is 30s, fixed IGS post-precise orbit and coordinate of standard station, the strategy of data disposal is in reference.

The estimated result of satellite clock offset and IGS post- precise clock offset which employs the method of second difference to wipe out the influence of clock offset criterion are compared. Fig. 1 shows the statistical accuracy of satellite clock offset under the condition of global observation stations distribution [4].

It can be seen from Fig. 1 that when observation stations are well-distributed globally, all the calculated result of satellite clock offset estimated by PANDA software as well as the RMS value of precise clock offset second difference are within 0.1ns.

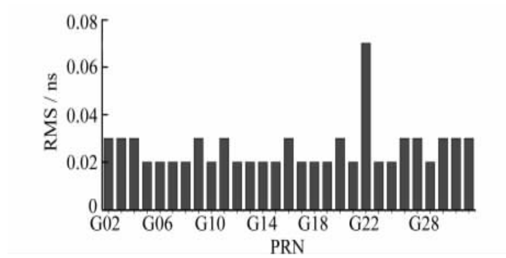

Fig. 1 Differences of GPS clock offset results based on globally stations from IGS final products

Fig. 2 shows the estimated result of satellite clock offset under the condition of different observation stations space, and the clock offset analysis of each satellite adopts the contrast and statistic of visible arc satellite clock offset as well as IGS post- clock offset. IGS station in Europe, and the blue station spots signify 500km observation stations distribution, the red ones, 1000km. It can be perceived from Fig. 2 that the calculated accuracy of satellite clock offset is strongly affected by the distance between observation stations, especially when the distance is 50km, the worst accuracy of No. 20 satellite clock offset can reach 0.8ns. With the increase of observation stations space, the estimated accuracy of clock offset will be improved gradually. When observation stations space increase to 50km、1000km, the calculated accuracy of clock offset corresponds to that of observation stations well-distributed globally, preceding 0.1ns.

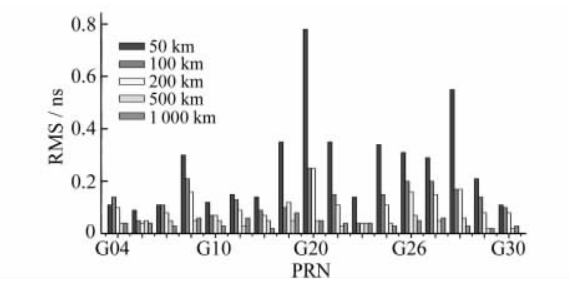

Fig. 2 Differences of GPS clock offset results based on different distributing station networks from IGS final products.

B. Estimation of satellite clock offset accuracy based on different observation stations distribution

Fig. 3 shows the relevant coefficient between satellite clock offset as well as receiver clock offset and tropospheric parameter under the condition of 5 different kinds of observation stations distribution [5]. Since all the numbers of observation stations in various observation stations distribution are 4, and 9 satellites are observed synchronously, the parameter order of abscissa and ordinate showed in the figure is: 1~9 are visible satellite clock offset parameters, 10~12 are receiver clock offset parameters of each observation station (there is one of the 4 observation stations acts as the referenced station), 13~16 are tropospheric parameters of each observation station.

It can be seen from Fig. 3 that the correlation of satellite clock offset and tropospheric parameter will be lowered with the increase of the distance between observation stations. When the distance between stations is shorter than 200km, the correlation of satellite clock offset parameter and tropospheric parameter is strong, and the normal equation is abnormal. As the distance between stations is enlarged to 500km to 1000km, the correlation of satellite clock offset parameter and tropospheric parameter could be reduced notably, which is in favor of solving normal equation [6].

Apart from the contrast of the estimated satellite clock offset parameters, it also analyses the estimated tropospheric parameter, in which the calculation of ZTD parameter is handled with PWC (piecewise linearity) strategy, 7200s intervals.

Fig. 3 shows the calculated contrasted result of ZTD parameter of each observation station estimated by different networks, observation stations which distribute according to 500km、1000km networks are IGS tracked stations, contrasting the calculated ZTD value with ZTD product issued by IGS. While 50~200km are CORS stations, contrasting the calculated result with the calculated ZTD value based on IGS post-product adopted by PANDA software, counting RMS of D-value respectively.

It can be perceived from Fig. 3 that the calculated accuracy of observation stations' ZTD parameter reduces wholly with the increase of distance between observation stations.When the distance is 50km, the accuracy of ZTD parameter is evidently different; when the distance is 500~1000km, the accuracy of ZTD parameter reaches to 1cm, which is identical to the change tendency of the calculated accuracy of clock offset. The accuracy of ZTD parameter in JOZE station of 1000km network is a bit worse, of which the cause needs further study [7].

It can be realized from the above analysis that when the distance between observation stations is short, the correlation of satellite clock offset and tropospheric parameter is strong, especially when the distance is 50km, it can affect the calculated accuracy of satellite clock offset and tropospheric parameter; when the distance reaches to 500~1000km, the network structure has no influence on the decorrelation and calculation of satellite clock offset as well as tropospheric parameter.

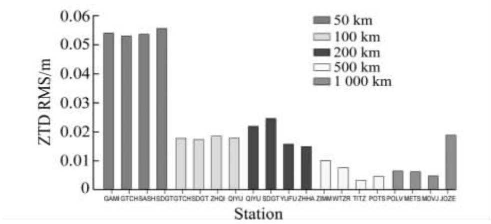

Fig. 3 Differences of ZTD results based on different distributing station networks.

C. Influence of satellite clock offset estimated by differently distributed observatin stations on positioning accuracy

The analysis of the influence of clock offset estimated by small area 50km、100km、200km, such 3 kinds of networks on positioning. The clock offsets calculated by those 3 kinds of networks are respectively used for users inside and outside the area to do precise point positioning dynamically. Since all the data of 3 kinds of networks are from CORS in Guangdong, the testing stations inside the area adopt MEZH station in CORS network, while those outside the area adopt WUHN in Wuhan station which is about 800km apart.

Besides the above 3 kinds of clock offset product, this example also makes a contrast between results of dynamical precise point positioning obtained by adopting IGS post-precise orbit and clock offset product.

Fig. 4 shows the contrast between the result of dynamical precise point positioning obtained by MEZH station adopting different clock offset product and the static result of a single day.

It can be seen that, as the analysis in last section, although the clock offset accuracy acquired from small area networks is not ideal, except for the positioning result acquired by adopting clock offset estimation of 50km network, the positioning accuracy obtained by employing estimated clock offset in area network is superior to that obtained by employing IGS post-precise clock offset. The major reason that leads to the unsatisfactory accuracy of clock offset estimation in small area is that the troposphere in small area separates rather difficultly from satellite clock offset.

However, the correlation of the influence of troposphere delay is fairly strong in the same area, therefore, in this condition, clock offset accuracy is not ideal, yet it can not reduce the positioning accuracy [8].[9]

Meanwhile, as the same software is employed by estimated clock offset in area network as well as precise positioning by users, its self-consistency is better than that adopted IGS post-precise ephemeris, thus the positioning accuracy is higher.

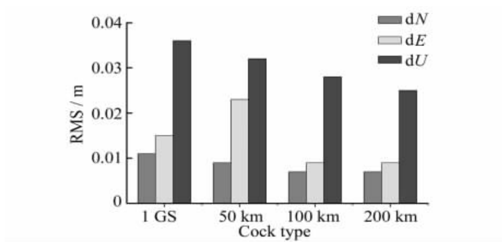

Fig. 4 Accuracy of PPP in local area networks based on different kinds of clock product.

IV. Conclusions.

When it is used for positioning by users, clock offset corresponds to the positioning accuracy of IGS precise clock offset.

However, the positioning accuracy of clock offset calculated by adopting 1000km network is about 0.5cm lower, and the reason is that the number of satellites available for part of the epoch clock offset is 1 to 2 fewer.

when the distance between observation stations reaches to 500km~1000km, the clock offset and tropospheric parameter can be differentiated, and tropospheric parameter has no influence on the estimated accuracy of clock offset parameter, just corresponding to the positioning accuracy supplyed by IGS post-precise ephemeris.

PANDA software estimation for satellite clock offset estimation and IGS compared with 1 ~ 2 ns systematic deviation.

We need to research the subject of how to make both the deviation is lower.

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