Study on the Real-Time Precise Orbit Biases Correction Technique for the GPS/VRS Network

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Abstract

A precise real-time method of using the IGS ultra rapid products (IGU) and the GPS broadcast ephemeris to calculate the VRS orbit corrections was presented here which was suited for GPS/VRS reference station network based positioning. Test data acquired from both the SGRSN (Sichuan GPS Reference Station Network) and SCIGN (Southern California integrated GPS network) were used to evaluate the performance of the modeling techniques. The new method was proven to be more precise and reliable compared with the existing conventional network-based orbit error interpolation method. It was shown that 0.004ppm relative accuracy was reached, namely the influence from the orbit bias for the RTK positioning within 100km area can be of sub-millimeter level.

Keywords: GPS ephemeris；VRS (Virtual Reference Station)；orbital correction；Network RTK

1 Introduction

The orbit quality was considered as one of the primary accuracy limiting factors in the applications of the GPS for geodesy and geodynamics, before the IGS started its operations on June 21, 1992. This statement was more serious for the long range kinematic GPS positioning because the accuracy of the GPS broadcast ephemeris that extensively used at present is only 2m level. In that much the orbit errors is highly distance-dependent, influence from using the GPS broadcast ephemeris could be centimeter level for GPS kinematic positioning on a baseline up to 100km.

The conventional network-rtk approach can mitigate the satellite orbit error in some extent, which tries to estimate the orbital corrections at the rover position using some regional interpolation model. Several error mitigation techniques based on ground-based GPS reference receiver networks (e.g. Rizos & Han, 2000; Gao et al, 1997, 1998; Wanninger, 1997;LI, 2005) have been proposed and appear to be well suited for both static surveying and precise kinematic positioning on the ground. The typical mitigation strategy is to estimate the effect of the residual delay on the user receiver by interpolating the delay determined at a number of GPS reference receivers. However, such approaches are dependent with the configuration of the CORS and the location of the rover. That means when the rover goes outside the network coverage, the performance of the network-based methods will become worse and worse. Field test proved that the orbital bias could reach 6 to 8mm, when the rover went up to 50km outside the network. Further more, both the accuracy and the integrity can not be assured for corrections of the satellite orbit are lumped together with other residual errors, e.g. the atmospheric delay errors and difficult to be divided.

A precise real-time method using the IGS ultra rapid products (IGU) and the GPS broadcast ephemeris to calculate the orbit corrections was presented here which was suited for GPS/VRS reference station network based positioning.

The estimated accuracies, based on analyses performed by the IGS Analysis Center Coordinator, are given in Table 8.2.

2 ANALYSIS OF THE ACCURACY OF THE BROADCAST AND IGU ORBITS

Several types of orbits are available today in which only 3 useful types we mention, namely (a) Broadcast Orbits (BRDC) (b) IGS Final Orbits (IGF) (c) IGS Ultra Rapid Orbits(IGU). The estimated accuracies, based on analyses performed by the IGS Analysis Center Coordinator are shown as table 1.

Table 1: Estimated quality of orbits in 2006

Orbit Type	Quality(m)	Delay of Availability	Available at
Broadcast Orbits	2.00	Real Time	Broadcast Message
IGS Final Orbit	0.05	After 13 days	IGS Data Centers
IGS Ultra Rapid Orbit	0.10	Real Time	IGS Data Centers

Though the accuracy of the IGS final orbit with the best quality reaches 5 cm, it is not suited to kinematic and sub-kinematic applications for its 13 days latency. So the BRDC and the IGU are practicable information for the kinematic users. Whereas day-to-day accuracy of navigation message ephemeredes (broadcast orbits) is not readily available, the accuracy of the BRDC and IGU can be estimated roughly through comparisons with the IGF products. And take the SCIGN (Southern California integrated GPS network) as example, some meaningful statistical analysis can be drawn on both the influence from the BRDC and IGU errors on the GPS/VRS reference network based differential positioning and its dependency on the length of baseline. The BRDC ephemeris and the IGU distributed at UTC 2005/12/3 are used here as in Figure1 and 2.

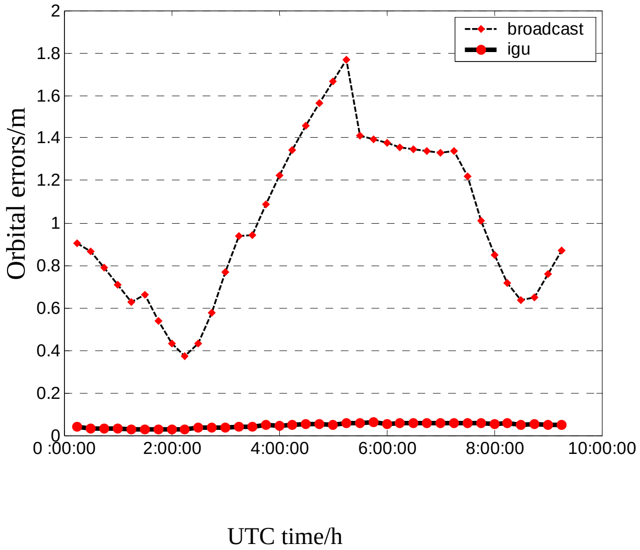

Fig.1 Compared between the position errors of IGS ultra rapid products (IGU) and the GPS broadcast ephemeris

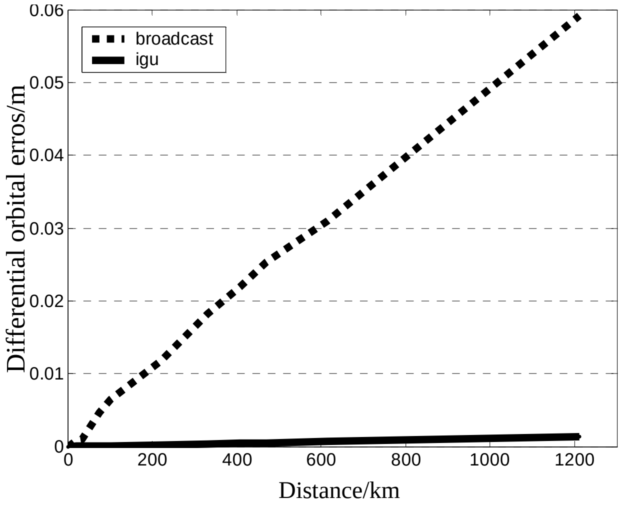

Fig.2 Influence of orbit errors on differential GPS tenique(SCIGN)

As shown in Fig. 1, the orbital biases of the IGU product as small whose RMS is below 10 centimeters, while it is very high (up to 1.8m) for the BRDC ephemeris. Figure2 shows that both the BRDC and IGU errors increase along with the length of baseline. However, it has shown distinctly in the rate of this incensement. The influence of BRDC can be up to 5cm for the 1000km-lengthed baselines, while influence of IGU is below 0.1cm. It is drawn that both the accuracy and the reliability of the IGU products is much higher than the BRDC navigation information and it's feasible to get sub-mm level accuracy correction of orbit based on the IGU products for long range positioning in real time.

3 METHODOLOGY FOR 'CORRECTION TERM GENERATION'

In order to generate the 'orbital correction terms' for the VRS observation, both satellite position of the BRDC(Navigation message) and IGU products should be collected and calculated by a satellite-by-satellite, epoch-by-epoch way. After the orbital corrections estimated by the server, they are send to the rover in time within the observations of the VRS to mitigate the orbital sysmatic errors.

$$\mathrm{CorO}_{\mathrm{VRS}} = \nabla\Delta \mathrm{R}_{\mathrm{uA}}(\mathrm{brd}) - \nabla\Delta \mathrm{R}_{\mathrm{uA}}(\mathrm{igu}) \tag{3}$$

Where $\Delta\nabla \mathrm{R}(\mathrm{brd})$ is the double-differenced satellite-to-receiver geometric distance derived by broadcast orbits, within which orbital bias is $\Delta\nabla \mathrm{O}(\mathrm{brd})$; $\Delta\nabla \mathrm{R}(\mathrm{igu})$ is the double-differenced satellite-to-receiver geometric distance derived by igu orbits, within which orbital bias is $\Delta\nabla \mathrm{O}(\mathrm{sp3})$;

Moreover, the accuracy of the above VRS orbital correction can be deduced as following:

$$\begin{aligned}\Delta\nabla \mathrm{O}(\mathrm{VRS}) &= \left[\nabla\Delta \mathrm{R}_{\mathrm{uA}}(\mathrm{brd}) - \nabla\Delta \mathrm{R}_{\mathrm{uA}}(\mathrm{true})\right] - \mathrm{CorO}_{\mathrm{VRS}} \\ &= \nabla\Delta \mathrm{R}_{\mathrm{uA}}(\mathrm{igu}) - \nabla\Delta \mathrm{R}_{\mathrm{uA}}(\mathrm{true}) = \Delta\nabla \mathrm{O}(\mathrm{sp3})\end{aligned} \tag{4}$$

Where $\Delta\nabla \mathrm{R}(\mathrm{true})$ is the true value of the double-differenced satellite-to-receiver geometric distance.

From equ.(3) it can be seen that the influence of the broadcast orbit reduce to the level of igu orbit after applying the VRS orbital correction, namely the orbital will remain only 1 to 2 mm on baseline with 1000km distance, as can be seen from figure 2.

As the rule of thumb derived by (Guo-chang Xu, 2003), the influence of the orbital errors on the baseline length is defined: $\mathrm{dx} \approx \frac{\mathrm{l(km)}}{25000(\mathrm{km})}\Delta \mathrm{X}$, where l is the length of baseline; $\Delta \mathrm{X}$ is the orbital error; Thus the calculation of the relative accuracy of the VRS orbital correction can be done as below: $\delta \mathrm{x} = \frac{\mathrm{dx}}{\mathrm{l}} \approx \frac{\Delta \mathrm{X(km)}}{25000(\mathrm{km})} = \frac{10*10^{-5}(\mathrm{km})}{25000(\mathrm{km})} = 0.004\mathrm{ppm}$, which means that for a baseline over 100km, the un-modeled orbital biases may be up to 1cm, meanwhile it will be mitigated below 0.4mm after using the VRS orbital correction.

4 EXPERIMENTAL RESULTS

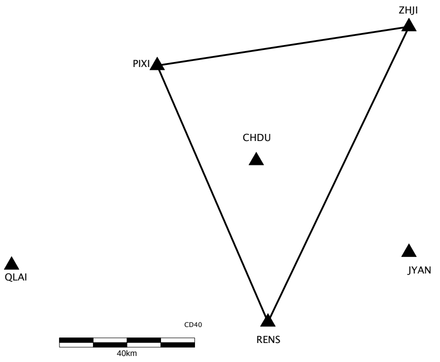

Fig.3 Configuration of SGRSN

Tests were conducted using data sets from Sichuan GPS Reference Station Network (SGRSN) comprised of four continuous operating reference stations(will extend to more than 12 in the near further). CHDU, PIXI, RENS, JYAN, ZHJI and QLAI, equipped with trimble 5700 GPS receiver and antenna, were chosen, their configuration is show as figure 3.

GPS data of Day of Year (DOY) 358/05 was processed. The observation session at local time is from 8:00:00 am. to 17:00:00 pm. CHDU, JYAN and QLAI was chosen as the rover station test performance of the new orbital correction methods, and the LIM model (Wanninger L., 1995) was chosen to take for the conventional network interpolating method to be contrasted.

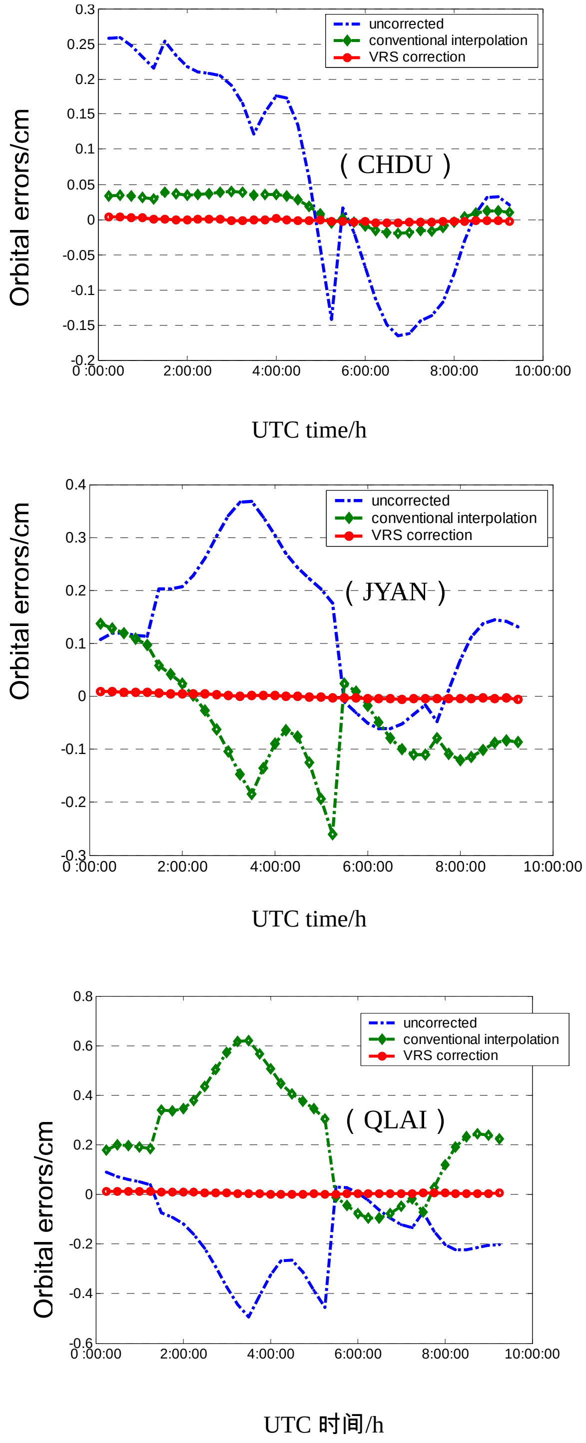

Fig. 4 Comparison of the correction errors estimated using the VRS correction method and the conventional Interpolation method

Tab 1 Statistic of the orbital correction methods at CHDU

Statistic index	(inside) CHDU orbital errors (cm) -baseline 48.8km		
	Original	conventional	VRS orrection
Max	0.2586	0.0400	0.0042
Mean	0.0665	0.0154	0.0012
RMS	0.1605	0.0261	0.0026

Tab 2 Statistic of the orbital correction methods at JYAN

Statistic index	(outside) JYAN orbital errors (cm) -baseline 47.4km		
	Original	conventional	VRS correction
Max	0.3681	0.2606	0.0096
Mean	0.1404	0.0533	0.0002
RMS	0.1918	0.1074	0.0047

Tab3 Statistic of the orbital correction methods at QLAI

Statistic index	(outside) QLAI orbital errors/cm-baseline 78.6km		
	Original	conventional	VRS correction
Max	0.4934	0.6199	0.0126
Mean	0.1686	0.2378	0.0016
RMS	0.2325	0.3211	0.0061

Inspecting Figure 4 and Table 1, it can be found that the accuracy of VRS orbital correction method are about 0.02 to 0.06mm and distributed evenly even outside the network coverage for up to 80km. While in contrast, the accuracy of the conventional interpolation method decrease dramatically when the rover moves to the margin of the network, the orbital biases varying quickly to 3-5mm at different position outside the network region. At all experimental positions, the performance of VRS orbital correction method is much better than the conventional network-based methods and the orbital biases after correction is below 0.1mm, which means that the influence from the orbital errors can be ignored after being mitigated to a sub-mm level.

5 CONCLUSIONS

The new method was proven to be more precise and reliable compared with the existing conventional network-based orbit error interpolation method. It was shown that 0.004ppm relative accuracy was reached, namely the influence from the orbit bias for the RTK positioning within 100km area can be of sub-millimeter level.

For long range real-time cm-level kinematic positioning applications, the biases by using broadcast orbit should be considered. A novel method of using the IGS ultra rapid products (IGU) and the GPS broadcast ephemeris to calculate the VRS orbit corrections is presented here which was suited for GPS/VRS reference station network based positioning. Series of tests conducted using Sichuan GPS regional reference station network and SCIGN demonstrate the exactness and effectiveness of proposed models. Results show that the generated corrections do significantly mitigate orbital errors and thus improve the accuracy of positioning. The accuracy of VRS orbital correction can be about 0.02 to 0.06mm even the rover deviates from large-scale network coverage for more than 80km. In general, the new method is proven to be more precise and reliable compared with the existing conventional network-based orbit error interpolation method. It is shown that the relative accuracy is 0.004ppm, namely the influence from the orbit bias for the RTK positioning within 100km area can be of sub-millimeter level, and namely centimeter level RTK accuracy can be improved.

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