

Retraction

Retracted: Autonomous Orbit Determination System of Navigation Satellite Based on Spaceborne GPS Technology

Security and Communication Networks

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

- [1] L. Yang, H. Ruan, and Y. Zhang, "Autonomous Orbit Determination System of Navigation Satellite Based on Spaceborne GPS Technology," *Security and Communication Networks*, vol. 2022, Article ID 7463315, 10 pages, 2022.

Research Article

Autonomous Orbit Determination System of Navigation Satellite Based on Spaceborne GPS Technology

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In recent years, many low-orbit satellites have been widely used in the field of scientific research and national defense in China. In order to meet the demand of high-precision satellite orbit in China's space, surveying and mapping, and other related fields, navigation satellites are of great significance. The UKF (unscented Kalman filter) method is applied to space targets' spaceborne GPS autonomous orbit determination. In this paper, the UKF algorithm based on UT transformation is mainly introduced. In view of the situation that the system noise variance matrix is unknown or the dynamic model is not accurate, an adaptive UKF filtering algorithm is proposed. Simulation experiments are carried out with CHAMP satellite GPS data, and the results show that the filtering accuracy and stability are improved, which proves the algorithm's effectiveness. The experimental results show that the Helmert variance component estimation considering the dynamics model can solve the problem of reasonable weight determination of BDS/GPS observations and effectively weaken the influence of coarse error and improve the accuracy of orbit determination. The accuracy of autonomous orbit determination by spaceborne BDS/GPS is 1.19 m and 2.35 mm/s, respectively.

1. Introduction

In satellite navigation system, the accuracy of satellite orbit position will directly affect the calculation of user position. If the single receiver completes the carrier navigation without obtaining the differential information, the satellite's orbit error and positioning error will be in the same magnitude [1]. If differential positioning is adopted, the orbit error's influence on the station's baseline should be significantly reduced, but to obtain the phase pair positioning 80% accuracy, the orbit error should be less than 2 m [2, 3]. With the gradual diversification of GPS modes, such as the establishment of wide-area difference system and wide-area enhancement system, and the proposal of real-time precise single-point positioning concept, higher requirements are put forward for the real-time performance and accuracy of navigation constellation orbit [4]. Precisely because of the recognition of the importance of precise orbit determination and orbit prediction for a navigation system, precise orbit determination technology and time synchronization

technology were taken as one of the important demonstration cores in the early stage of Galileo's system demonstration and throughout the whole process of the establishment of Galileo satellite navigation system. International GNSS Service (IGS), founded in 1994, is an international organization of organizations dedicated to providing high quality GNSS products for global Earth science research, multidisciplinary applications, and education [5]. IGS is affiliated with more than 10 world-famous satellite navigation system data processing centers, which are based on part of the data of more than 400 continuous tracking stations distributed around the world. First, each data analysis center generates its own products, and then IGS synthesizes the products of each analysis center to generate the final released products [6]. The products include high-precision orbit, high-precision high-frequency satellite clock, tracking station position, earth orientation parameters, tropospheric parameters, and ionospheric parameters. In data processing, each data analysis center has established its own routine data processing strategy. In addition, it also

formed a more famous data processing and analysis software [7]. At present, the GNSS data processing and analysis software published and used mainly includes GAMIT\GLOBK, developed by the Scripps Institute of Oceanography (SIO) at the Massachusetts Institute of Technology (MIT) and the University of California, San Diego, USA, and GIPSY OASIS developed by the Jet Propulsion Laboratory (JPL) and BERNESE software developed by BERNE University in Switzerland. In recent years, the accuracy and reliability of orbit determination results in various data processing centers have been constantly improved [8].

On the one hand, more data from tracking stations have been used, and stations' distribution is more reasonable. On the other hand, the orbit determination technology has been continuously improved due to the continuous improvement of data processing strategies [9, 10]. The accuracy of autonomous orbit determination by spaceborne BDS/GPS is 1.19 m and 2.35 mm/s, respectively. When GPS signal is interrupted, that is, the three-dimensional position error reaches 3.73 m. The ground tracks of BDS (5GEO/5IGSO/4MEO) are shown in Figure 1.

IGS precision ephemeris will eventually need to be delayed for more than a week, but with the development of society and economy, the high precision requirements for real-time trajectories are getting higher and higher. It is updated every 6 hours [11]. The first 24 hours of the orbit arc is the calculated value and the last 24 hours is the forecast value. The accuracy of the forecast orbit has been greatly improved since 2003. In addition, IGS also provides a fast track to meet the needs of different aging users [4]. In order to shorten the calculation time to obtain the near real-time orbit, MIT, CODE, and other data processing centers have proposed the orbit determination method which is formed by the method equation and then superimposed by the method equation. GPS observations are based on the clock frequency signals of satellites and receivers, and the positioning accuracy of users is closely related to the satellite clock difference and orbit accuracy [12].

At present, the satellite clock error accuracy of broadcast ephemeris used as navigation message transmission is 7 ns. IGS provides a precision clock error product with the minimum time interval of 30 s and the accuracy is better than 0.1 ns. The delay of the final precision ephemeris after the event is one week, and the delay of the fast precision ephemeris is 17 hours [13, 14]. The delay of the ultra-fast precision clock difference (observation value estimation part, accuracy 0.2 ns) is at least 3 hours, which can meet the requirements of the high accuracy application after the event. China successfully launched two BeiDou navigation test satellites in 2000, and a backup satellite, known as the BeiDou Navigation Test System for short, in 2003. By March 2012, China's BeiDou Navigation Satellite System had built a regional navigation constellation consisting of seven satellites, initially forming the Asia-Pacific region's navigation and positioning service capability [15, 16]. After the successful construction of the system, it is realized that the BDS provides guarantee for high-precision applications in the

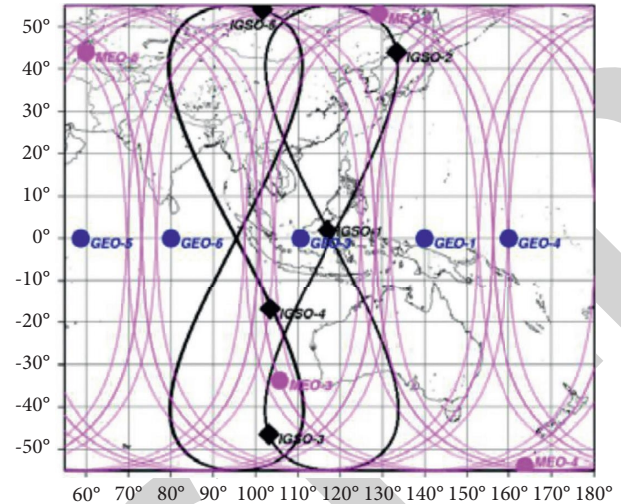


FIGURE 1: The ground tracks of BDS (5GEO/5IGSO/4MEO).

fields of precision navigation, positioning, timing, and scientific research [17]. At the same time, in order to launch BeiDou satellite navigation system and related application research, our country provides wide-area and local-area reference station networks in the Asia-Pacific region and the Wuhan BeiDou satellite navigation system (9 stations, 6 stations in the country, and no data outside the Indonesian station), and for the first time, the precise orbit of BeiDou navigation satellite is better than 10 cm and high-precision satellite clock error. The positioning performance of the BeiDou navigation satellite system and the performance of the onboard atomic clock are evaluated. Because the constellation of BeiDou is composed of MEO, geostationary orbit (GEO), and inclined synchronous orbit (IGSO), and the range of ground stations is small, it is still faced with great difficulties and challenges to obtain higher precision orbit [18–20].

Knowledge of position and velocity is a practical requirement for all earth-orbiting spacecraft. Some satellite systems have requirement of autonomous orbit determination onboard. Reference [21] focuses on developing methods for estimating absolute positions of two satellites using relative range and bearings. Near-range relative orbit determination has significant effect on on-orbit service. Reference [22] proposed the relative orbit determination method with the monocular sequential images based on the cylindrical coordinate for the near-range noncooperative target in three-dimensional space.

Low-orbit satellites have been used in many fields, such as land surveying and mapping, resource exploration, atmospheric exploration, marine dynamic environment monitoring, geomagnetic field, and gravity field research, and these application fields all have high requirements for the orbit accuracy of low-orbit satellites. For example, Haiyang-2 satellite requires radial accuracy within 5 cm, and Ziao-3 satellite position accuracy is better than 20 cm. Gravity satellite has more demanding demands on orbit accuracy. They mainly include the following three aspects:

(1) Theory of satellite orbital dynamics

The theory of orbital dynamics is based on celestial mechanics, namely, Newton's gravity and Kepler's three laws. Kepler's law is mainly used to describe the two-body problem; the so-called two-body problem is not considering the interference of other celestial bodies and the trajectory of the object under the action of gravity. For the satellite, the two-body problem force is the most basic force acting on the satellite, which must be taken into consideration for the orbit calculation of any earth satellite.

(2) Satellite tracking and observation technology

At present, these techniques are relatively mature, and the results obtained are more reliable; the accuracy can generally reach 3–5 cm. Its single ranging accuracy has reached the centimeter level, and it is one of the highest single-point sampling accuracies among various positioning observation methods. With the improvement of observation accuracy, the extension of observation period, the increase of observation density, the increase of observation targets, the increase of the number of stations, and the rationalization of the geometric distribution of stations, SLR has become an important tool of space geodesy in the study of earth dynamics. However, SLR observation is easily affected by weather, and the daily observation arc of low-orbit satellites is short (only the transit can be tracked), so SLR has always been used as the verification of the orbit determination results of other means. Spaceborne GPS orbit determination is a kind of all-weather, high-precision, continuous orbit determination technology. Due to its light equipment and low cost, it is widely used in various low-orbit satellites. The accuracy of the French DORIS system can reach within 10 cm, but the global network is relatively small. The orbit determination accuracy of PRARE system in Germany can reach 5 cm. However, due to relatively expensive equipment and a small number of global observation stations, not many satellites carry this system. It is worth pointing out that in recent years, the continuous development of low-orbit satellite orbit determination technology is continuously developing.

(3) Precise orbit determination method

Taking the satellite-borne GPS orbit determination as an example, according to the corresponding GPS positioning mode, the satellite-borne GPS orbit determination methods can be divided into non-difference, double difference, and three difference methods. According to the different time of obtaining the orbit determination results, the satellite-borne GPS precise orbit determination methods can be divided into two kinds: real-time orbit determination and post-orbit determination. According to the relationship between perturbation

force and the perturbation mechanics model, satellite-borne GPS low-orbit satellite orbit determination can be divided into three methods: pure geometry method, dynamic method, and simplified dynamic method. However, the overall level is still far from that of some famous research institutions in Europe and America, such as GFZ, CSR, CODE, and JPL.

Our contributions include the following three points:

- (1) In this paper, the UKF algorithm based on UT transformation is mainly introduced. In view of the situation that the system noise variance matrix is unknown or the dynamic model is not accurate, an adaptive UKF filtering algorithm is proposed.
- (2) Simulation experiments are carried out with CHAMP satellite GPS data, and the results show that the filtering accuracy and stability are improved, which proves the effectiveness of the algorithm.
- (3) The experimental results show that the Helmert variance component estimation considering the dynamics model can not only solve the problem of reasonable weight determination of BDS/GPS observations but also effectively weaken the influence of coarse error and improve the accuracy of orbit determination.

2. Data Processing Policies

2.1. Data Preparation and Processing Process. By calculating the observed values of the receiver, the autonomous orbit determination results can be obtained by the simulation verification software. Comparing the results with the satellite orbit output by the simulator, the autonomous orbit determination capability of the high dynamic BDS/GPS receiver using the low-orbit satellite can be comprehensively analyzed. The following is the flow chart of simulation verification of onboard BDS/GPS autonomous orbit determination.

The experimental data used in this paper are as follows: BDS precision ephemeris and clock difference on September 5, 2014, and GPS precision ephemeris and clock difference on September 5, 2014. The BDS/GPS simulation observation data generated by the high dynamic signal simulator on September 5, 2014, and the broadcast ephemeris as well as the actual orbit of the low-orbit satellite on September 5, 2014.

2.2. Data Processing

2.2.1. Equation of State and Observation Equation. Autonomous orbit determination of satellite-borne BDS/GPS is a process of optimal estimation of satellite operating state parameters and dynamic model parameters. Autonomous orbit determination usually adopts sequential or recursive methods for data processing and parameter estimation and generally adopts the EKF method [23].

For low-orbit satellites, the two nonconservative forces greatly influence the satellite orbit and are difficult to be accurately modulated. In dynamic orbit determination, atmospheric drag coefficient C_D and solar pressure coefficient C_R are often used as state parameters to estimate. Therefore, the state vector of the autonomous orbit determination system is determined as

$$X = [x, y, z, \dot{x}, \dot{y}, \dot{z}, d_G, d_C, d_{G-C}, \dot{d}_G, \dot{d}_{G-C}, C_D, C_R, w_R, w_T, w_N]^T, \quad (1)$$

where $x, y,$ and z are the satellite orbital positions; $\dot{x}, \dot{y},$ and \dot{z} are the satellite velocities; $\delta t_G, \delta t_C,$ and $\delta \dot{t}_G$ are GPS clock difference, BDS clock difference, and GPS clock speed of spaceborne receiver, respectively.

Flow chart for validation of BDS and GPS autonomous orbit determination is shown in Figure 2.

$\delta \dot{t}_{G-C}$ is the change rate of time deviation of BDS and GPS system; C_D is the atmospheric drag coefficient; $w_R, w_T,$ and w_N are the three components of compensated acceleration in the RTN direction.

Using the nondifferential linear combination of the ionospheric pseudo-range PC observations, the system time deviation is obtained as δt_{G-C} of BDS/GPS.

2.2.2. Observation Model and Dynamics Model. Table 1 shows the specific observational model. For low-orbit satellites, atmospheric drag, and solar pressure, two nonconservative forces have great influence on satellite orbit and are difficult to be accurately modulated. Atmospheric drag coefficient and solar pressure coefficient are often used as state parameters in dynamic orbit determination. The detailed dynamic model is shown in Table 2.

2.3. Right Determination Strategy. Because the distribution, frequency characteristics, orbit accuracy, and observation data quality of the Big Dipper are different from that of GPS, it is an important problem for the autonomous orbit determination of satellite-borne BDS and GPS how to weight the observation data reasonably. In the actual process, there are three ways to determine the weight of observation data: (1) use the standard deviation provided in the observation documents; (2) determine the power based on experience; (3) use variance component estimation. Helmert variance component estimation is a method of adaptively determining the ratio of similar observations through iterative calculations. It can automatically adjust the ratios of different types of observations during the calculation process and automatically review the entire solution. It is inevitable for the observation information to have gross error and the orbit forecast value to be abnormal. In order to reduce the influence of the gross error and the orbit forecast value anomaly on the results of autonomous orbit determination, the Helmert variance component estimation method [24], which takes into consideration the dynamics model, is adopted to carry out the satellite-borne BDS/GPS.

2.4. Ambiguity Resolution Strategy. The fixed ambiguity is one of the key techniques to improve the precision of navigation satellite orbit determination. However, since the nondifferential ambiguity includes the initial phase delay of the receiver and satellite, it does not have the whole cycle characteristic. Only the quadratic difference between satellite and receiver can eliminate the initial phase delay and restore the whole cycle characteristics of ambiguity. Therefore, whether the observed data are nondifferential or double differential, only the ambiguity of the double differential can be fixed directly. Generally speaking, the processing method of mold paste includes the following two steps: first, the real solution of mold paste is obtained by solving the ambiguity parameter together with other parameters; secondly, the real number of fuzzy degrees is fixed as integer by using real number solution and covariance information. Because the number of unknown parameters can be reduced obviously after the ambiguity is fixed correctly, the accuracy of orbit determination can be improved effectively by fixing the ambiguity parameters correctly.

Common methods for fixing ambiguity include

(1) Round method (round)

The integral method is a simple fuzzy searching method that does not depend on any covariance information and directly fixes the fuzzy floating-point solution to a close integer. When the baseline is more than a few kilometers, this method is generally difficult to fix the ambiguity correctly. Therefore, this method is generally not used in reality.

(2) Search

The search method is based on the hypothesis test of mathematical statistics theory. It uses the first adjustment to provide all the information, including the solution vector and the coordination factor matrix and the corresponding unit weight mean error. Determine the unknown number of the integer solution combination within a certain confidence interval, and then reverse it. Use this to combine the unknown number of whole weeks as a known quantity into an equation. The method of adjustment is used to search for the optimal solution of a group of unknowns with the smallest variance and variance after adjustment.

(3) Search method based on sigma

Assuming that P_i and P_j are double-difference ambiguity, after the first adjustment, the posterior median error of each ambiguity parameter P_i can be calculated based on the variance information after adjustment.

3. Orbit Integrals

3.1. The Exact Expression of Ordinary Differential Equations in Numerical Integrators. Ordinary differential equations are usually solved numerically; the equation needs to be described as follows:

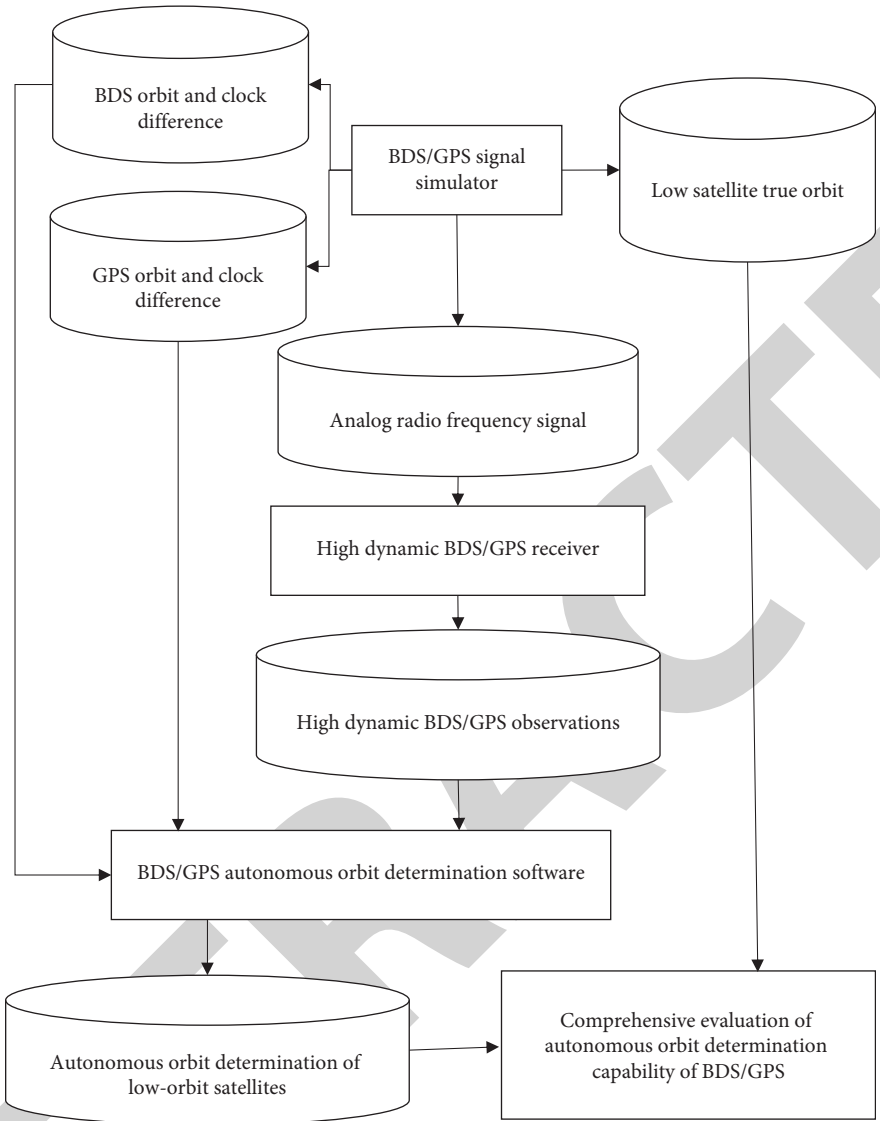


FIGURE 2: Flow chart for validation of BDS and GPS autonomous orbit determination.

TABLE 1: Observation models and parameters.

Parameter	Model	A priori constraint
Observed quantity	PC nondifferential linear combination	P1 3.0 m
By the angle	0°	
Sampling interval	1 s	
Observation weighting	For different systems, Helmert variance component estimation was adopted. It has to do with the height angle E	
Receiver clock difference	Gaussian white noise	Process noise: 100 m/s

$$\begin{cases} \frac{dx}{dt} = F(x, t), \\ x|_{t_0} = x_0. \end{cases} \quad (2)$$

If only the satellite ephemeris table needs to be solved, the state vectors in the integrator are satellite positions. But if

you need to determine the precise orbit of the satellite, more parameters are needed for calculation.

While in the linear multistep method, Adams or Adams-Cowell method is used for the fast quadration of the subsequent nodes. Working together, they can be used to calculate the satellite ephemeris table conveniently, accurately, and quickly and to obtain the state transition matrix in precise orbit

TABLE 2: Dynamic models and parameters.

Parameter	Model	A priori constraint
The gravity field	EGM2008 50 * 50	
Center of gravity	The sun, moon, and other planets (DE405)	
The tides	Earth tides, sea tides, and polar tides	
The sun light pressure	Light pressure model based on integral to satellite surface	Initial solar pressure coefficient error: 1.3
Atmospheric drag	DTM94	Initial atmospheric drag coefficient error: 2.3
Empirical dynamic parameter	First order Gaussian Markov process	Random noise for compensating acceleration: $1E-8$

determination. The specific algorithm of numerical integration is briefly introduced below.

3.2. Basic Principles of Numerical Integration. For the motion equation of the satellite, as shown in equation (2), if the state vector x_i at time t_i is known and x_{i+1} at time t_{i+1} is calculated, assuming that the distance h between x_i and x_{i+1} is sufficiently small, then Taylor series expansion is most used as follows:

$$x_{i+1} = x_i + h \left(\frac{dx}{dt} \right)_{t_i} + \frac{h^2}{2!} \left(\frac{d^2x}{dt^2} \right)_{t_i} + \frac{h^3}{3!} \left(\frac{d^3x}{dt^3} \right)_{t_i} + \dots, \quad (3)$$

where p is a positive integer, representing the highest order of Taylor expansion. This is a discretization method. In order to obtain x_{i+1} , we need to find the derivatives of $F(x, t)$ in equation (3). But in precise orbit determination, because $F(x, t)$ is very complex, so Taylor polynomial cannot be directly applied; the usual solution is to use a number of right function values to replace the value of the lower order derivative; to simplify the calculation, this is the basic principle of numerical solution of differential equations.

3.3. Single-Step Method: RK Method and RKF Method. The common method is RK method, which is used to replace the derivative of $F(x, t)$ with the linear combination of several right functions on the interval $[t_i, t_{i+1}]$. The corresponding combination coefficient is determined by Taylor expansion. Since the coefficients to be determined are more than the order, the RK method can have various forms. The

Kutta formula in the fourth-order RK method is given as follows:

$$\begin{cases} x_{i+1} = x_i + \frac{1}{8} (k_1 + 3k_2 + 3k_3 + k_4), \\ k_1 = hf(x_i, t_i), \\ k_2 = hf\left(x_i + \frac{1}{3}k_1, t_i + \frac{1}{3}h\right), \\ k_3 = hf\left(x_i + \frac{1}{3}k_1 + k_2, t_i + \frac{2}{3}h\right), \\ k_4 = hf(x_i + k_1 - k_2 + k_3, t_i + h). \end{cases} \quad (4)$$

The fourth-order RK method is widely used and is suitable for the problems with low accuracy in celestial mechanics. Since RK truncation error is difficult to estimate, Fehlberg's RKF method (Runge-Kutta-Fehlberg), which is a nested RK method, can be used for numerical integration of satellite motion equation with high accuracy requirement. In other words, because the calculation formula of order $n+1$ and order N RK is less different, it only needs to calculate many right functions, but the local truncation error can be obtained simultaneously. Because of this advantage, RKF method is easy to implement on a computer and convenient to change the step size. Moreover, it can maintain the required accuracy and has good stability, so it is the most commonly used method at present. The 6th and 7th order RKF formulas are given as follows:

$$\begin{cases} x_{n+1} = x_i + h \sum_{k=0}^7 c_k f_k + O(h^7), \\ \hat{x}_{n+1} = x_i + h \sum_{k=0}^9 c_k f_k + O(h^8), \\ f_0 = f(x_i, t_i), \\ f_k = f\left(x_i + h \sum_{k=0}^{k-1} c_k f_k, t_i + a_k h\right). \end{cases} \quad (5)$$

The truncation error is

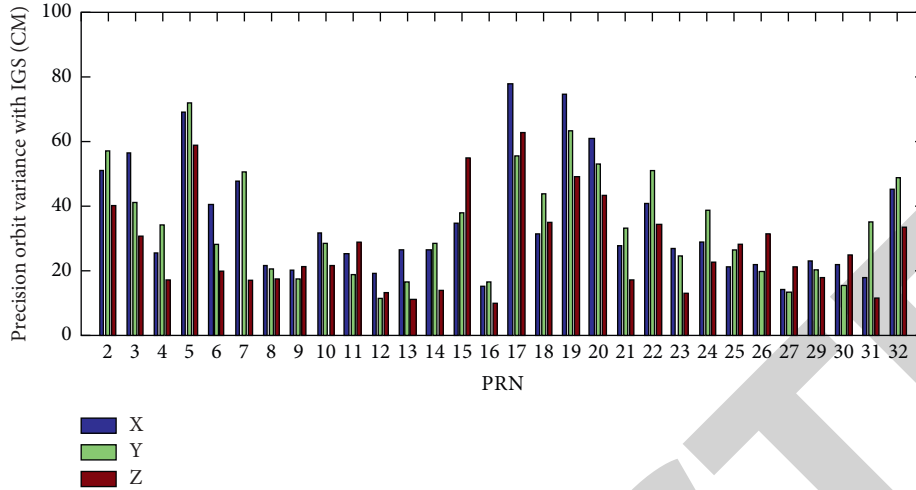


FIGURE 3: The result of comparing GPS satellites' orbit with precise orbit of IGS at 2010.121.

$$T_{i+1} = \frac{11}{270} (f_0 + f_7 - f_8 - f_9)h. \quad (6)$$

3.4. Multistep Method: Prediction and Correction Method Based on Adams Formula. In the numerical integration of the satellite motion equation, the single-step method is only the starting algorithm for the multistep method. When sufficient step points are derived by the single-step method, the high-precision multistep method can be used to calculate forward. Adams and Adams-Cowell methods are commonly used in linear multistep methods. As Adams-Cowell method cannot deal with the atmospheric drag model related to satellite velocity, a simple description of Adams method is given below.

For the initial value problem, the general calculation formula of the linear multistep method is

$$x_{n+1} = \sum_{i=0}^k \alpha_i x_{n-i} + h \sum_{j=-1}^q \beta_j f_{n-j}. \quad (7)$$

When $\beta = 0$, it is explicit; when $\beta \neq 0$, it is implicit. Adams' explicit formula is also known as Adams-Bashforth formula, and the implicit formula is known as Adams-Moulton formula.

In the numerical integration calculation of the satellite motion equation, the two formulas should be used at the same time. Firstly, the explicit formula is used to calculate the approximate value x_{i+1}^0 at the step point of t_{i+1} , and then the implicit formula is used to correct the approximate value to get the required x_{i+1} . In mathematics, this process is called PECE algorithm, that is, the predict-correction algorithm.

4. Calculation Example Analysis

The orbit prediction is based on the previous part of the single-day solution of GPS satellite orbit. The GPS satellite orbit is estimated, the orbit prediction is made using the estimated orbit results, and then the forecast results are

compared with the final orbit of IGS center, and the corresponding orbit accuracy is evaluated.

- (1) 24-hour accuracy of GPS navigation constellation orbit forecast of 26 tracking stations distributed globally:

The result of comparing GPS satellites' orbit with precise orbit of IGS at 2010.121 is shown in Figure 3. The average change in the X direction is 34.85 cm, the average change in the Y direction is 33.98 cm, the average change in the Z direction is 27.35 cm, and the three-dimensional position error is 55.84 cm. The orbit accuracy of GPS satellite forecast is about 55 cm.

- (2) 12-hour accuracy of GPS navigation constellation fast orbit forecast for 38 tracking stations in the world: prediction results of GPS satellite orbit and IGS precise orbit at 2010.121 are shown in Figure 4.

The average change in the X direction is 20.43 cm, the average change in the Y direction is 22.09 cm, the average change in the Z direction is 16.34 cm, and the three-dimensional position error is 34.24 cm, which can meet the orbit forecast of about 35 tracking stations. 24-hour accuracy of 35 cm is required.

- (3) The 24-hour accuracy of GPS navigation constellation fast orbit forecast for 55 tracking stations worldwide: the result of comparing GPS satellites' orbit with precise orbit of IGS at 2010.121 is shown in Figure 5.

The average change in the X direction is 17.87 cm, the average change in the Y direction is 16.00 cm, the average change in the Z direction is 10.77 cm, and the three-dimensional position error is 26.30 cm, which can meet the requirement that the accuracy of orbit prediction segment of about 50 tracking stations is less than 25 cm. The precision of ten days' PRN2 orbits is shown in Figure 6.

The maximum position error of the difference between the estimated orbit and the precision orbit of PRN2 is 25.047 cm, the minimum is 5.662 cm, and the average position error is 15.337 cm.

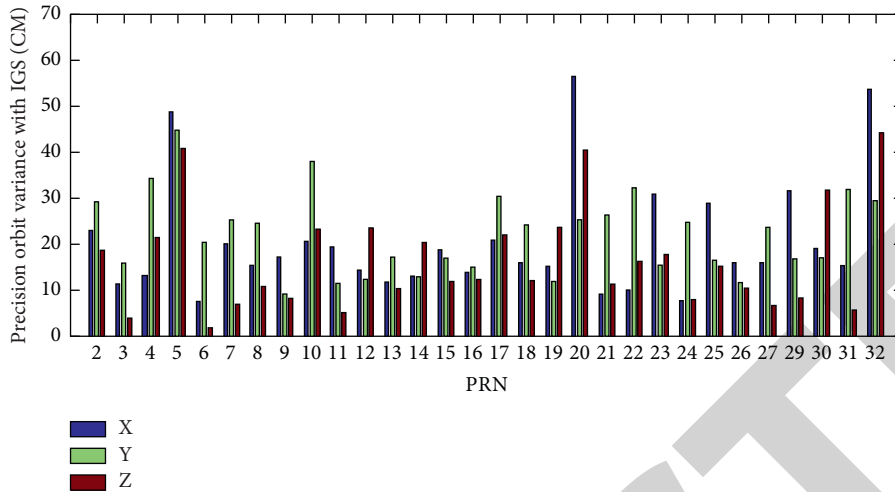


FIGURE 4: Prediction results of GPS satellite orbit and IGS precise orbit at 2010.121.

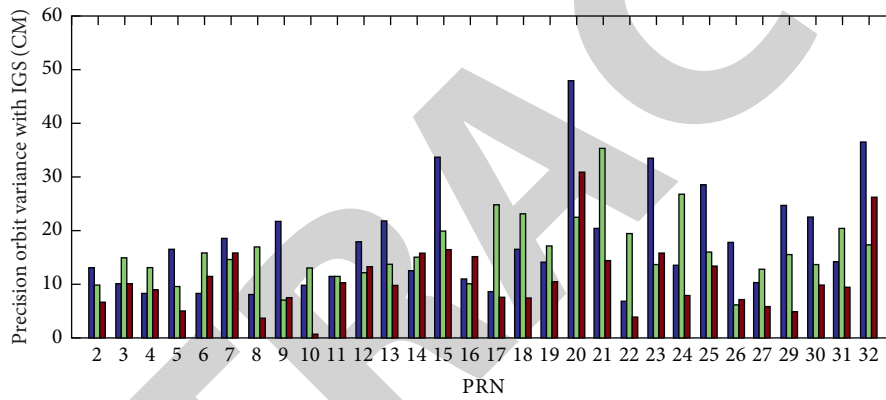


FIGURE 5: The result of comparing GPS satellites' orbit with precise orbit of IGS at 2010.121.

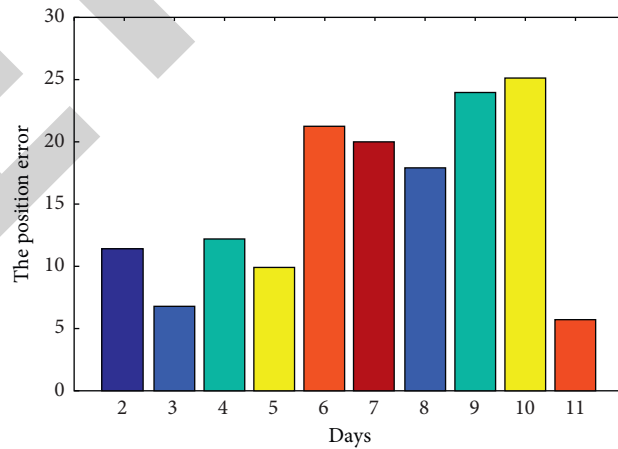


FIGURE 6: The precision of ten day's PRN2 orbits.

5. Conclusion

In this paper, the onboard BDS and GPS simulation data generated by high dynamic signal simulators are used to analyze the autonomous orbit determination accuracy of BDS/GPS with different weight determination strategies, and the autonomous orbit determination accuracy of GPS, BDS, and BDS/GPS is analyzed.

- (1) Helmert variance component estimation and Helmert variance component estimation considering dynamics model are improved significantly in tangential and normal directions compared with empirical weighting method, considering the dynamics model.
- (2) The accuracy of autonomous orbit determination using only GPS observation data is similar to that of joint autonomous. With the addition of BDS observation data, the radial, tangential, and normal position errors of joint autonomous orbit determination using BDS/GPS increase by 3.42%, 5.09%, and 5.44%, respectively. The three-dimensional position error is increased by 4.81%. The three-dimensional position error of BDS/GPS joint autonomous orbit determination is 1.19 m, and the velocity error is 2.35 mm/s.
- (3) When the GPS signal is interrupted, the three-dimensional position error reaches 3.73 m, which can meet the application requirements of some fields of orbit position and provide the possibility to change the situation of China's dependence on GPS.

With the rapid construction and continuous improvement of China's BDS system, it will form a global distribution of satellite navigation system. At that time, the number of visible satellites of BDS will increase and the geometric distribution structure will be improved, and at the same time, it will further reflect the advantages and application prospects of BDS/GPS autonomous orbit determination.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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