E3S Web of Conferences **165**, 03009 (2020) https://doi.org/10.1051/e3sconf/202016503009
CAES 2020

Performance evaluation of GPS / BDS combined single-point positioning based on RTKLIB

Li Yan-yi[1], Huang Jin[1*] ,Tang Ming-xiu[1]

[1]College of Geomatics, Shandong University of Science and Technology , 266590 Shandong Qingdao, China

Abstract. In order to evaluate the performance of GPS / BDS, RTKLIB, an open-source software of GNSS, is used in this paper. In this paper, the least square method, the weighted least square method and the extended Kalman filter method are respectively applied to BDS / GPS single system for data solution. Then, the BDS system and GPS system are used for fusion positioning and the positioning results of the two systems are compared with that of the single system. Through the comparison of experiments, on the premise of using the extended Kalman filter method for positioning, when the GPS signal is not good, BDS data is introduced for dual-mode positioning, the positioning error in e direction is reduced by 36.97%, the positioning error in U direction is reduced by 22.95%, and the spatial positioning error is reduced by 16.01%, which further reflects the advantages of dual-mode positioning in improving a system robustness and reducing the error.

1 Introduction

With the continuous development and improvement of GNSS technology, the research on related principles, equipment and data processing methods has gradually increased [1-3]. In terms of navigation and positioning, if the receiver only uses a single GNSS system for navigation and positioning, its accuracy will certainly not be as high as that of the multi-mode receiver [7-9], and with the continuous promotion of the application scope of China's Beidou system, the research on the data processing method integrating Beidou and other satellite systems will gradually become a research hotspot [4-7].

At present, each satellite system has its own data interface specification[8,9]. Therefore, how to integrate resources and make each system compatible with each other is a research focus now and in the future. In this paper, based on the RTKLIB package of GNSS, the single point positioning method is used to compare the performance of GPS single system, BDS single system, GPS and BDS double system and the bad environment, and further study the advantages of combining multiple satellite navigation system data, so as to provide some reference and inspiration for GNSS multi system joint positioning.

2 Experimental platform

The simulation platform in this paper is RTKLIB. RTKLIB is an open source platform based on C language, which can be used for GNSS standard positioning and precise positioning. It includes the following GUI and Cui applications, as shown in Table 1.

Table 1. RTKLIB application

Function	GUI AP	CUI AP
AP launcher	RTKLAUNCH	-
Real-Time Positioning	RTKNAVI	RTKRCV
Communication Server	STRSVR	STR2STR
Post-Processing Analysis	RTKPOST	RNX2RTKP
RINEX Converter	RTKCONV	CONVBIN
Plot Solutions and Observation Data	RTKPLOT	-
Downloader for GNSS Products and Data	RTKGET	-
NTRIP browser	SRCTBLBROWS	-

This paper uses rtkpost application, which is mainly used for post-processing and positioning of navigation data. The interface function mainly used for posteriori positioning is postpos function, and the call relationship of each function during calculation is shown in Figure 1：

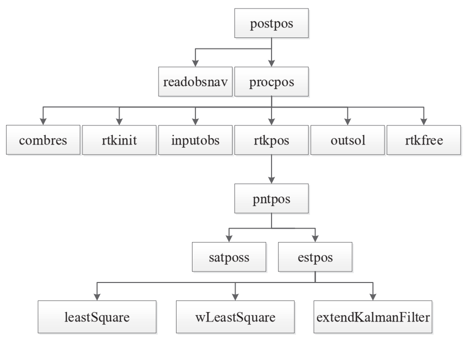

Fig.1. Call structure of postpos function

* Corresponding author: 201801020510@sdust.edu.cn

The processing flow is as follows:

Step1. Prepare the navigation data file to be processed, configure the processing options, result output options, file options in the program, and call the postpos function.

Step2. Call the readobsnav function to read the observation files and navigation data files, and finally call the procpos function to process the observation data and navigation data files read from each epoch.

Step3. When processing each epoch, first call inputobs to read out the results of the first epoch, then call rtkpos to locate the single epoch, calculate the result and call the outsol output result, so that the procpos processing is finished until all the epoch of the current observation data is processed.

Step4. Because this paper uses single point positioning, rtkpos function calls pntpos single point positioning function. In this function, satpos function is called first to solve the satellite position, and then estpos is called to solve the base station position.

Step5. When calling the estpos function, the source code uses the least square method, which is implemented in the function LSQ.

The three algorithms to be studied in this paper are least square (LS), weighted least square (WLS), extended Kalman filter (EKF). Therefore, the functions corresponding to WLS method and EKF method are added to the estpos function, and the incompatibility between Beidou and GPS positioning is improved. Based on the standard data of the laboratory, the single point positioning mode is selected, and the positioning calculation is carried out under the single GPS system, single BDS system and dual GPS / BDS system respectively, and the experimental phenomena are observed.

3 Analysis of single system positioning results of BDS / GPS

First, select a single system for positioning calculation and analysis. The original data is the observation data and navigation data from 10:00:00 on November 10, 2016 to 10:59:59 on November 10, 2016 when GPS is used. The satellite visual image of this period is shown in Figure 2, and the satellite sky map is shown in Figure 3.

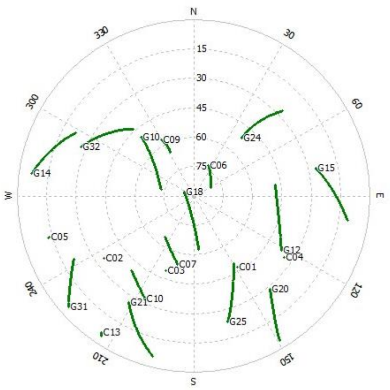

Fig.2. Satellite visibility of raw data

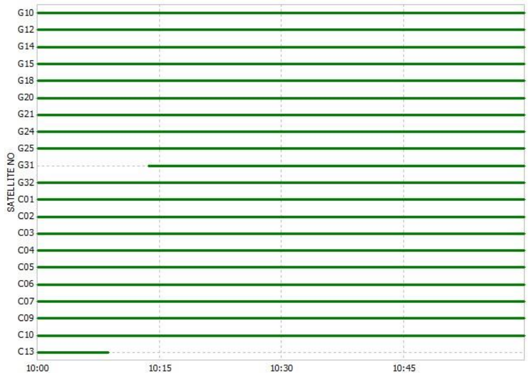

Fig.3. Satellite sky map of original data

The 120 second data in the original data is taken for analysis, and the interval of 1 second is one epoch. By solving the data of each epoch, the solution error of GPS system as shown in Figure 3 and BDS system as shown in Figure 4 can be obtained. The horizontal axis of the coordinates in Fig. 4 and Fig. 5 is the time, 0 seconds from the first epoch; the vertical axis of the coordinates is the error between the solution result of each epoch and the real coordinates of the point, the unit is meters, and the coordinate system is the coordinates under the ENU station center coordinate system (with the accurate position calibrated by the receiver as the reference point). Different curves represent the positioning solution using different methods.

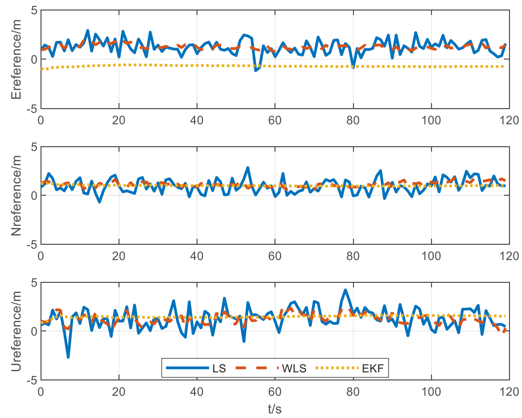

Fig.4. GPS system positioning solution error

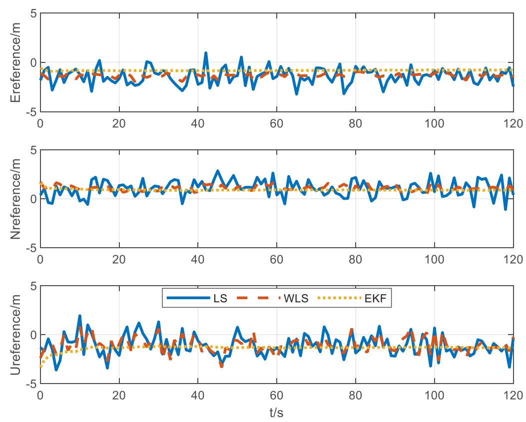

Fig.5. Positioning solution error of BDS system

Figure 6 and figure 7 below are the location error diagrams of the two systems in the two-dimensional plane. The red origin represents the real position of the reference station, and the other blue scatter represents the solution value of each epoch.

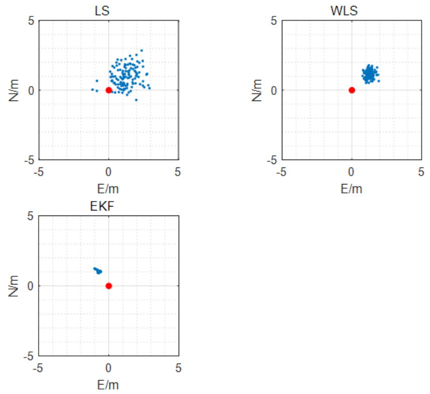

Fig.6. Two dimensional coordinate positioning error diagram of GPS system

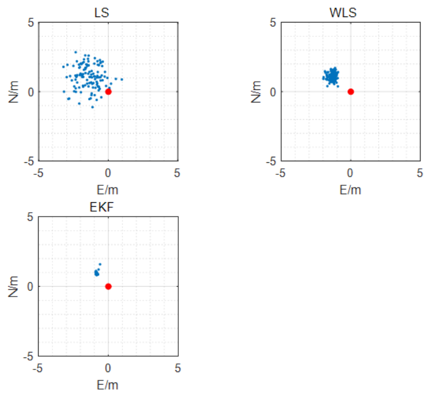

Fig.7. Two dimensional coordinate positioning error diagram of BDS system

The experimental results show that the error of LS method is very large, because the observation noise of the satellite is not used in the calculation of each epoch, and the flow station itself may have the influence of high-rise block and other environmental factors, the quality of data received by each satellite is not the same. If the LS method is used, it is equivalent to considering the reliability of the observation data of each satellite as the same, so this result is produced. If the errors of satellite position, satellite clock, pseudo range observation value, troposphere and ionosphere parameters of each observation satellite are taken into account, the magnitude of observation noise of each satellite can be calculated. Based on this observation noise, a weight matrix can be constructed, which can be solved iteratively and the WLS solution of the system can be obtained. From the error curve of EKF method, it can be seen that EKF method is not so sensitive to the change of system observation data. Even if the observation changes greatly in a certain epoch, EKF method can also adjust the Kalman gain adaptively, making the observation curve tend to a relatively stable value very gently. All in all, through data analysis, the accuracy of EKF is better than that of WLS, and the positioning accuracy of WLS is better than that of LS.

4 Analysis of GPS + BDS dual mode positioning results

4.1 GPS + BDS dual-mode positioning effect in normal environment

In the previous part, the results of single-mode positioning are analyzed. In this section, the results of GPS / BDS dual-mode positioning are analyzed. Compared with the single-mode system, the root mean square error (RMSE) of each method is given. At the same time, in order to show the advantage of strong reliability of double system positioning, this paper also does the positioning calculation of double system and single system in the case of a small number of GPS satellites, and compares the root mean square error of positioning in the two modes.

First of all, using the same data as the previous section, choose GPS / BDS dual-system navigation, based on three different methods of GPS / BDS dual-mode positioning, you can get the positioning solution error of the dual-system and the solution situation on the two-dimensional plane, as shown in Figure 8 and figure 9, integrate the results of the previous part, calculate the root mean square error of each positioning method, and get Table 2.

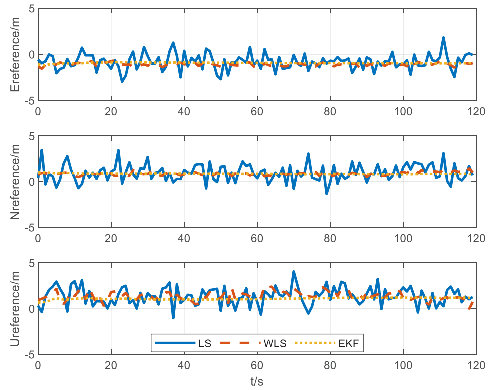

Fig.8. Double system positioning solution error

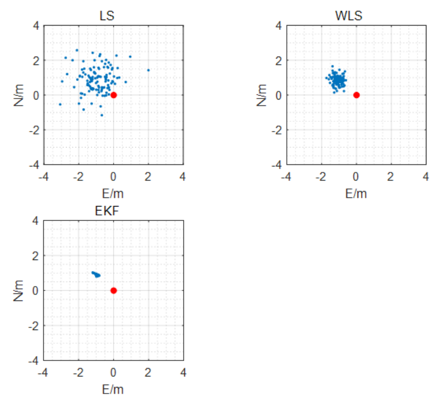

Fig.9. Two dimensional coordinate positioning error diagram of double system

 https://doi.org/10.1051/e3sconf/202016503009

We can see clearly from table 2 below that the positioning accuracy of BDS system is basically the same as that of GPS system, while the overall performance of double system positioning is higher than that of single system, but it is still in an order of magnitude, and there is no significant improvement in quality. At the same time, it can be seen intuitively that whether single-mode positioning or dual-mode positioning, the accuracy of the algorithm is the highest in EKF method, followed by WLS method, and the lowest in LS method. However, if a system fails in a short time, the number of observable satellites decreases, or the number of observable satellites drops sharply due to urban canyon effect in the city, the reliability of dual system positioning can be truly reflected. Next, we will make experimental verification on this aspect.

Table 2. Comparison of positioning errors

Method	RMSE_E/m	RMSE_N/m	RMSE_U/m	RMSE_3D/m
BDS_LS	1.6467	1.3537	1.4533	2.5800
BDS_WLS	1.3699	1.1494	1.3389	2.2339
BDS_EKF	0.8211	0.9041	1.4024	1.8597
GPS_LS	1.3959	1.2042	1.5324	2.3973
GPS_WLS	1.2710	1.1589	1.3514	2.1875
GPS_EKF	0.8128	1.0007	1.4895	1.9699
MIX_LS	1.1364	1.0885	1.6456	2.2769
MIX_WLS	1.0924	0.8905	1.4504	2.0224
MIX_EKF	0.9458	0.8594	1.4165	1.9078

4.2 The effect of GPS + BDS dual-mode positioning when the number of GPS satellite observations is small

Because it is difficult to find the data to meet the experimental requirements, based on this data, after some processing, some GPS satellites of this section of data can be removed, and the removed satellite visual image is shown in Figure 10. On this basis, the experiment is carried out again, and it is concluded that the positioning results of GPS system are as shown in FIG. 11 and FIG. 12, and the positioning results of dual system are as shown in FIG. 13 and FIG. 14. At the same time, the RMS error value of Table 3 is obtained, as shown below.

Fig.10. Satellite visualization after excluding some GPS satellites

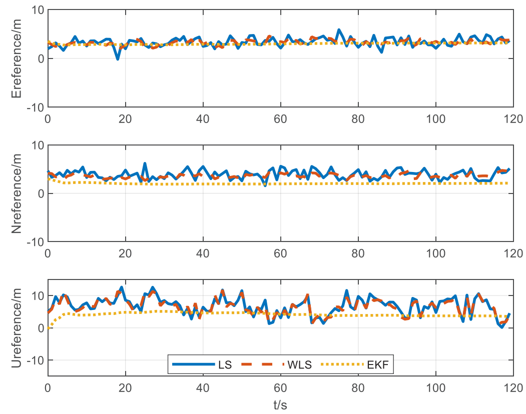

Fig.11. Error diagram of GPS system positioning solution under the condition of few GPS satellites

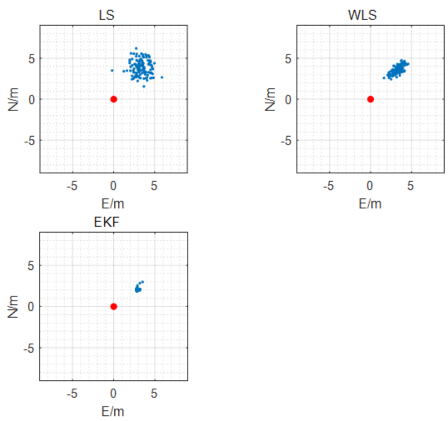

Figure.12. Two dimensional coordinate positioning error diagram of GPS system with few GPS satellite

Table 3. Comparison of positioning errors with few GPS satellites

Method	RMSE_E/m	RMSE_N/m	RMSE_U/m	RMSE_3D/m
BDS_LS	1.6467	1.3537	1.4533	2.5800
BDS_WLS	1.3699	1.1494	1.3389	2.2339
BDS_EKF	0.8211	0.9041	1.4024	1.8597
GPS_LS	3.6075	4.1667	7.3357	9.1754

GPS_WLS	3.2962	3.6005	7.0476	8.5731
GPS_EKF	2.9916	2.0334	4.1723	5.5220
MIX_LS	2.4844	3.1359	3.9270	5.6061
MIX_WLS	2.3117	3.1250	3.9492	5.5413
MIX_EKF	1.8851	2.3079	3.2153	4.3839

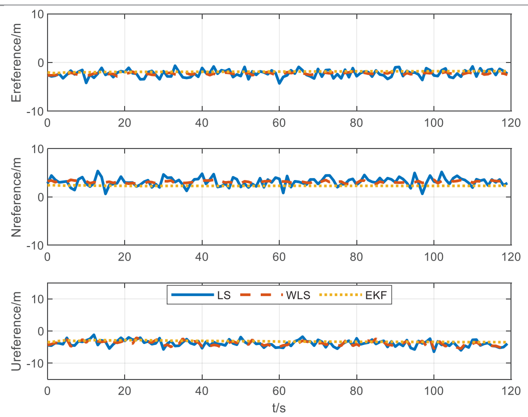

Fig.13. Positioning calculation error of two systems with few GPS satellites

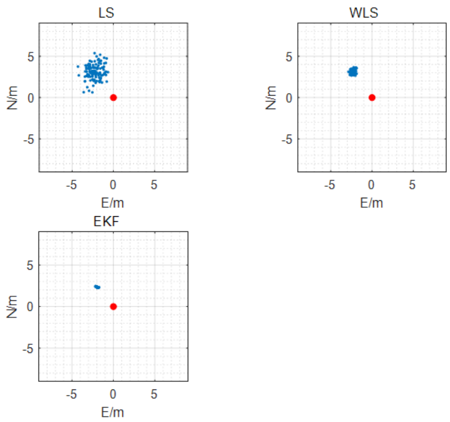

Fig.14. Two dimensional coordinate positioning error of two systems with few GPS satellites

It can be clearly seen from these charts that, because of the same data, the BDS positioning error is no different from that before. However, the number of GPS satellites that can be observed in this data is becoming smaller, the GPS positioning error is rising sharply, and the calculation error of some epoch is more than 5m. In contrast, the positioning accuracy of the double system is always between GPS system and BDS system. This is because when GPS is lack of satellites and the positioning accuracy is very poor, BDS system can get a compromise result by integrating with GPS. Although the accuracy is reduced, the stability of the system is improved. In the last section of this paper, we know that the accuracy of the algorithm is the highest of EKF method, so on the premise that EKF method is used for positioning, BDS data is introduced for dual-mode positioning in the case of poor GPS signal, the positioning error in E direction is reduced by 36.97%, the positioning error in U direction is reduced by 22.95%, and the overall space positioning error is reduced by 16.01%. These data further show the advantages of dual-mode positioning in improving system robustness and reducing errors.

5 Summary

Based on the RTKLIB open source platform, this paper uses LS algorithm, WLS algorithm, EKF algorithm to solve the location problem in the normal observation situation, the reduction of GPS satellite number and the simulation of the harsh environment. It can be concluded that the reliability of the dual system is better than that of the single system, highlighting the advantages of developing the joint positioning of multiple systems.

Additional information

Funding

This research was supported by the Major Science and Technology Innovation Projects of Shandong Province [grant number 2019JZZY020103].

References

1. Kaplan E.D. Hegarty C., Kou Yanhong translated GPS principles and applications [M]. Beijing: Electronics Industry Press, 2012 .
2. Liu Yanliang, Zhang Haiping, Xu Yantian, et al. Status and progress of global satellite navigation systems [J]. Journal of Navigation and Positioning, 2019, 7 (1): 18-21.
3. Wang Qiang. Design and implementation of GPS / BD2 dual-mode receiver positioning algorithm [D]. Nanjing: School of Electronic Science and Engineering, Southeast University, 2016.
4. Wang Yixi, Mi Jinzhong, Xu Yantian, etc. Research on BDS / GPS / GLONASSRTK positioning algorithm [J]. Bulletin of Surveying and Mapping, 2018 (3): 9-13 ..
5. Miao Yuewang, Zhou Wei, Qin Wenzhen, et al. Analysis of Beidou relative positioning accuracy [J]. Beijing Surveying and Mapping, 2017 (S1): 37-39.
6. Wu Chunjie, Hu Yukun, Peng Pan BDS / GPS Observation Quality Evaluation and Analysis [J]. Beijing Surveying and Mapping, 2017 (S1): 32-36.
7. Bai Zhengdong, Wu Gangxiang, Ren Chang. Quality inspection and analysis of Beidou observation data [J]. Bulletin of Surveying and Mapping, 2014 (6): 10-13.
8. Michael J.Dunn. NAVSTAR GPS Space Segment/Navigation User Segment Interfaces : IS-GPS-200J. 25-APR-2018[S]. USA: Global Positioning Systems Directorate，2018.
9. China Satellite Navigation System Management Office. Beidou Satellite Navigation System Space Signal Interface Control File (public service signal BII, version 3.0) [S]. Beijing: China Satellite Navigation System Management Office, 2019.