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

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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.

| Function                          | GUI AP | CUI AP |
|----------------------------------|--------|--------|
| AP launcher                      |        |        |
| 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                    |        |        |

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

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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.

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.

Figure 6 and figure 7 below are the location error diagrams of the two systems in the two-dimensional
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.

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.
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.

| 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   | 2.3993    |
| GPS_WLS  | 1.2710   | 1.1589   | 1.5514   | 2.1875    |
| GPS_EKF  | 0.8128   | 1.0007   | 1.495    | 1.9699    |
| MIX_LS   | 1.1364   | 1.0885   | 1.6456   | 2.2769    |
| MIX_WLS  | 1.0924   | 0.8905   | 1.4904   | 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.

| 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    |

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    |
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

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