

The Application of BDS/GPS/GLONASS Data Fusion in FAST Measurement

Benning Song, Lichun Zhu, Dongjun Yu and Hui Yuan

Abstract Five-hundred-meter Aperture Spherical Radio Telescope (FAST) is a Chinese mega-science project to build the largest and most sensitive single dish radio telescope in the world. To achieve precise positioning of FAST feed cabin, we need all-weather, large-span and high-precision real-time dynamic measurements. The coarse-adjusting measurement of the FAST feed support, uses RTK (Real Time Kinematic) with the fusion of BDS/GPS/GLONASS. This paper introduces the RTK measurement program of FAST feed support coarse-adjusting system. Combined with the measured data, it indicates the importance of BDS/GPS/GLONASS data fusion. We also use total station to evaluate the accuracy of RTK measurement. The results show that the accuracy of RTK with fusion of BDS/GPS/GLONASS meets the technical requirements, which can guarantee the normal observation and safe operation of FAST.

Keywords FAST · RTK · BDS · Data fusion · Application

1 Introduction

FAST is a Chinese mega-science project to build the largest and most sensitive single dish radio telescope in the world. It is designed independently by our scientists. The site of FAST is located in Qiannan, Guizhou province. Compared with the existing international giant single-dish radio telescope, there are three main innovations:

1. the karst depression used as the site, which is large to host the 500-m and deep to allow a zenith angle of 40° ;

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2. the active main reflector correcting for spherical aberration on the ground to achieve a full polarization and a wide band without involving complex feed systems;
3. the light-weight feed cabin driven by cables and servomechanism plus a parallel robot as a secondary adjustable system to move with high precision.

Six suspension cables are driven and supported by six towers and capstans, which are uniformly distributed on a circle with a diameter of 600 m. Feed cabin is dragged by these suspension cables, which makes it to be able to move within a 206 m diameter meter range in the altitude of 150 m. Based on the astronomical plan and measurement feedback, we operate the feed cabin and reflectors synchronously to achieve the high the high accuracy astronomical track movement. Figure 1 shows the FAST panorama and optical geometry.

Main structure of FAST is moving when we observe, and there is no solid connection between the reflector and the feed cabin. Therefore, the large-span, high-sampling rate and high-precision real-time dynamic positioning, is the key to successful construct FAST feed with no support of platform.

The BeiDou Navigation Satellite System (BDS) is a global satellite navigation system designed and developed by China. The BDS was officially put into operation in December 27, 2012. It already has the ability of independent RTK positioning with double frequency. Researches show that, the fixed rate and the reliability of fuzzy degree solution are remarkably improved by the combination of BDS and GPS. In the case of short baseline, the accuracy of the dynamic positioning measured by carrier phase differential, is improved over 20% by the combination of BDS/GPS than the single GPS. The satellite navigation and positioning system can provide all-weather and real-time 3D coordinates of the vector, and it has the characteristics of non-accumulation of error, high sampling rate and so on. Using RTK measurement technique with multi satellite fusion, we can achieve the accuracy of horizontal ± 10 mm and vertical ± 20 mm.

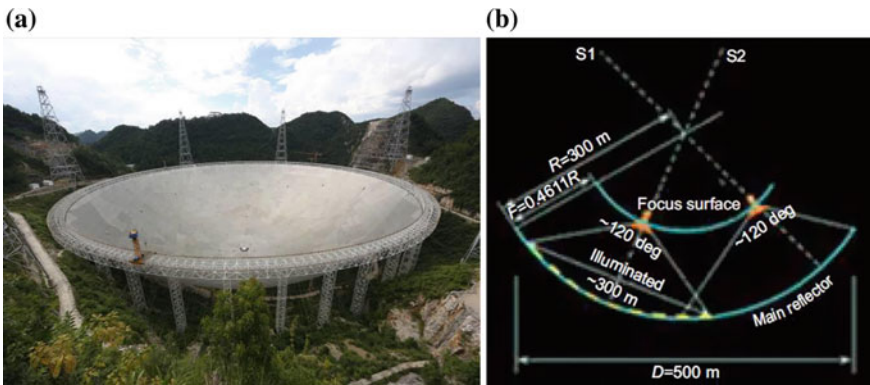


Fig. 1 FAST panorama (a) and optical geometry (b)

This paper introduces the RTK measurement of FAST feed support coarse-adjusting system. Combined with the measured data, it indicates the importance of BDS in the fusion.

2 The RTK Measurement of FAST Feed Support Coarse-Adjusting System

The FAST feed cabin system has no platform support and is composed by the three-tier adjustment agencies in series (Fig. 2): star frame, AB axes and Stewart fine-adjusting platform. Star frame is dragged by cables to achieve coarse position determination. AB axes mechanical structure is designed to determine the coarse attitude determination. Stewart fine-adjusting platform system is for the precise adjustment of the position and attitude.

2.1 Technical Specifications and Requirements

As the feedback source of the feed support control system, the feed support measurement system includes two parts: coarse-adjusting system and fine-adjusting system. The technical specifications and requirements of the feed support measurement system is:

1. Coarse-adjusting system:
 Location accuracy: ± 17 mm;
 Measurement frequency: 5 Hz;

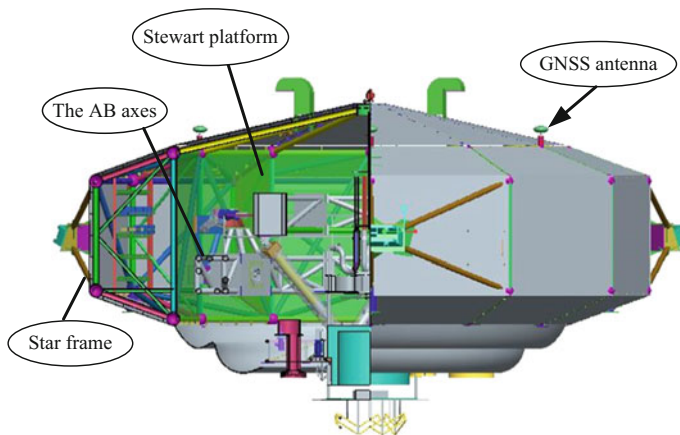


Fig. 2 The main structure of the feed cabin

2. Fine-adjusting system:

Location accuracy: ± 3 mm;

Measurement frequency: 5 Hz;

In order to meet the requirements, coarse-adjusting system measurement uses RTK and total station measurement (Fig. 3). The RTK measurement can guarantee the safe operation of FAST when the total station cannot work, such as rain, fog and other inclement weather. In addition, the RTK measurement data can be used to verify whether the total station lost target or target confusion, and drive the total station pointing to the correct target.

2.2 RTK Measurement

1. RTK base station is installed on the surrounding mountain peak with a wide view.
2. The GNSS antennas of RTK rover stations are installed at the top of star frame, and its receivers are inside the feed cabin. The antennas are connected to the receivers through the filter.
3. The difference data of the base station is transmitted to the rover station receiver in real time by the optical fiber.
4. The serial server collects the measurement data obtained by rover station, and sends them to the measurement server.

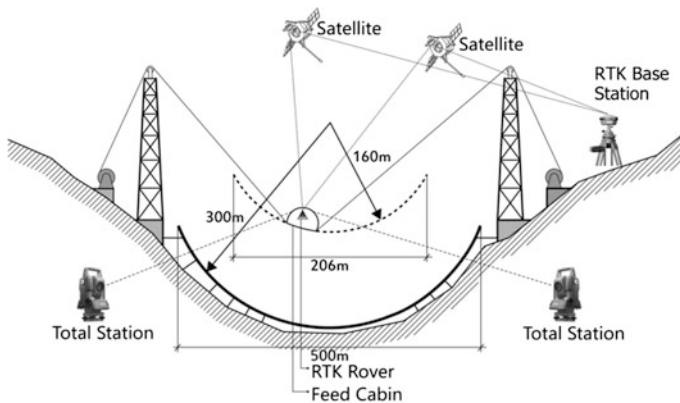


Fig. 3 FAST feed support coarse-adjusting measurement

2.3 Position and Attitude Solution

First of all, to establish the FAST measurement and control coordinate system: the center of the reflector sphere is the origin of the coordinate; the vertical direction is the positive direction of Z axis; the north direction is the x axis, and the y axis direction is determined by the right-hand rule. The following coordinate data are the coordinates in the FAST measurement and control coordinate system.

Based on the calibrated coordinates of GNSS antennas, TPS targets and AB axes center in the initial state of feed cabin, we establish the local Cartesian coordinate system where the origin G1 and $\overrightarrow{G1G2}$ is x-axis. The unit matrix of local coordinate system $M = [\vec{x} \ \vec{y} \ \vec{z}]$ can be obtained in the initial state as the following:

$$\begin{cases} \vec{x} = \frac{\overrightarrow{G1G2}}{|\overrightarrow{G1G2}|} \\ \vec{z} = \frac{\overrightarrow{G1G2} \times \overrightarrow{G1G3}}{|\overrightarrow{G1G2} \times \overrightarrow{G1G3}|} \\ \vec{y} = \vec{x} \times \vec{z} \end{cases} \quad (1)$$

Similarly, by the GNSS measurement, we can calculate the unit matrix of local coordinate system $N = [\vec{x} \ \vec{y} \ \vec{z}]'$ at any time. Then, the attitude K of the star frame in the global coordinate can be obtained as:

$$K = M * N^{-1} \quad (2)$$

The real-time position of AB axes center O_{ab} is:

$$[x' y' z']' = K * \overrightarrow{G1O_{ab}}' + [x_{G1} y_{G1} z_{G1}]' \quad (3)$$

3 The Importance of BDS/GPS/GLONASS Data Fusion

Because FAST is located in the Karst depression, the surrounding mountains and the reflectors can cause a lot of problems, if we only use the common GPS + GLONASS RTK measurement model. The number of available satellites decreases, and multipath effects happen in the raise and fall of feed cabin. These can affect the RTK measurement accuracy. Therefore, to improve, the RTK measurement accuracy, we need to add more high-precision and high-reliability visible satellites. Based on the rapid development of the BeiDou navigation and positioning system and its regional positioning advantages in China, we proposed to use the RTK measurement of BDS/GPS/GLONASS data fusion. Figures 5 and 6 show

that the static RTK measurement data from GPS + GLONASS and BDS + GPS + GLONASS at the lowest point. The collecting time is respectively 16 and 24 h, and the measured frequency is 5 Hz (Fig. 4).

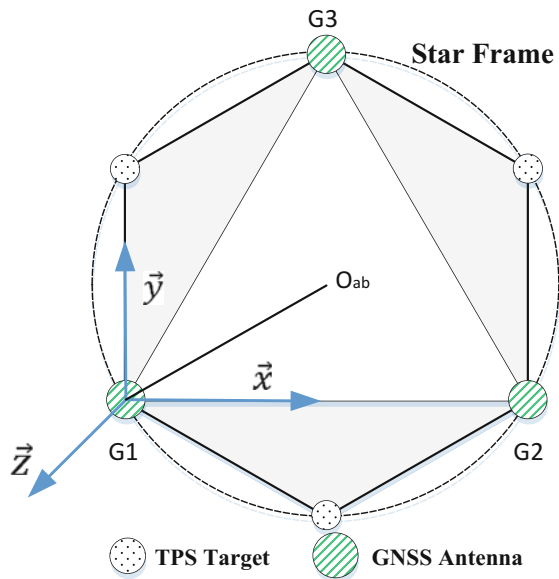


Fig. 4 Layout of GNSS antenna and TPS target

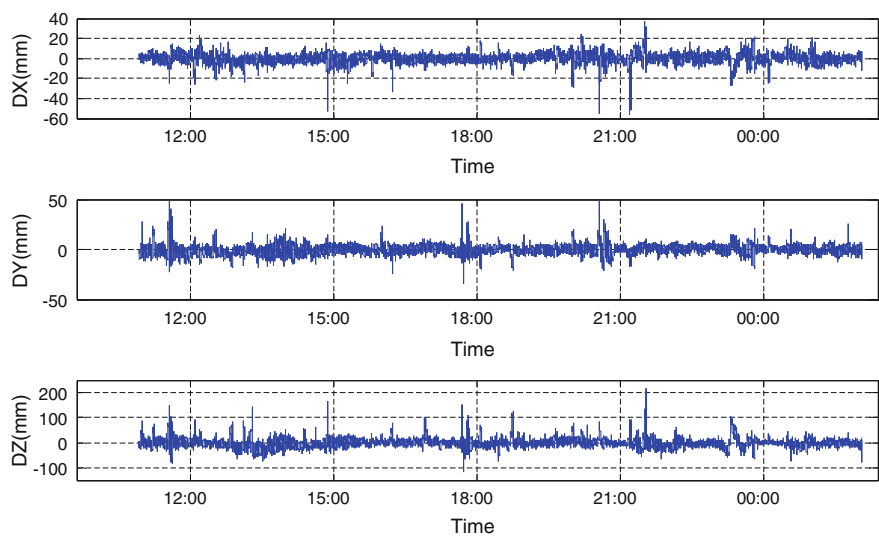


Fig. 5 Deviation of the GPS + GLONASS measured data (the lowest point)

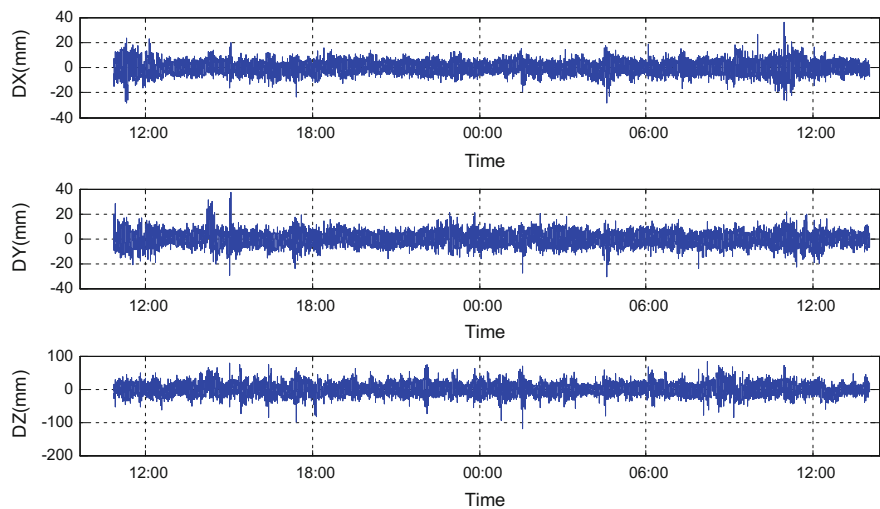


Fig. 6 Deviation of the BDS + GPS + GLONASS measured data (the lowest point)

- The improvement of combining BDS are
1. RMS decreases in all directions: horizontal direction from 5 mm reduced to 3.6 mm; elevation direction from 18 mm reduced to 12 mm.
 2. The range of data becomes smaller: horizontal direction from 50 mm reduced to 40 mm; elevation direction from 230 mm reduced to 120 mm.

Figure 7 shows the number of BDS/GPS/GLONASS available satellites at the lowest point (24 h). The minimum number of GPS and GLONASS available

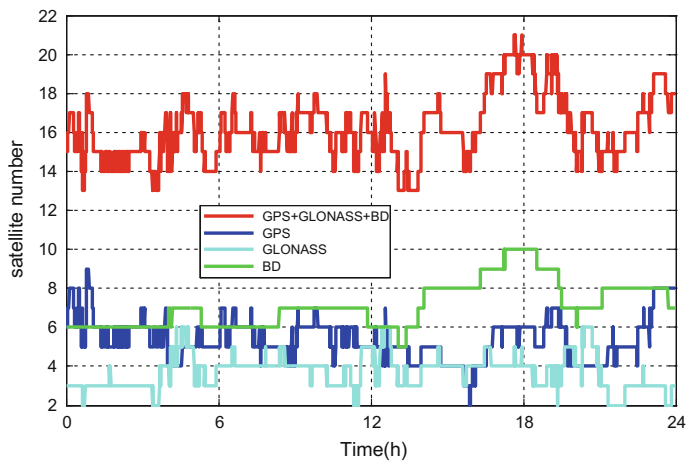


Fig. 7 The number of available satellites at the lowest point

Table 1 Comparative the RMS of measurements before and after the added BDS (mm)

	X_RMS	Y_RMS	Z_RMS
GPS + GLONASS	5	4.6	18.8
BD + GPS + GLONASS	3.6	4	12.9

satellites is two. At this time, only using the single satellite GPS, GLONASS, or double satellite GPS + GLONASS RTK measurement will not obtain the fixed solution. The minimum number of BeiDou satellite is five, which makes it available to obtain a fixed solution. However, the BDS + GPS + GLONASS fusion RTK will get more stable and reliable measurement data to ensure the safety during the raise and fall of feed cabin (Table 1).

4 Analysis of RTK Measurement Accuracy

The measurement accuracy of total station is 0.6 mm + 1 ppm, higher than RTK accuracy. By comparing total station and RTK measurement data on the trajectory of feed cabin, we can analyze RTK accuracy.

Select the data measured on January 4, 2016 as a comparison. Figure 8 shows the trajectory of AB axes center (the movement speed is 24 mm/s).

The total station data is considered as the true value, to compare with RTK data. Figure 9 shows the deviation of RTK measurement data in the horizontal direction and elevation direction.

As can be seen from Fig. 9, when the speed of feed cabin goes up to 24 mm/s, except for some bad points. The deviation range of RTK measurement data is ±10 mm in the horizontal direction and ±20 mm in elevation direction.

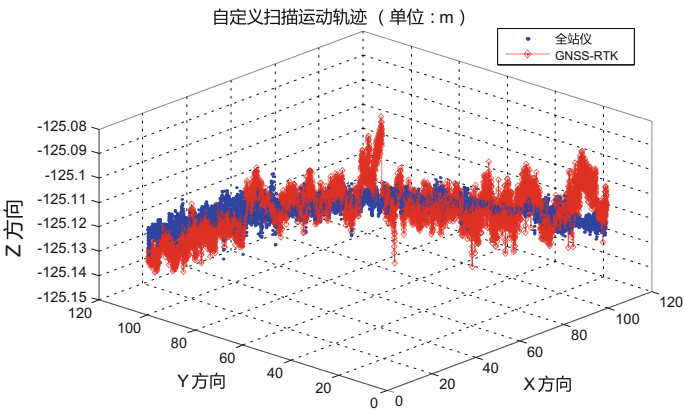


Fig. 8 The trajectory of AB axis center

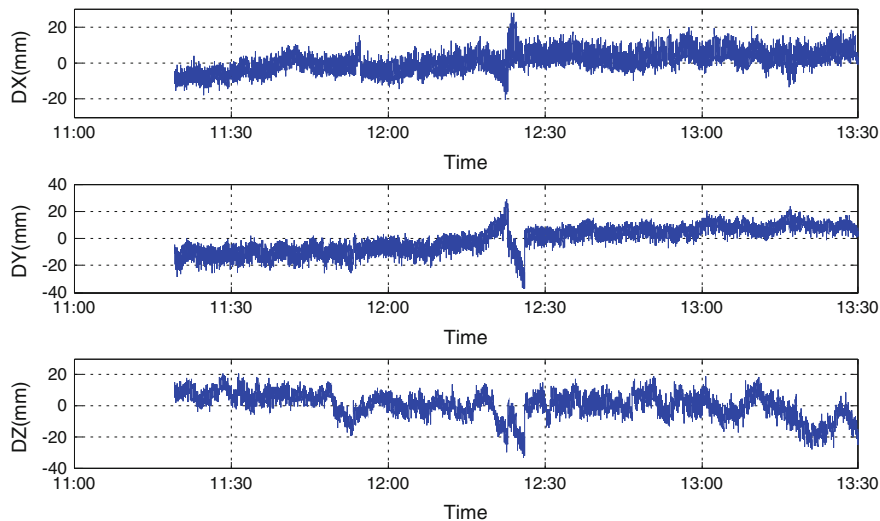


Fig. 9 Deviation of measured data

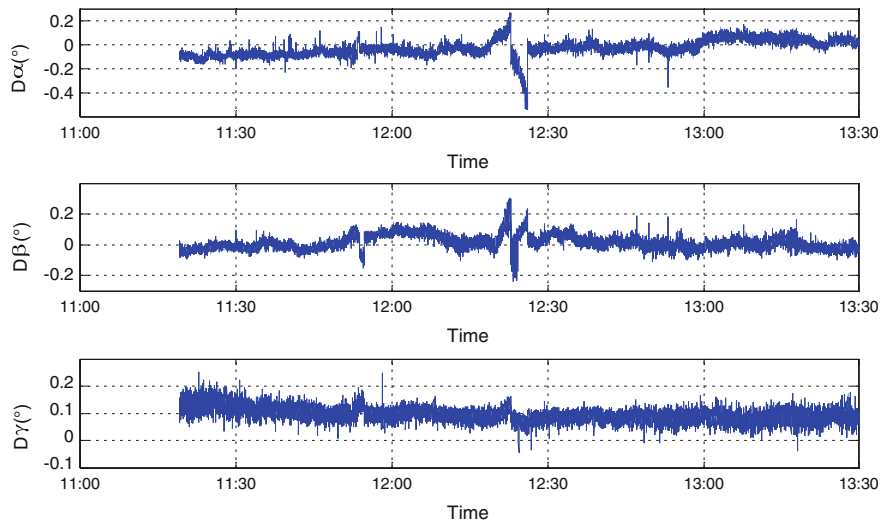


Fig. 10 Deviation of attitude angle

Pre-analysis shows that, the reason why this the bad points jumped away from the average, is that the location of the feed compartment near the surrounding mountains at that time. The deviation range of spin angle is $\pm 0.1^{\circ}$ (in Fig. 10). The RMS of RTK measurement data is in Table 2.

Table 2 RMS of RTK measurement data(mm)

	X	Y	Z
RMS	3.8818	5.5179	7.5990

The above data show the measurement accuracy of fusion RTK. In actual astronomical observation, the running speed of feed cabin is 11 mm/s. With the reduction of the speed (24–11 mm/s), the measurement accuracy of fusion RTK will be improved. Therefore, the accuracy of BDS/GPS/GLONASS fusion RTK measurement meets technical requirements, and it can guarantee the normal observation and safe operation of FAST.

5 Summary and Conclusions

Taking positioning advantage of the BeiDou satellite navigation system in China, we combine this BDS with GPS and GLONASS satellite navigation and positioning system, to do the RTK measurement. It can reach location accuracy of the feed cabin (≤ 17 mm) for astronomical observation, and guarantee the safe operation of FAST when the total station cannot work, such as rain, fog and other inclement weather. In the future, we will adopt the method of filtering to improve measurement accuracy and stability of fusion RTK.

In addition, the successful application of fusion RTK measurement in FAST, provides an effective solution for the real-time dynamic positioning of all weather and high precision for the upcoming large astronomical telescopes.

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