

Research on Special Vehicle Attitude Measurement Technology Based on High-Precision Positioning System

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Abstract. The Beidou/GPS high-precision differential positioning system was built for attitude detection of special vehicles. Based on this system, the effects of single and double baseline antennas on attitude measurement were studied, and the orientation accuracy of the system was verified. The experimental results show that under the dual-baseline antenna measurement, the measurement of the attitude angle of a special vehicle can be satisfied, which has certain engineering practical value for realizing the intelligent assessment of special vehicles.

1. Introduction

With the advancement in weaponry and equipment technology, one-button testing (free testing) and one-button launching have entered the development of models, and the operational automation of traditional key positions such as missile testing and launch has been increasingly improved, so the impact of bugler operational skills of the performance of missile weapon equipment is weakening. But the development trend in the field of special vehicle driving is just the opposite. The advances in weapon and equipment technology have further enhanced the dependence on special vehicle driving buglers and higher requirements for driving skills. With the continuous advancement of satellite positioning and navigation technology, especially the maturity of China's Beidou centimeter-level high-precision positioning technology [1], its real-time and accurate positioning function has been widely used in various industries. Based on high-precision positioning system, this paper proposes to install the mobile receiver on the special vehicle to detect the attitude information of the vehicle in real time, which is used as the basis for the driver's driving skill evaluation.

2. High-precision differential positioning system composition and basic principles

For high-precision GNSS measurements, it is necessary to use real-time kinematic (RTK) positioning [2]. That is to say, when two GNSS receivers are not far apart, the satellite signal propagation path and propagation process of the two receivers have a high degree of spatial and temporal correlation, so satellite clock bias, tropospheric error, ionospheric error, and other GNSS error sources are also highly correlated. And the above error is eliminated by means of difference between two receiver pseudoranges or carrier observations. The basis of differential positioning is to use a receiver whose position is known accurately as a reference station, otherwise the differential positioning is meaningless.

In this article, when building the system, the mobile station is installed on the test vehicle, and the reference station is installed on the top of the experimental building. The reference station is the



reference framework of the entire positioning system. It receives the position information transmitted by the satellite and compares this signal with the known precise position of the reference station to obtain the differential calibration information of the reference station. Base station differential correction information is broadcasted in real-time and high-precision carrier phase differential data and initial coordinates for vehicle receivers are provided in real time through a wireless data radio station [4]. The signal of the onboard mobile station receiving space satellite and the base station difference data are solved by RTK in real time, and the high-precision real-time coordinates of centimeter-level are obtained. As shown in figure 1.

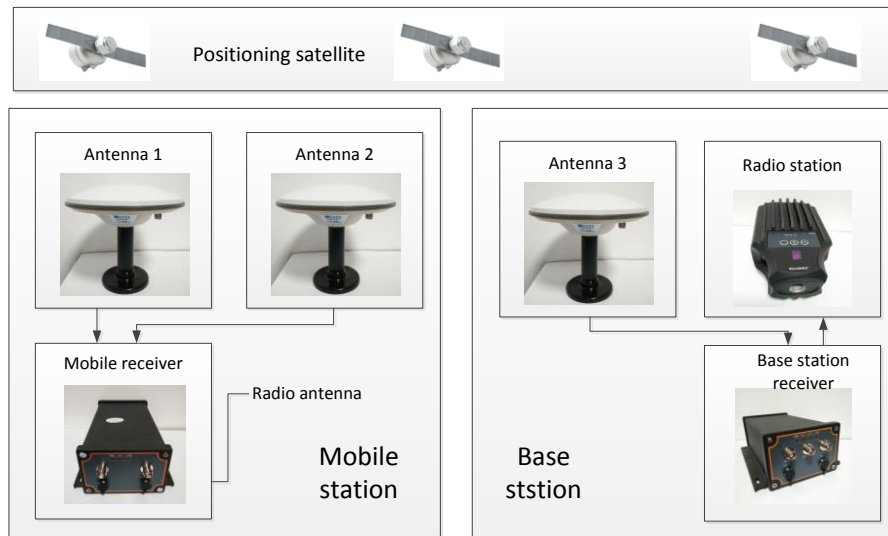


Figure 1. Structure of high-precision differential positioning system.

The experimental platform uses the M300 GNSS dual-mode receiver designed and developed by Shanghai Sinan Satellite Navigation and has an inertial navigation module. When the satellite signal is lost, the inertial navigation module intervenes to provide short-term inertial smooth positioning. The output data format is the unified RTCM standard protocol NMEA-0183 for GPS navigation devices. It mainly contains GGA (positioning information), RMC (Recommended Positioning Information), and VTG (ground speed information) and so on. The main parameters are shown in Table 1.

Table 1. High-accuracy receiver performance Index.

Parameter Name	Performance Index
Band	BDS B1/B2/B3 GPS L1C/A, L1/L2P, L5
Orientation accuracy /°	Directional accuracy(0.2/R) Roll or pitch accuracy(0.4/R) (R is the baseline length in m)
Carrier accuracy /mm	BDS: B1=0.5/B2=0.5/B3=0.5 GPS: L1=0.5/L2=1/L5=0.5
Static accuracy /mm	level: $\pm(2.5+0.5 \times 10^{-6}D)$ Vertical: $\pm(5+0.5 \times 10^{-6}D)$
RTK accuracy /mm	level: $\pm(10+0.5 \times 10^{-6}D)$ Vertical: $\pm(20+0.5 \times 10^{-6}D)$
Speed accuracy /m/s	0.03
Data update frequency /Hz	1/5/10/20(optional)
Data Format	NMEA-0183/CMR/RTCM2.X/ RTCM3.X

3. Construction of High Precision Differential Positioning System

3.1. Base Station Location and Signal Test

After selecting the reference station position at the top of the building (to ensure that there is no obstruction at 15 degrees above the horizontal line of the antenna), the signal quality test must first be performed to check whether the search is in good condition. Using CRU software for testing, the renderings are as follows:

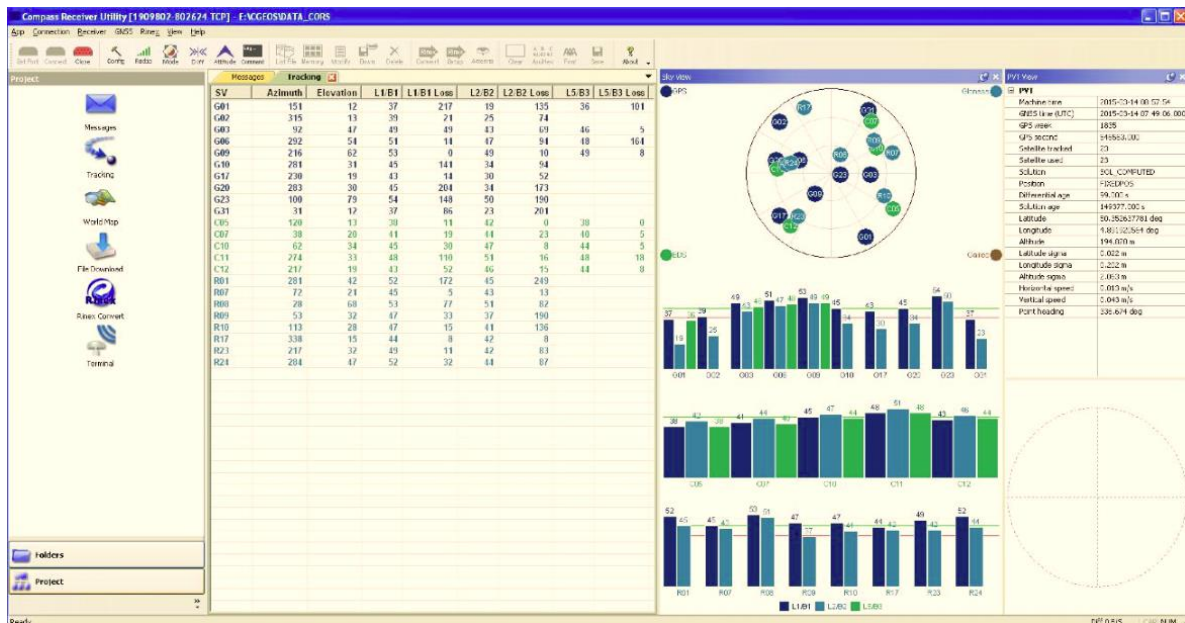


Figure 2. CRU search effect chart.

From the data table or histogram, the number of currently tracked satellites and the signal intensity of each satellite can be observed. Generally, the number of satellites should be more than 15 and evenly distributed on the star chart. The general judgment of satellite signal strength is shown in table 2.

Table 2. Comparison of satellite signal strength.

Satellite System	L1	L2	B1	B2	Remarks
GPS	48	38			At least 3 satellites meeting standards
BDS			48	45	At least 3 satellites meeting standards
GLONASS	48	45			At least 3 satellites meeting standards

It can be seen that the satellite signal quality satisfies the requirements and the base station erection position can be determined.

3.2. Obtaining Base Station Coordinates

After ensuring that the receiver's star search has been completed and the satellite signal quality meets the requirements, it is necessary to determine the exact coordinates of the base station to provide differential data for the mobile station.

First request the bestpos data of the base station receiver, the command is as follows:

```
fix none // Clear previous reference coordinates
log bestpos ontime 1 // Set positioning data to output at 1Hz
```

The data obtained is:

```
#BESTPOSA, COM1, 0, 60.0, FINESTEERING, 1728, 439514.900, 00000000, 0000, 1114;
SOL_COMPUTED, SINGLE, 34.31364906980, 109.12397355434, 477.3508, 0.0000, WGS84,
0.2436, 0.7712, 1.0611, "0000", 99.000, 1.000, 19, 19, 19, 19, 0, 0, 0, 0*55c94c5c
```

The three groups of bolded data represent the latitude coordinate, longitude coordinate, and elevation of the base station, respectively. The format of latitude and longitude is dd.ddddddddddd. The longitude and latitude units are degree and the elevation unit is meter. When obtaining the coordinates, the average value of the bestpos coordinate data for a certain period of time (usually taken for 10 minutes) should be selected as the coordinates of the project base station.

In the second step, the coordinates of the latitude, longitude, and elevation in the bestpos data are assigned to the reference station coordinates. The command is as follows:

```
fix position 34.31364906980, 109.12397355434, 477.3508 // Constrain base station coordinates
saveconfig // Save settings
```

3.3. Setting Up Differential Data Output

Base station differential correction information is broadcast to the mobile station. Send a set command from com1 and output differential data from com3 for convenient operation. The command is as follows:

```
Unlogall // clear previous settings
fix position 34.31364906980, 109.12397355434, 477.3508 // Constrain base station coordinates
com com3 38400 // Set the com3 port baud rate is 38400
log com3 rtm1104b ontime 3 // Set up BDS observation data output from com3
log com3 rtm1004b ontime 3 1 // Set up GPS observation data output from com3
log com3 rtm1012b ontime 3 2 // Set the GLO observation data from com3 output
log com3 rtm1005b ontime 5 // Set base station position information at 0.2HZ output
saveconfig // Save settings
```

3.4. Radio Parameter Configuration and Mobile Station Initialization

According to the type and frequency of the transmitting station selected by the reference station, the CDL station was used in the experiment and the frequency was set to 460.050 MHZ. In order to obtain the parameter configuration of the mobile receiver, through the computer's RS232 serial port, input the following instructions from the DC / ① port:

```
Unlogall // clear previous settings
fix none // Clear previous reference coordinates
interfacemode com2 auto auto on / com2 port configured for automatic differential mode
interfacemode com3 auto auto on // com3 port configured for automatic differential mode
set pjckpara 6378245298.3 0 105 0 500000 // Set coordinate projection parameters
log com1 ptnlpjk ontime 0.2 // Set com1 output pjk data, 5HZ
log com1 gptra ontime 0.2 // Set com1 output gptra data, 5HZ
log com1 gpvtg ontime 0.2 // Set com1 output gpvtg data, 5HZ
saveconfig // Save settings
```

At this point, the differential system is set up and the receiver is initialized.

4. Attitude measurement technology

The so-called attitude of the carrier generally refers to the angular relation of each axis between the carrier coordinate system and the local geographic coordinate system. The attitude of the carrier is determined by three attitude angles, namely, pitch, roll, and yaw. The relevant data of the attitude measurement of the carrier are obtained by the WGS-84 coordinate system, so the coordinate system conversion is needed to obtain the attitude of the carrier. The common three coordinate transformation rotation matrix is

$$\begin{aligned}
 R_x(\theta) &= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & \sin \theta \\ 0 & -\sin \theta & \cos \theta \end{bmatrix} \\
 R_y(\theta) &= \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \\
 R_z(\theta) &= \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}
 \end{aligned} \tag{1}$$

Where: $R_i(\theta)$ represents a transformation matrix that rotates any angle along the i-axis.

After installing a mobile receiver on the special vehicle under test, first arrange two receiving antennas (ie, a single baseline). In the experiment, a single baseline is placed in the direction of the vehicle's major axis. The vehicle body can be approximated as a rigid body. When the two receiver antennas are fixed on the carrier, the relative positions of the two antennas will not change, so the relative coordinate position of the baseline composed of the antennas in the carrier coordinate system is determined, as shown in figure 3.

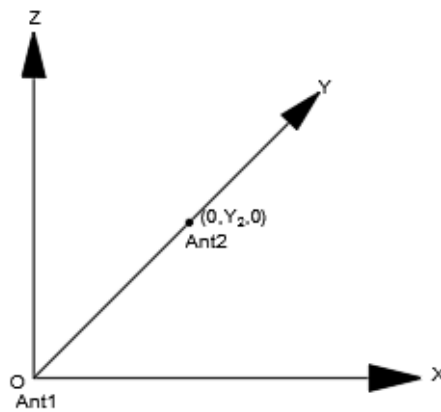


Figure 3. Single-baseline antenna configuration.

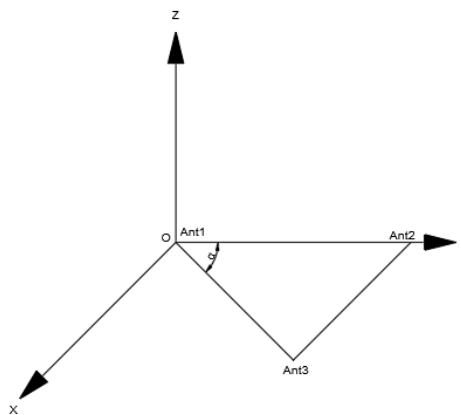


Figure 4. Double-baseline antenna configuration.

After differential carrier phase measurement, the coordinates of the two antennas can be obtained, and the relative positions of the two antennas in the geocentric earth-fixed coordinate system can be obtained. At the same time, there is a conversion between the local horizontal coordinate system and the geocentric earth-fixed coordinate system [5], so we can get the position of the two antennas in the local horizontal coordinate system. From this, we can calculate the 2D attitude angle of the baseline:

$$y = \arctan \frac{y_2}{x_2} \quad (2)$$

$$p = \arctan \frac{z_2}{\sqrt{x_2^2 + y_2^2}} \quad (3)$$

When the three antennas are arranged on the test vehicle to form a dual-baseline antenna measurement, as shown in FIG. 4, the antenna 1 is taken as the origin of the carrier coordinate system, and the coordinates of the antennas 2 and 3 in the carrier coordinate system are $(0, l_{12}, 0)$, $(l_{13} \sin \alpha, l_{13} \cos \alpha, 0)$. When the attitude of the vehicle changes, that is, the coordinate system rotates around Z, X, and Y. The antenna 1 remains unchanged, and the coordinates of the antennas 2 and 3 in the geographic coordinate system are (x_2, y_2, z_2) , (x_3, y_3, z_3) . By the rotation method, the conversion relationship between the two coordinate systems can be obtained:

$$X^b = R_y(r)R_x(p)R_z(y)X^l \quad (4)$$

The superscripts b and l in the formula represent the carrier coordinate system and the geographic coordinate system, respectively. From the above formula, we can draw:

$$X' = R_x(p)R_z(y) X^l = R^{-1}_y(r) X^b \quad (5)$$

And $X'_3 = [x'_3 \ y'_3 \ z'_3]^T$, $X^l_3 = [x_3 \ y_3 \ z_3]^T$, then we can find:

$$r = -\arctan \frac{z'_3}{x'_3} \quad (6)$$

From the formula (5) conversion, we can calculate:

$$z'_3 = x_3 \sin p \sin y - y_3 \sin p \cos y + z_3 \cos p \quad (7)$$

$$x'_3 = x_3 \cos y + y_3 \sin y \quad (8)$$

In summary, we can conclude:

$$r = -\arctan \frac{x_3 \sin p \sin y - y_3 \sin p \cos y + z_3 \cos p}{x_3 \cos y + y_3 \sin y} \quad (9)$$

In this way, all three attitude angles are obtained. The advantage of this solution method is that as long as we know the coordinates of the three antennas in the local horizontal coordinate system (the beidou/GPS measurements coordinate conversion), three attitude angles can be solved without any prior determination of the coordinates in the carrier coordinate system. It can be seen from the solution process that the two receiver antennas (ie, single baseline) can only calculate the 2D attitude of the carrier, the specific which two attitudes angle depending on the antenna installation location, and three or more than three not collinear receiving antenna can determine the three-dimensional carrier attitude. The more antennas, the higher the redundancy and the higher the accuracy, but it is not conducive to the solution process.

After the experimental demonstration, the relationship between the length of the baseline and the orientation accuracy is shown in Table 3:

Table 3. Orientation accuracy when the baseline length is fixed.

Baseline length	Orientation accuracy
1m	$\pm 0.20^\circ$
1.5m	$\pm 0.14^\circ$
2m	$\pm 0.10^\circ$

5. Conclusion

This article establishes the method of differential correction information output from the base station to improve the Beidou/GPS positioning accuracy, which realizes the detection of the three-dimensional attitude angle of a special vehicle and provides technical support for judging the driver's driving skills. The experimental results show that the double baseline measurement accuracy can meet the needs of training assessment, and has certain theoretical and engineering application value.

References

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