Comparison and analysis of positioning accuracy between DGPS and GPS

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Abstract. By observing the same GPS receiver, getting positioning data of 1000 sets of GPS and DGPS each, the two groups of data were calculated by utilizing the probability and statistics, and the average position of the two was GPS: 38°52′.111N, 121°33′.029E, DGPS:38°52′.107N, 121°33′.033E, 95% of mean square error circle radius of GPS respectively 6.975015372m, DGPS:3.267239581m. By comparison, the positioning accuracy of DGPS is more than twice that of GPS.

1. Introduction

Global Positioning System (GPS) is a three-dimensional satellite navigation system that mainly conducts omnidirectional and near real-time navigation and positioning in the sea, land and air. At present, the number of GPS satellites in orbit is 30 [1]. The positioning accuracy of military P code can reach 1 meter and that of civil CA code can reach 20 to 30 meters. After more than 30 years of development, GPS has become the satellite navigation system with the largest number of users in the world.

Due to the common errors in GPS positioning, including satellite clock error, ephemeris error, ionospheric refraction error, tropospheric refraction error, etc., it is difficult to meet the needs of users with high positioning accuracy. Later, DGPS appeared. The so-called DGPS is to make GPS observation on the reference station, calculate the pseudorange correction from the reference station to the satellite by using the known precise coordinates of the reference station, and send this correction out in real time. The user receiver also receives the pseudorange correction number of the base station while performing GPS observation, and corrects the pseudorange observation. Thereafter, the corrected pseudorange is used for positioning calculation to obtain an accurate position of the user receiver. Thereby eliminating common errors and achieving higher precision positioning.

At the same time, the appearance of GPS also aroused the interest of geodetic experts. A geodetic receiver has been developed and developed to post-process real-time positioning with positioning accuracy up to millimeter level. This technology has been widely used in crustal deformation measurement and the establishment of geodetic control network. However, this kind of measurement belongs to static relative measurement and is difficult to be applied in real-time dynamic measurement. Faced with the positioning accuracy of the navigation receiver is not high enough and the geodetic receiver can not be used for real-time dynamic situation, differential GPS positioning technology (DGPS) came into being. So the DGPS navigation system has developed rapidly. At present, the positioning accuracy of the CA code receiver can be increased to the centimeter level by carrier phase difference.
In order to verify the accuracy of DGPS, DGPS and GPS are observed simultaneously through the same receiver. Their observation data are obtained respectively, and the observation results are analyzed and compared so as to further grasp the positioning accuracy of DGPS and GPS.

2. Experimental methods

2.1. Test time and place
Experimentation time: From 9:30 to 12:30 on May 11, 2018.
Experimental site: Electronic Chart Room, 6th Floor, Laboratory Building, Dalian Ocean University.
Experimental weather conditions: Fine.
Experimental equipment: The GP-1600 GPS receiver of Japan's Gono Company.

2.2. Parameter Setting and Satellite State
HDOP is set to 2, three-dimensional positioning is adopted, the antenna height is 50m, and the selected coordinate is WGS-84.

| NO. | ELV | AZM | SNR |
|-----|-----|-----|-----|
| 12  | 18  | 041 | 47  |
| 14  | 74  | 086 | 43  |
| 22  | 28  | 190 | 47  |
| 29  | 19  | 118 | 44  |
| 31  | 55  | 292 | 50  |
| 32  | 27  | 303 | 43  |
| 20  | 5   | 323 | 43  |
| 25  | 50  | 053 | 50  |

See Table 1 for the status of the receiving satellite, which shows the satellite number, elevation angle, azimuth and signal-to-noise ratio.

2.3. Operating method
In the test, the same meter-level GP-1600 receiver with differential function (differential card) was used for continuous fixed-point observation [2] (the positioning accuracy is within 10m). The DGPS position data and GPS position data are recorded at the same time every 3-5 seconds, and are observed 1000 times continuously. The DGPS and GPS position observation data are 1000 groups respectively, and the probability statistical analysis is carried out on the two groups of data respectively.

3. Mathematical Model of Data Processing

3.1. Longitudinal and Latitude Mean Value [3]
\[
\overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i
\]
Where: n is the number of observations (1000) and is the average latitude or longitude.

3.2. Standard deviation of longitude and latitude samples
\[
S = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n-1}}
\]
3.3. Latitude conversion

\[
L_\varphi = 1852.25 - 9.31 \cos 2\varphi
\]  
(3)

Where: \( \varphi \) is the average latitude.

\[
S_{L_\varphi} = S_\varphi \times L_\varphi
\]  
(4)

Where: \( S_\varphi \) is the standard deviation of latitude samples.

3.4. Latitude and longitude conversion

\[
L_\lambda = 1855.36 \times \cos \varphi
\]  
(5)

\[
S_{L_\lambda} = S_\lambda \times L_\lambda
\]  
(6)

Where: \( S_\lambda \) is the standard deviation of longitude sample.

3.5. 95% probability zone of longitude and latitude, in points (,)

95% probability area of latitude:

\[
\varphi_{95\%} = 1.96 S_\varphi
\]  
(7)

95% longitude probable zone:

\[
\lambda_{95\%} = 1.96 S_\lambda
\]  
(8)

95% probability zone of longitude and latitude (in m):

3.6. 95% probability zone of longitude and latitude, in minutes (m):

95% probability area of latitude:

\[
M_{\varphi_{95\%}} = 1.96 S_{L_\varphi}
\]  
(9)

95% probability interval of longitude:

\[
M_{\lambda_{95\%}} = 1.96 S_{L_\lambda}
\]  
(10)

3.7. 95% probable ship position circle radius (in m)

\[
R_{95\%} = \sqrt{M_{\varphi_{95\%}}^2 + M_{\lambda_{95\%}}^2}
\]  
(11)

4. Data Computation and Analysis

4.1. Data calculation results

Table 2 lists the calculation results of DGPS and GPS observation data.

| Project       | DGPS Latitude (38 degrees 52' N) | DGPS Longitude (121 degree 33'0 E) | GPS Latitude (38 degrees 52' N) | GPS Longitude (121 degree 33'0 E) |
|---------------|----------------------------------|-----------------------------------|---------------------------------|-----------------------------------|
| Average value | 107193                           | 33429                             | 11084                           | 29042                             |
| Standard deviation | 0.000663409                    | 0.000780749                        | 0.001730721                     | 0.001059886                       |
| 95% probabilistic interval (m) | 2.405874363                     | 2.210570748                        | 6.276519128                     | 3.000894953                       |
| 95% Probabilistic interval (') | 0.001300281                     | 0.001577604                        | 0.003391212                     | 0.002077377                       |
| 2 times mean square error circle radius (m) | 3.267239581                     |                                   | 6.975015372                     |                                   |
| Distance average Deviation | 0.00015985                      | 0.00003276                         | 0.000176834                     | 0.00033462                       |
| Distance Deviation (m) | 0.296043607                     | 0.060671572                        | 0.32749824                      | 0.619717309                      |
| Distance minimum value (m) | 0.302196718                     |                                   | 0.7034003                       |                                   |
4.2. Data analysis

It can be seen from Table 2 that the average values of DGPS and GPS fixed-point positioning data are 38°52'107193 N, 121 33'.033429 E, 38 52' 11084 N, 121 33'. 029042 E respectively, and the average difference values are 0'.003646 and 0'.00438 respectively, corresponding distances are -6.7542m and 8.1247m. The average difference between the two is relatively large, which is related to the observation point being located on land. The distance between the observation point and the reference station of Dalian Sanshan Island Differential Station is 16.9nm. However, due to the blocking of the mountain where Nanmenzui and other stations are located, the differential signals emitted by the differential station do not propagate in a straight line and have some bending, which has some influence on the differential results. At the same time, the differential station adopts pseudo-range differential method, and the accuracy of differential is lower than that of differential methods such as carrier phase, so the differential positioning effect is not ideal. However, the accuracy of the difference is still higher than that of GPS. It can be seen that DGPS is 3.70775791 m smaller than that of GPS, and the accuracy is more than double.

In addition, the difference between the DGPS and GPS maximum and minimum values is compared in the latitude and longitude direction, respectively: 7.745561m, 17.22117m, and 0.302196718m, 0.7034003m. The value of DGPS is more than double the value of GPS. According to the probability and statistical analysis, there are 5% of the observation data beyond the radius of 2 times the mean square error circle, which is called singular point. The error of 5% of the observation data is larger. Generally not used.

In terms of the distribution of the location points, the GPS location points are mainly distributed in the latitude direction. It is more than doubled in the latitudinal direction than DGPS, and the DGPS position is mainly distributed in the longitude direction. This is also the difference in the location of the two. Figure 1 and Figure 2 show the distribution of DGPS and GPS error circles and observation points.

Fig.1. Distribution of GPS error circle
Fig. 2. GPS Error Circle and Observation Distribution and observation value

From the comparison between Figure 1 and Figure 2, it can be seen very intuitively that the distribution of DGPS position points is concentrated, and many points are roughly the same. The GPS location points are loosely distributed, and the number of locations is the same as DGPS. The positions of the singular points are relatively concentrated and the distance from the average is far.

In a word, DGPS's fixed-point positioning accuracy is better than GPS's fixed-point positioning accuracy, and its distribution is more concentrated.

4.3. Factors Influencing GPS and GPS Positioning Errors

Because DGPS and GPS both have certain errors in fixed-point positioning, there are many factors affecting these errors, which can be divided into public errors and non-public errors in general.

This observation data is as many as 1000 times, and the average value is obtained. This average value can be approximated to a true value, to a large extent avoiding accidental errors.

4.3.1. The main factors affecting GPS positioning errors include [4]:

Satellite-related errors: ephemeris error, satellite clock residual error and group delay error;

Signal propagation error: ionospheric refraction error, tropospheric refraction error and multipath effect. A total of 8 satellites have been received in this observation, with elevation angles ranging from 5 to 74, and tropospheric refraction error varies greatly.

The receiver used in this observation is an 8-channel receiver, therefore, there are inter-channel channel error, navigator noise and quantization error;

Geometric error: When the above error is fixed, when the spatial geometry of the user is different from the satellite, the positioning error is also different. The HDOP value of this observation is 2, which is smaller, in the geometric accuracy of the satellite. The requirements are higher, the geometry of the satellite is better, and the accuracy of the observation is higher.

4.3.2. The positioning errors affecting GPS include:

DGPS can eliminate or approximately eliminate ephemeris error, satellite clock residual error, ionospheric delay and tropospheric delay error.

The paths of DGPS users and the differential reference station to the satellite go through different paths, thus causing signal delay, thus causing additional positioning errors. This influence is different between the location of users and the location of the reference station [5]. In addition, there is high mountain blocking between the DGPS users and the differential reference station in this observation, thus the differential signal propagation is affected to a certain extent, and certain errors are also generated.

As with GPS, there are still inter-channel channel errors, navigator noise, and quantization errors.

5. Conclusion

The fixed-point positioning accuracy of DGPS is higher than GPS through observation and calculation. This is mainly because DGPS eliminates common errors including satellite clock error, ephemeris error,
ionospheric refraction and tropospheric refraction error. It is better than GPS in fixed-point positioning accuracy and positioning stability. The difference between the two is 3.70775791 m, which shows that the current GPS positioning accuracy is also relatively high. For ocean-going ships, the positioning accuracy can completely meet the positioning requirements. As DGPS becomes farther away from the differential table, the corrected positional accuracy will also become worse, and the effect is not satisfactory. In addition, because the differential base station has a limited working distance (about 300 nautical miles) and there is no base station in the ocean, it is not necessary to install DGPS on ships sailing in the ocean. However, for industries with high positioning accuracy requirements, carrier phase differential GPS can provide higher positional accuracy, and the accuracy can reach centimeters or even millimeters.

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