Calibration of GPS receivers based on IGS and CORS techniques

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Concerning the traditional methods, more technical details and more strict conditions are required for global positioning system (GPS) receiver’s calibration especially for mid and long baseline which influenced by the environment around easily, and more investigations have to be done. In this paper, a new method on how to calibrate GPS receivers is suggested, which is based on the convenient condition that Kunming has one international GPS service station and its own continuously operating reference stations, and the method is confirmed by a test using six different types of GPS receivers. Compared with the traditional methods, the new method is more efficient by decreasing routine calibration works up to 50%.

Keywords: IGS; CORS; GPS receiver; calibration; baseline

1. Introduction

Extensive application of global positioning system (GPS) for positioning promotes the progress in surveying and mapping technology, and the development of the national economy. The precise calibration of GPS receivers is fundamentally important for the precise and reliable positioning. Highly accurate calibration is crucial for consistency in length, and to ensure the quality of the GPS network in keeping with the rigorous and efficient national measurement standard.

An urgent requirement for GPS receivers is a baseline (1). In urban areas, influenced by all sorts of factors such as inconvenient position choices restricted by surrounding conditions, or difficulties imposed by rapid urban development, the protection and management of baseline points is difficult. During mid and long baseline calibration, work is usually disturbed by surrounding conditions generating more work, and a higher ratio of repeated calibrations. Therefore, improving the reliability, accuracy, and efficiency of calibration fieldwork is a goal, thereby reducing costs as well as improving efficiency.

The International GPS Service (IGS) agency is a permanent GPS service organization managed by the International Association of Geodesy whose purpose is to serve the geodesy and geophysics research activities. More than 200 permanent high-precision tracking stations collect data, and provide users with high-precision GPS satellite ephemeris. Each IGS tracking station’s coordinates, speed, satellite clock, and station clock information as well as the Earth’s rotation parameters and the ionosphere, troposphere information are also provided, to support astrogeodynamics research (2, 3).

Nine GPS Continuously Operating Reference Stations (CORS) have been built by IGS, located in Kunming, Beijing, Shanghai, Wuhan, Xian, Lhasa, Changchun, Urumqi, and Taipei in China. The accuracy of the coordinates of each station can be at cm-level precision. KUNM is in Yunnan Observatory. Its position is relatively stable, and the observation condition is well, so the data come from it are released in good condition. Since June 1998 when KUNM was completed, efficient observation records have been obtained year round except nine days’ observation data lost in 2000 due to equipment failure (3).

KMCORS was constructed by the Kunming Institute of Surveying and Mapping in May 2005 (2). The entire system is composed of a reference station subsystem, a communication network subsystem, a data control center subsystem, and a sub-user applications system. The KMCORS reference subsystem is made up of eight reference stations covering in total about 8000 km², whose main function is to receive GPS satellite signals continuously 24-h a day, collecting the original observation data, and sending them to users.

KMCORS was developed into a binary system in August 2008, using the professional GPS receiver GRX1200 and LEIAT504GG choke antenna, with GNSS-Spider3.0.1 as reference station software packages, and a static fiber fixed IP instead of the original dynamic
asymmetric digital subscriber line. Based on analysis of the quality of the KUNMING GPS reference station’s data using Leica GNSS Spider QC v3.0, it shows that the environment around each of the reference stations has no obvious electromagnetic signal interference, the observation conditions are very good, and the observational data are of high quality, for more details see reference (2).

2. Design and measurement of the baseline calibration network by applying KUNM and KMCORS

General requirement of the points is as follows (4, 5),

1. The points of baseline coming from the GPS calibration fieldwork should be stable; above a 10-degree elevation angle and the sky should have no obstructions. In order to manage and maintain the baseline points well and keep the equipment safe, adjacent traffic must be considered.

2. Baseline points must be far away from electromagnetic interference sources and places where it is easy to produce multipath signals. Microwave stations, radio transmitters, high-voltage electronic lines and tall buildings easily influenced by lightning metal objects’ reflective surfaces, and water zones, etc. generally should not be less than 100 m away.

3. In order to ensure that baseline points avoid being influenced by multipath or other electromagnetic signals while GPS data are collected, the chosen positions should be tested.

4. Based on analysis, KUNM and KMCORS are ideal positions. Their observation data are reliable enough to satisfy the requirements of the GPS receiver calibration baseline points.

We designed the mid and long baseline network as follows.

(1) According to the “calibration norm” requirements, mid and long baselines should consist of 2, 5, 10, 15, 20, 25, and 30 km lengths. Applying six KMCORS stations and KUNM stations, an 11-point mid and long baseline network was formed as shown in Figure 1.

(2) After optimizing the mid and long baseline network based on KUNM and six KMCORS stations, 148 baselines were obtained. The longest side of the lines reaches 53.6 km. Baselines are distributed reasonably and satisfy the requirements of the norm. The detail conditions of baselines are shown in Table 1.

Baseline measurement results are composed of two parts.

(i) Field measurements

According to the requirements for accuracy and design of the GPS calibration baseline, measurements of the network referenced to A-class requirements from “Specifications for GPS Surveys” GB/T18314-2001. Eleven (5) baseline points, KUNM, and six KMCORS stations formed a simultaneous loop. The main technical requirements for observations are shown in Table 2.

(ii) Baseline solutions and network adjustment

(1) GAMIT software and precise ephemeris (SP3 format) were used during data processing in order to improve the accuracy of the satellite orbit, GPS tracking station data from surrounding areas were added as certain constraints, and automatic cycle slips repair techniques were used to obtain better results (9, 10).

(2) The baseline network adjustment is calculated by the COSAGPS 3.0 software, as KUNM’s position...
is known, results obtained based on the WGS-84 coordinate system show that the relative accuracy meets the order of $10^{-7}$ or more, satisfying the relevant technical standards except short sides less than 1 km. The complete after calculation results of quality details are shown in Table 3.

3. GPS receiver calibration based on IGS and CORS technology

The determination of basic requirements for calibration is important. The GPS receiver calibration method based on IGS station and CORS technology (a new calibration method will be termed NCM) meets the following conditions apart from the conventional:

(1) Chooses some CORS stations (usually the number should be more than two) with the similar distances to the GPS calibration points as auxiliaries, especially including IGS stations if possible. The CORS control center must exist to ensure that dual-band data be obtained during calibration while collecting data at a normal interval of 15 s or 30 s.

(2) During each GPS calibration measurement, baseline data should include CORS and IGS together.

Based on the number of receivers (usually three or four) to be calibrated, at distance range from 24 to 5000 km, select the corresponding conventional baseline points, within which including two ~ four CORS points as auxiliary calibration points. The following requirements should be met:

(i) If the short baseline is within 2000 m in length, the number of the baselines should not be less than three;

(ii) While in range from 2000 to 30,000 m, the number of the lines should not be less than six; and

(iii) The height difference between various types of calibration points should be less than 5%.

In the process of observing for mid and long baseline calibration, considering that GPS receivers are placed on the baseline points at the same time, so IGS and CORS’s data should be included during data processing so that

Table 1. Conditions of baselines.

| Baselines (km) | Total |
|---------------|-------|
| $2 \leq S < 5$ | 15    |
| $5 \leq S < 10$ | 27    |
| $10 \leq S < 20$ | 15    |
| $20 \leq S < 30$ | 28    |
| $30 \leq S < 40$ | 41    |
| $S \geq 40$ | 22    |

Note: Baselines between IGS and six KMCORS are excluded.

Table 2. Main technical requirements for observations.

| Specification                 | Mid and long baseline field |
|------------------------------|----------------------------|
| Elevation mask angle (°)     | $\geq 10$                  |
| Observation sessions         | $\geq 4$                   |
| Session length (h)           | $\geq 23$                  |
| Collection interval (s)      | 30                         |

Figure 2. Comparison between two calibration methods.

Table 3. Detail baseline results after calculation.

| Type of baseline (m) | 600–2000 | 2000–10,000 | 10,000–30,000 | 30,000–53,000 |
|----------------------|----------|-------------|---------------|---------------|
| Length (m)           | 661.792 m| 3521.824    | 10,404.536    | 31,319.775    |
| Weakest relative deviation (ppm) | 1.25  | 0.21        | 0.05          | 0.02          |
| Limit (ppm)          | 1.44     | 1.0         | 0.3           | 0.1           |

Figure 3. Accuracy comparison between two calibration methods.
the solved baselines and the standard baseline can be compared simultaneously (6–8).

4. Calibration test and analysis

Coming from the well-known brands including Topcon, Trimble, Leica, Zhonghaida, South, and Huace, 40 sets of GPS receivers are used to compare the conventional calibration method with NCM, applying technical norms according to Refs. (4, 5). The two sets of data’s accuracy and their regulations have been analyzed and compared as Figures 2 and 3.

Figure 2 shows that the results with two different calibration methods are consistent, while from Figure 3, NCM data show that they have more mean accuracy.

Based on IGS, KMCORS, and Kunming GPS baseline calibration fieldwork, NCM was used to calibrate four GPS receivers. Receivers such as GA6, GA7, GA8, and GA19, only require placement at points within 1000 m and have better traffic conditions. Compared with conventional methods, field operation time was reduced to 60%, staff reduced to two people in the field, with more than 50% improved efficiency. Baselines details including six KMCORS and an IGS station are shown in Table 3, the observation number increased up to 34, among the shortest baseline is of 31 m, and the longest is of 46,857 m, guaranteeing that each GPS receiver has a different length baseline observation, so the baseline distribution is pretty good in Table 4.

Due to substantial different length baselines available, the NCM can effectively improve the reliability of GPS baseline calibration, while also avoiding some unnecessary work during GPS calibration processing.

5. Conclusion

The NCM based on KUNM and KMCORS is reliable and can fully meet requirements of the calibration norm. Testing shows that during baseline calculation including the observations of KUNM and KMCORS, each GPS receiver gets calibration baselines from the original \((n−1)\) to \((n+7)\) section, the length also increases, so qualified baselines number will be increased, the relative accuracy is superior to conventional methods, and the NCM also improves their stability and reliability. Comparing NCM with conventional methods, the former will decrease field work more than 50%, and improve work efficiency greatly.

Table 4. Length of baselines (m).

| pn | GA7 | GA8 | GA19 | KMCK | SAIM | CHGO | GHXX | KUNY | YILI | KUNM |
|----|-----|-----|------|------|------|------|------|------|------|------|
| GA6 | 734 | 719 | 36   | 3521 | 7888 | 18,319 | 33,594 | 42,097 | 46,827 | 10,042 |
| GA7 | 31  | 714 | 2975 | 8182 | 18,796 | 33,088 | 42,812 | 46,808 | 9817  |
| GA8 | 699 | 2967| 8200 | 18,765| 33,098 | 42,830 | 46,835 | 9839  |
| GA19| 3523| 7868| 18,319| 33,594| 42,097 | 46,827 | 10,064 |

Note: Baseline pinot CORS station IGS station

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