remote sensing

Editorial

Editorial for Special Issue "Precise GNSS Positioning and Navigation: Methods, Challenges, and Applications"

Zhetao Zhang [1,*], Wenkun Yu [2] and Giuseppe Casula [3]

[1] School of Earth Sciences and Engineering, Hohai University, Nanjing 211100, China
[2] School of Geosciences and Info-Physics, Central South University, Changsha 410083, China; geowkyu@csu.edu.cn
[3] Istituto Nazionale di Geofisica e Vulcanologia (INGV)—Sezione di Bologna, Viale Berti Pichat 6/2, 40127 Bologna, Italy; giuseppe.casula@ingv.it
* Correspondence: ztzhang@hhu.edu.cn; Tel.: +86-188-8877-0616

1. Introduction

The Global Navigation Satellite System (GNSS) can provide users with high-precision positioning information continuously and benefits all walks of life, e.g., unmanned driving, urban navigation, deformation monitoring, etc. The important scientific research and application value of GNSSs have prompted many countries and regions to develop GNSS technologies. GNSS core positioning technologies, such as Precise Point Positioning (PPP) and Real-Time Kinematic positioning (RTK), can provide decimeter-level or even centimeter-level positioning accuracy in open environments. However, active GNSS positioning technologies are susceptible to complex conditions, including canyon environments, low-cost receivers, and multi-GNSS situations, and, on occasion, cannot provide accurate, continuous, and reliable positioning information. The diversification of GNSS systems and constellations, receiver types, and observation environments puts forward higher requirements for technology and algorithms to maintain high-precision positioning and navigation services. Advanced algorithms are key to solving GNSS practical application problems and expanding the scope of GNSS applications.

This Special Issue aims at studies covering improved methods and the latest challenges in precise GNSS positioning and navigation, especially under complex conditions for various research investigations as well as a range of practical applications. Both theoretical and applied research contributions to the GNSS high-precision technology in all disciplines are considered. Topics may cover anything from precise muti-GNSS positioning algorithms and GNSS data processing to more comprehensive targets and scales. Therefore, new algorithms for high-precision positioning and navigation, GNSS receivers, software development for data collection and processing, and their applications in various fields are all included.

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2. Overview of Contributions

The following is the synthesis of results obtained in each paper published in the Special Issue "Precise GNSS Positioning and Navigation: Methods, Challenges, and Applications".

Wang et al. [1] evaluated both a multi-baseline solution (MBS) model and a constrained-MBS (CMBS) model that had prior constraints of the spatial-correlated tropospheric delay in deformation monitoring. The reliability and validity of the MBS model was verified using the GPS/BDS data set from ground-based settlement deformation monitoring, with a baseline length of about 20 km and a height difference of about 200 m. They reported that the MBS model reduced the positioning standard deviation (STD) and root-mean-squared (RMS) errors by up to (47.4/51.3/66.2%) and (56.9/60.4/58.4%) in the north/east/up components compared with the single-baseline solution (SBS) model, respectively. Moreover, the combined GPS/BDS localization performance of the MBS model outperformed the

GPS-only and BDS-only localization models by an average of about 13.8 and 25.8 percent, respectively, with highest accuracy improvements of about 41.6 and 43.8 percent. With the additional tropospheric delay constraint, the CMBS model improved monitoring precision in the up direction by about 45.0%.

Guo et al. [2] verified the impact of random interference from walkers on positioning signals in an indoor environment. Based on this phenomenon, the authors proposed a novel real-time dynamic Beacons selection method (RD) in the field of indoor positioning. First, the authors introduced a machine learning algorithm for the real-time anomaly detection of received signals from different Beacons. Then, the Beacon selection was completed based on the real-time anomaly detection results and RSSI. In an indoor scene, the authors verified the positioning accuracy of three other methods when selecting various numbers of Beacons. Then, the authors used the best selection strategies to compare with the RD method. Experiments showed that the RD method can use the least Beacons to obtain higher accuracy and stable positioning results.

Liu et al. [3] verified that the broadcast clock offset had smaller and more stable biases in the long term to compare with the post-processing clock offset and proposed a regional clock offset estimation strategy using broadcast clock offsets for a priori constraints. The results showed that the new algorithm could effectively reduce the biases in PPP-B2b clock offsets. The new clock offset product could improve convergence speeds by 25% and 10% in the horizontal and vertical directions, respectively. For positioning accuracy, the improvements were 22% and 17%, respectively. The absolute error of timing could also be reduced by 60%.

Yang et al. [4] proposed a new strategy to real-time estimate high-accuracy satellite clock offsets. The clock offsets estimated by the new strategy showed good consistencies with the GBM clock offsets. The averaged STD of their differences in the MEO was 0.14 ns, and the clock offsets estimated by the new strategy presented less fluctuations in the 1-day fitting residuals. Applying the new clock offsets to prediction, BDS-3 could reduce its clock offset errors from 1.05 ns to 0.29 ns (RMS), which was a value of about 72%. The above results indicated that the new estimated strategy for clock offsets could improve the accuracy of the clock offset parameters of BDS-3 effectively.

Liu et al. [5] deduced a strategy based on the "density" of common satellites (OBS-DEN) to guarantee baselines of the highest accuracy to be selected. It takes the number of co-viewing satellites per unit distance between stations as the criterion. This method ensured that the independent baseline network had both sufficient observations and short baselines. With single-day solutions and annual statistics computed with parallel processing, the method demonstrated that it had the ability to obtain comparable or even higher positioning accuracies than the conventional methods. With a clearer meaning, OBS-DEN could be an option alongside the previous methods in an independent baseline search.

Qu et al. [6] carried out a series of experiments with a shaking table to assess the structural health monitoring performances of a set of 100 Hz GNSS equipment and three commonly used GNSS positioning techniques: PPP (precise point positioning), PPP-AR (precise point positioning with ambiguity resolution), and RTK (real-time kinematic). They found that the standard deviations of the 100 Hz GNSS displacement solutions derived from PPP, PPP-AR, and RTK techniques were 5.5 mm, 3.6 mm, and 0.8 mm, respectively, when the antenna was in quasi-static motion, and about 9.2 mm, 6.2 mm, and 3.5 mm, respectively, when the antenna was vibrating (up to about 0.7 Hz), under typical urban observational conditions in Hong Kong. They also found that the higher the sampling rate of a, the lower the accuracy of a measured displacement series. On average, the 10 Hz and 100 Hz results were 5.5% and 10.3%, respectively, which were noisier than the 1 Hz results.

Lan et al. [7] provided a comprehensive evaluation of the accuracies of the satellite's precise real-time orbit and clock products, including BDS-3 PPP-B2b precise products and the precise real-time products provided by four IGS centers (CAS, DLR, GFZ, and WHU). In addition, the influences of these real-time precise satellite products on the PPP positioning accuracies with single-frequencies and dual-frequencies were also studied.

Furthermore, the accuracies of the broadcast ephemeris and IGS ultra-rapid products were studied, as well as their impacts on the PPP accuracies. The results illustrated that the orbit accuracies of the PPP-B2b orbits were 9.42 cm, 21.26 cm, and 28.65 cm in the radial, along-track, and cross-track components, which were slightly lower than those of the real-time orbits provided by the four IGS centers. However, the accuracy of the PPP-B2b clock biases was 0.18 ns, which was higher than those provided by IGS Real-Time Service (RTS). In the static positioning test, the 3D positioning accuracy of the B1I+B3I dual-frequencies PPP and the B1C single-frequency PPP were centimeter-level while using the PPP-B2b service, which were slightly lower in the horizontal components compared to those obtained based on the IGS RTS products. The results of the dynamic vehicle test indicated that the positioning accuracies of the B1I+B2b dual-frequency PPP were about 50 cm and 120 cm in the horizontal and vertical components, respectively, which were close to those of the B2b single-frequency PPP using the PPP-B2b service.

Wang et al. [8] proposed a new empirical PWV grid model (called ASV-PWV) using the zenith wet delay from the Askne model, improved by the spherical harmonic function and vertical correction. The proposed method was convenient and enabled the user to gain PWV data with only four input parameters (e.g., the longitude and latitude, time, and atmospheric pressure of the desired position). The profiles of 20 radiosonde stations in Qinghai Tibet Plateau, China, along with the latest publicly available C-PWVC2 model, were used to validate local performance. The PWV data from ASV-PWV and C-PWVC2 were generally consistent with the radiosonde (the average annual bias was −0.44 mm for ASV-PWV and −1.36 mm for C-PWVC2; the root mean square error (RMSE) was 3.44 mm for ASV-PWV and 2.51 mm for C-PWVC2). The proposed ASV-PWV performed better than C-PWVC2 in terms of seasonal characteristics. In general, a sound consistency existed between PWV values of ASV-PWV and the fifth generation of the European Centre for Medium-Range Weather Forecasts Atmospheric Reanalysis (ERA5) (a total of 7381 grid points in 2020). The average annual bias and RMSE were −0.73 mm and 4.28 mm, respectively. The ASV-PWV had a similar performance as the ERA5 reanalysis products, indicating that ASV-PWV was a potentially alternative option for rapidly gaining PWV.

Min et al. [9] carried out a model by integrating between-satellite single-differenced (BSSD) PPP, a low-cost Inertial Navigation System (INS), and an odometer via an extended Kalman filter. The performance of this integration model was assessed with vehicle-borne data. The results demonstrated that the position RMS (Root Mean Square) values of the BSSD PPP were 64.33 cm, 53.47 cm, and 154.11 cm. Compared with BSSD PPP, position improvements of about 31.2%, 23.3%, and 27.3% could be achieved by using INS. Further enhancements of the RMS positions benefiting from the odometer were 1.34%, 1.41%, and 1.73% in the three directions. The accuracy of the BSSD PPP/INS/Odometer tightly coupled integration was slightly higher than that of the undifferenced PPP/INS/Odometer integration, with average improvement percentages of 7.71%, 3.09%, and 0.27%. Meanwhile, the performance of the BSSD PPP/INS/Odometer integration during the periods with satellite outages was better than the undifferenced PPP-based solutions. The improvements in attitudes from an odometer were more significant on heading angles than the other two attitudes, with percentages of 25.00% each. During frequent GNSS outage periods, the reduction in average maximum position drifts provided by the INS were 18.01%, 8.95%, and 20.74%. After integrating with an odometer, the drifts could be decreased further by 25.11%, 15.96%, and 20.69%. For attitude, an about 41.67% reduction in the average maximum drifts of the heading angles was obtained.

Zhang et al. [10] comprehensively assessed the BDS-2/BDS-3 final (ISC), rapid (ISR), and ultra-rapid (ISU) products based on B1I/B3I and B1C/B2a frequencies from the international GNSS Monitoring and Assessment System (iGMAS). Specifically, at first, the precise orbits from iGMAS were compared with the ones from the IGS ACs. Based on this, the Satellite Laser Ranging inspected the precise orbits from iGMAS. Finally, the orbit errors were discussed systematically by considering the Beta and Elongation angles. Using one year of data, the orbit accuracies of geostationary orbit, inclined geosynchronous orbit, and medium earth orbit (MEO) satellites could reach an almost meter to decimeter level, a decimeter to sub-decimeter level, and a centimeter level, respectively, where the ISC products were the best. The ISC, ISR, and ISU products based on B1I/B3I frequencies were generally better than the ones based on B1C/B2a frequencies. Additionally, according to the SLR data, the results showed that the accuracy of the precise orbits of the BDS-3 was better than that of the BDS-2. The mean values of orbit biases of the BDS-3 MEO satellites were approximately 2.88 cm. In addition, the orbit errors were related to the beta angle and elongation angle to some extent, and the manufacturers may also have had an influence on the orbit errors.

Zhou and Wang. [11] provided a comprehensive analysis of pseudorange-based/single point positioning (SPP) among GPS, BDS-3, and Galileo on a global scale. First, the positioning accuracy distribution of adding IGSO and GEO to the MEO of BDS-3 was analyzed. The results showed that the accuracy of the third dimension in the Asia–Pacific region was significantly improved after adding IGSO and GEO. Then, the positioning accuracies of the single-system and single-frequency SPPs were validated and compared. The experimental results showed that the median RMS values for the GPS, Galileo, and BDS-3 were 1.10/1.10/1.30 m and 2.57/2.69/2.71 m in the horizontal and vertical components, respectively. For the horizontal component, the GPS and Galileo had better positioning accuracy in the middle- and high-latitude regions, while the BDS-3 had better positioning accuracy in the Asia–Pacific region. For the vertical component, poorer positioning accuracy could be seen near the North Pole and the equator for all three systems. Meanwhile, in comparison with the single-system and single-frequency SPPs, the contribution of adding pseudorange observations from other satellite systems and frequency bands was analyzed fully. Overall, the positioning accuracy could be improved to varying degrees.

Viler et al. [12] focused on the quality of 2D and 3D kinematic positionings of different geodetic and low-cost GNSS devices, using the professional mobile mapping system (MMS) as a reference. Kinematic positionings were performed simultaneously with a geodetic Septentrio AsteRx-U receiver, two u-blox receivers—ZED-F9P and ZED-F9R—and a Xiaomi Mi 8 smartphone, which were then compared with Applanix Corporation GPS/INS MMS reference trajectories. As expected, some results in the GNSS positionings were subject to position losses, large outliers, and multipath effects; however, after removing them, they were quite promising, even for the Xiaomi Mi8 smartphone. From the comparison of the GPS and GNSS solutions, as expected, the GNSS processing achieved many more solutions for position determination and allowed a relevant higher number of fixed ambiguities, even if this was not true, in general, for the Septentrio AsteRx-U, in particular, in a surveyed non-urban area with curves and serpentines characterized by a reduced signal acquisition. In the GNSS mode, the Xiaomi Mi8 smartphone performed well in situations with thresholds less than 1 m, with the percentages varying from 50% for the urban areas to 80% for the non-urban areas, which offered potential in view of future improvements for applications in terrestrial navigation.

Shang et al. [13] investigated the temporal behaviors of differential inter-system bias (DISB) and implemented an inter-system model for smartphones. They accessed the data from a Huawei P40 (HP40) smartphone and reported: (1) For the HP40, the frequencies of code-division-multiple-access systems were free of receiver channel-dependent phase bias, which provided chances for additional interoperability among these systems. However, the code observations of HP40 were affected by the receiver channel-dependent code bias. Therefore, it was suggested to set a large initial STD value for code observations in the positioning. (2) GPS L1/ QZSS L1 and BDS-2 B1I/BDS-3 B1I were free of phase DISB, and there were evident phases DISB between GPS L1 and Galileo E1. Even then, the valuations were sufficiently stable, with an STD close to 0.005 cycles. However, the GPS L1/BDS B1I phase DISB was unstable. (3) For kinematic positioning, when the stable phase DISB was introduced, a 3–38.9% improvement in the N/E/U directions of the positioning accuracies in the inter-system differencing was achieved compared with the intra-system differencing.

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