The Validation and Performance Assessment of the Android Smartphone Based GNSS/INS Coupled Navigation System

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The Validation and Performance Assessment of the Android Smartphone Based GNSS/INS Coupled Navigation System

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Abstract. The significant improvement of the performance of the GNSS and INS modules inside the smartphones, arising a great promotion of precise applications at the mass market. In order to validate the Android smartphone based GNSS/INS coupled navigation system, we developed the data acquisition platform for the GNSS and INS embedded inside the smartphones, which can synchronously collect the raw data from the two internal hardware. Then the corresponding processing software was developed. With the purpose of the assessment of the precision and stability for the proposed coupled navigation system, a terrestrial dynamic test was designed, and the Huawei latest smartphone "P40" in the year 2020 was taken during this test. The GNSS and INS data from the "Huawei P40" were synchronously logged through the model of "EMUI DESKTOP" by our developed app. Besides the smartphone, a high grade GNSS receiver Trimble R10 and the NovAtel IGM-A inertial navigation system were strapped in the same platform as the P40 smartphone, and the coupled navigation solutions as, position and the attitude obtained from the Trimble R10 GNSS and NovAtel IGM-A were taken as the references to assess the precision and stability of the proposed navigation system. The comparison results indicate that, the position differences with respect to the reference are around 0.2 m in the root mean square statistic, and the roll and the pitch are around 0.16°, and the yaw are around 1.7°, which means that, the high level performance of the coupled navigation system, based on the Android internal GNSS and INS modules can be witnessed.

Keywords: GNSS/INS coupled navigation · Android smartphones · Kalman filter

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1 Introduction

With its rich built-in sensors, reliable power supply, powerful operating system, low price and other factors, smartphones play an increasingly important role in many areas of public production and daily life, such as smart city, sports monitoring, care for the elderly and children monitoring. Smartphone high-precision navigation and positioning technology is one of the core technologies in the development of these various applications. The navigation and positioning function of smartphones is mainly completed through the modules of the built-in GNSS, communication (2–5G), Wi-Fi, etc. Google released Android 7.0 operating system at the end of 2016, which began to support the output of GNSS raw observation data from the smartphones, making it possible for high-precision navigation and positioning using a standalone smart device. It is meaningful for the current field of unmanned vehicle and intelligent transportation [1, 2].

Due to the limitation of device cost and manufacturing process, the quality of GNSS signal received by smartphones and the positioning accuracy are usually not high, which are mainly reflected in the complicated characteristics of observation error and significant multipath effect. In the process of the quality assessment of GNSS signal received by smartphones, researchers found that the carrier to noise ratio (C/N_0) is 10 dBHz lower than that from the professional GNSS receiver [3]. These device problems degraded the development of precision navigation and positioning applications by the smartphones. Some scholars used external antenna [4] and multipath suppression device [5] to improve the strength and stability of mobile phone GNSS signal reception. However, these methods need to introduce additional equipment, so as there are still great shortcomings in the device cost and the user populations.

Other researchers also studied the methods to improve the positioning accuracy and stability of the smartphone GNSS, from the perspectives of time differential filtering [3], carrier ambiguity resolution [6, 7], pseudo-range/carrier differential positioning [8, 9], which also made significant progress.

By analyzing the existing literatures, it can be found that the positioning accuracy of smartphone GNSS module can reach sub meter level [3], and the static positioning accuracy of fixed ambiguity can reach centimeter level [7, 9–11], but the dynamic high-precision positioning is still a challenge task during current research and application. Besides the GNSS module, the performance of INS module in smartphones has also been significantly improved in recent years. In the previous research, we integrated the specific acceleration and gyro angular velocity of INS module from smartphone with the professional level GNSS receivers, and the positioning accuracy is 0.2 m, the velocity measurement accuracy is 0.3 m/s, the roll and pitch angle accuracy is 1°, and the heading angle accuracy is 5° [12, 13]. which shows that the smartphone has the fundamental hardware conditions for the GNSS/INS coupled navigation.

In order to validate the GNSS/INS coupled navigation system based on the Android smartphone, we developed the GNSS/INS data synchronous acquisition platform for the smartphone, and also developed the corresponding coupled navigation program. In order to assess the accuracy and stability of the proposed coupled navigation system, taking the P40 mobile phone released by Huawei in 2020 as an example, we carried out a vehicle test.

2 The Android Smartphone Based GNSS/INS Coupled Navigation System

The coupled navigation system based on GNSS/INS can take the full advantages of GNSS high-precision positioning and INS high-frequency estimation of the position, attitude, and velocity. The performance of GNSS and INS modules coupled in current Android smartphones have been greatly improved, and they have the hardware fundamental for the coupled navigation. In the building process of the GNSS/INS coupled navigation system based on the smartphones, we need to solve the problems of synchronous data acquisition of GNSS and INS, as well as the problems of the design and structure adjustment of the Kalman filter.

2.1 The Synchronous Data Acquisition Platform of GNSS and INS for the Android Smartphones

The GNSS/INS coupled navigation system needs to synchronously collect the data of these two modules. Currently, the apps that can collect GNSS raw observation data from the Android smartphones mainly include: Geo++ RINEX logger, Google Gnsslogger, FLAMINGO, etc. Google Gnsslogger is open source, but the quality of the recorded data is not as good as the other closed source apps, and most of current research are based on the Geo++ RINEX logger, which is a closed source app.

Due to the limitation of the mechanism of the Android interaction, the system allows one active layout only, which makes it difficult to synchronously record the data of INS module when logging the GNSS data using the app of Geo++ RINEX logger. Recent years, the smartphone manufacturers have released the new mobile desktop systems, such as Huawei's EMUI desktop mode, Samsung's DEX desktop, and Smartisian TNT desktop, which can run multiple apps on one "wireless projected display" like the PC platform. Based on this platform, we developed an app for INS data collection via Android studio. The time system for the collected INS data is synchronized with GPS time. In the process of data collection, we use Huawei's EMUI desktop mode to project the Geo++ RINEX logger and the developed app onto a laptop's display, as shown in Fig. 1, so as to realize the synchronous collection of GNSS and INS data.

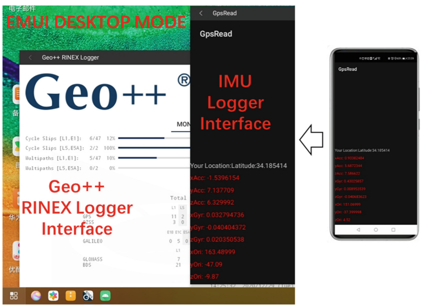


Fig. 1. The smartphone internal GNSS/INS data requisition interface in the Huawei "EMUI Desktop" mode.

2.2 The Kalman Filter for the GNSS/INS Coupled Navigation

The Kalman filter for the GNSS/INS coupled navigation system consists of two parts: the prediction process and the observation update process. The prediction process consists of INS accelerometer and gyroscope observations, and the update process consists of GNSS observations. The detail explanations of the prediction and the update process of the Kalman filter can be found in the reference of [13, 14], which are not listed in this article.

In practical application, we also found that the sampling frequencies of some Android accelerometers and gyros are inconsistent. For instance, the acceleration of Huawei P40 is in 100 Hz, while the gyroscope is in 50 Hz, so it is difficult to adapt the inconsistent data to the Kalman filter process. If resampling the acceleration data to 50 Hz, the half of acceleration data will be lost, which will degrade the precision of the results of coupled navigation. The method of adjusting the structure of the prediction equation can include all the acceleration data, so as to improve the accuracy and stability of the system [13].

3 Vehicle Test

In order to assess the accuracy and stability of the GNSS/INS coupled navigation system, we conducted a vehicle test in the campus of China University of mining and technology, on December 10, 2020.

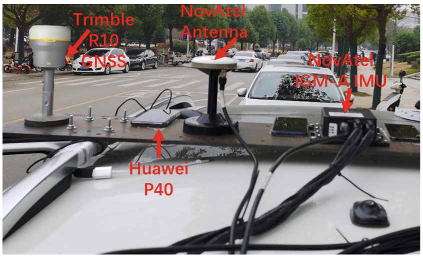


Fig. 2. The setting up of the devices in the road test.

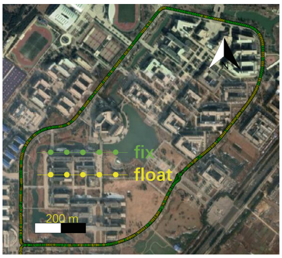
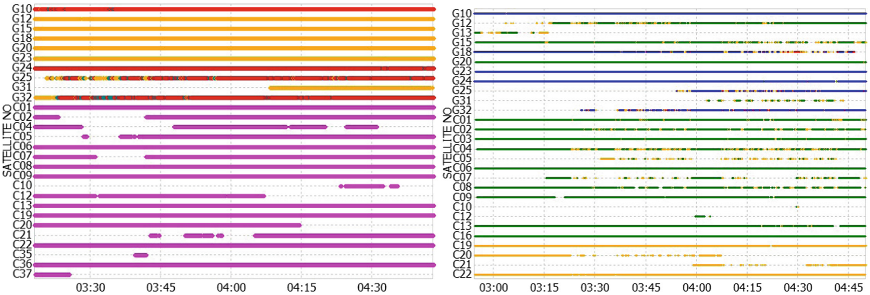


Fig. 3. The trajectory of the road test.

As shown in Fig. 2, we fixed a metal plate on the top of a Sports-Utility-Vehicle, and fixed a Trimble R10 GNSS receiver (1 Hz), a NovAtel IGM-A INS (200 Hz) device, and a Huawei P40 mobile phone on the metal plate. Besides the devices strapped on the vehicle, another Trimble R10 GNSS receiver (1 Hz) was fixed as the differential base station at the experimental area. During this test, the vehicle speed is about 25 km/h, the trajectory is shown in Fig. 3, and the data acquisition time is about 50 min.

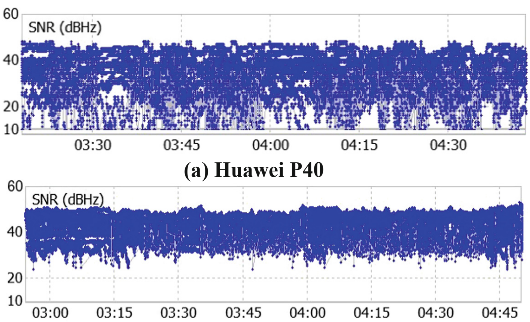
3.1 The Performance of the Smartphone's GNSS



(a) Huawei P40 **(b) Trimble R10**

Fig. 4. The satellite vision plots of the Huawei P40 and Trimble R10. Colors: green-L1/2; red-L1/5; orange-L1; pink-L2; blue-L1/2/5.

For the analysis of Huawei P40 and Trimble R10 GNSS and the collected GNSS data, the visible GPS/BDS satellite situation is shown in Fig. 4, and the SNR (Signal Noise Ratio) is shown in Fig. 5. As can be seen from Fig. 4, the GNSS module built in Huawei P40 mobile phone supports the reception and decode of the L1/L5 dual frequency multi constellation data (only GPS and BDS are analyzed in this paper), but its stability is still far behind that of Trimble R10, a professional receiver. By comparing the signal-to-noise ratio in Fig. 5, it can be found that the average signal strength of Huawei P40 GNSS is about 35 dBHz, which is about 10 dBHz lower than the mild average signal strength of Trimble R10, which is consistent with the conclusion of other literatures [3, 15].



(b) Trimble R10

Fig. 5. The SNR plots of the Huawei P40 and Trimble R10.

In this article, the RTKLIB software was used to process the rover GNSS data from the Trimble R10 and the Huawei P40 (Hi-1101 chip) in the post differential model, combing with the GNSS reference station. The overview of the position difference between the Huawei P40 and Trimble R10 is 10–20 cm in the horizontal direction, and around 50 cm in the vertical direction.

3.2 Huawei P40 GNSS/INS Coupled Navigation

The GNSS positioning results and the IMU data were coupled for the navigation processing, and the strategies are:

- (Trimble) R10-GNSS/IGM-A (NovAtel) navigation results (high precision GNSS and INS, reference)
- (Trimble) R10-GNSS/INS (Huawei P40) coupled navigation results (high precision GNSS and low precision smartphone INS coupled navigation, result 1)
- (Huawei P40) GNSS/INS coupled navigation results (only low precision smartphone coupled navigation, result 2)

During these strategies, the IMU data from the Huawei P40 (ICM-20690 chip) was taken as the INS information, and the detailed specifications about this IMU could also be referred to [13].

3.2.1 Accuracy Assessment

Taking the (Trimble) R10-GNSS/IGM-A (NovAtel) high-precision coupled navigation results as the reference of this test, the accuracy and stability of (Trimble) R10-GNSS/INS (Huawei P40), and (Huawei P40) GNSS/INS are compared and analysed. Figure 6 shows the differences between the position/attitude results and reference values. The differences show a stable trend between the time of 3:58 and 4:08, since the car was pull over for checking the working status of these devices.

By analysing the trends in Fig. 6, we can find that Huawei P40 INS can achieve significant results in the coupled navigation either with high-precision GNSS Trimble R10 (blue line in the figure) or with its own GNSS module (red line). The accuracy of the results is further analyzed, as shown in Table 1. It can be concluded from the table that the root mean square of the differences between the position calculation result and the reference value is about 0.2 m, the roll and pitch attitude angle is about 0.16°, and the heading angle is 1.7°. This shows that the coupled navigation system based on GNSS and INS modules from this Android smartphone can achieve high accuracy results in the positioning and attitude determinations.

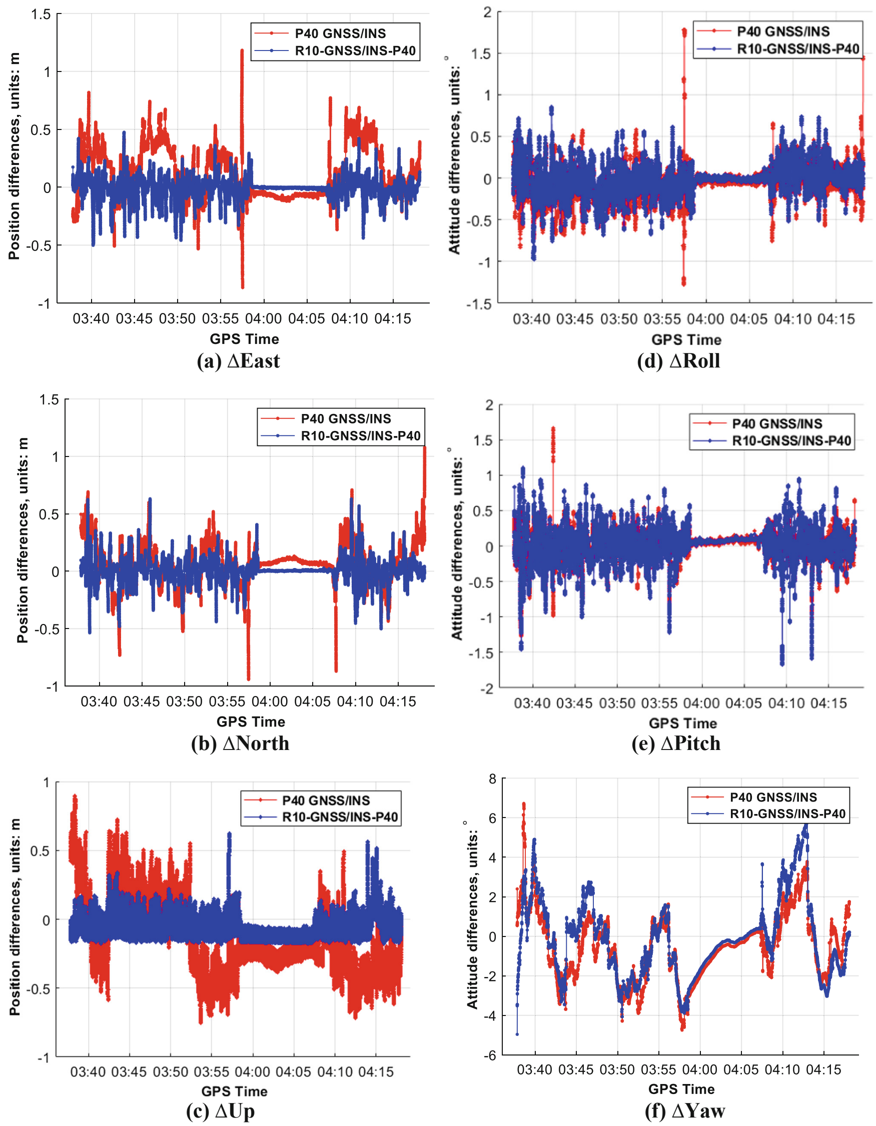


Fig. 6. The position and the attitude differences between the P40 coupled navigation and the references.

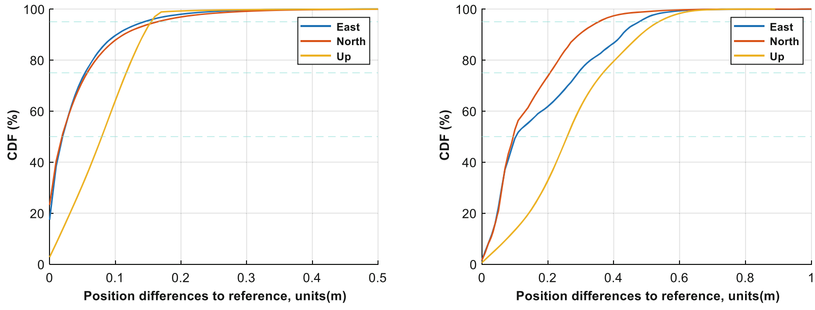
Table 1. The statistics of the differences between the R10-GNSS/P40-INS coupled and the references, between the P40 GNSS/INS coupled and the references.

	R10-GNSS/P40-INS				P40 GNSS/INS			
	min	max	mean	rms	min	max	mean	rms
ΔNorth (m)	−0.5360	0.6300	0.0030	0.0769	−0.9420	1.0780	0.0686	0.1689
ΔEast (m)	−0.5010	0.4740	−0.0068	0.0678	−0.8660	1.1820	0.1151	0.2135
ΔDown (m)	−0.1822	0.6242	−0.0603	0.0781	−0.7556	0.8949	−0.1486	*0.2764*
ΔRoll (°)	−0.9856	0.8552	−0.0194	0.1681	−1.2791	1.7826	−0.0588	0.1641
ΔPitch (°)	−1.6805	1.1142	0.0243	0.2351	−1.2762	1.6606	0.0191	0.1696
ΔYaw (°)	−4.9617	6.0949	−0.1665	1.9643	−4.7646	6.7237	−0.5474	*1.7095*

3.2.2 Stability Analysis

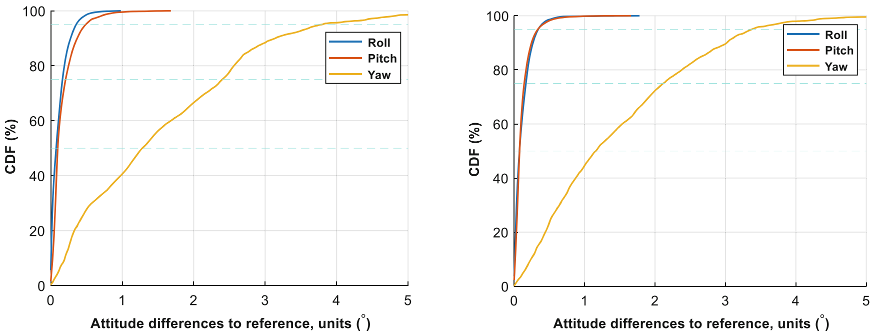
To further analyze the stability of Huawei P40 GNSS/INS coupled navigation system, we performed CDF (Cumulative Distribution Function) analysis on the difference sequences in Fig. 5, as shown in Figs. 7 and 8.

As can be seen from Fig. 7(b), 95% of the position difference is distributed within 0.5 m, and 75% is distributed within 0.3 m; as can be seen from Fig. 7(b), the stability of attitude difference in roll and pitch attitude is in a good condition, 95% is concentrated within 0.3°, while the stability of heading angle is not well enough, around 75% is within 2°. Therefore, the stability of P40 GNSS/INS coupled navigation results also reach a significant level.



(a) R10-GNSS/Huawei-INS **(b) Huawei P40 GNSS/INS**

Fig. 7. The CDF curves of position differences between the P40 GNSS/INS coupled navigation and the references.



(a) R10-GNSS/Huawei-INS **(b) Huawei P40 GNSS/INS**

Fig. 8. The CDF curves of attitude differences between the P40 GNSS/INS coupled navigation and the references.

4 Conclusion

Through the research of the GNSS/INS coupled navigation method based on the Android smartphone, we can see that using the smartphone can obtain high precision and stability determination results of the position and attitude. It can greatly promote the applications of precision navigation in the mass market, and has great potential especially in the areas of current unmanned vehicle, smart city, and disaster quick response. In the application, we also found that the quality and integrity of GNSS data observed by smartphones are still insufficient, the rate of integer ambiguity solving is very low, and the accuracy of coupled navigation heading angle is not good enough. We need to further explore more effective and lower cost methods to solve these problems, for instance, the fusions of multi frequencies of the GNSS constellations [16–18], and the adoption of the artificial intelligence strategies [19].

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