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Optimal weighting approach for real-time positioning with Android smartphones

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Abstract

The performance of real-time positioning with Android smartphones is evaluated in this study considering two fundamental weighting approaches, which rely on satellite elevation angle and carrier to noise ratio (C/N0) values, respectively. The experimental test conducted in this study includes the observation dataset of Xiaomi Mi 8 and Google Pixel 4 smartphones collected by the Android GPS team in the kinematic environment. First, this study analyzes the observation dataset to understand the stochastic characteristics of observations acquired from smartphones. The analyses revealed that the dependency of smartphone observations on satellite elevation angle is considerably lower compared with high-grade geodetic receivers. The experimental tests indicated that it is possible to obtain more accurate positioning solutions when applying the C/N0-dependent weighting approach. Compared with the elevation-dependent weighting approach, the C/N0-dependent weighting approach improves the positioning performance of Xiaomi Mi 8 and Google Pixel 4 smartphones by 30.1% and 36.5%, respectively.

1. Introduction

The raw GNSS (Global Navigation Satellite System) observations collected from Android devices have been accessible since 2016. From this date on, positioning, navigation, and timing applications with Android devices, especially smartphones, have received considerable interest from the GNSS community. The main reason behind this substantial attention is that low-cost chipsets on smart devices still dominate the GNSS mass market (GSA 2019). However, due to the specific restrictions, such as the high noise level of observations, low protection against the multipath effect, and discontinuities in carrier phase observations, it is very demanding to achieve high positioning performance with smartphones (Paziewski et al. 2019). As a result, many studies have been made in recent years to evaluate and advance the positioning performance of smartphones based on the positioning techniques of real-time kinematic (RTK), single- and dual-frequency Precise Point Positioning (PPP) (Robustelli et al. 2019; Odolinski and Teunissen 2019; Liu et al. 2021).

In the current literature, many studies have analyzed the performance of smartphones with relative or differential positioning techniques that depend on reference stations equipped with geodetic receivers (Geng and Li 2019; Gao et al. 2021). Besides, some studies employ another smartphone as the reference station, named smartphone-to-smartphone positioning (Paziewski et al. 2021). As revealed by these studies, it is possible to reach relatively high positioning accuracy with smartphones using relative or differential positioning techniques. Still, the base station(s) requirement is the main limitation of these techniques. Also, relative or differential positioning techniques require carrier phase observations to achieve high positioning accuracy, although carrier phase observations acquired from smartphones are usually disrupted because of missing phase observations and abrupt phase shifts (Paziewski et al. 2019; Zangenehnejad and Gao 2021). On the other side, absolute positioning applications that include a single GNSS receiver are of great interest to GNSS users. This substantial interest is mainly because of eliminating the requirement for a simultaneous reference station or network. In addition, absolute positioning techniques can present the desired positioning accuracy for most location-based services applied with smartphones. Therefore, a considerable number of studies have recently been conducted for standalone positioning

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applications with smartphone observations in the literature (Aggrey et al. 2020; Wang et al. 2020; Robustelli et al. 2021).

Regardless of the applied positioning technique, the application of a proper stochastic model is one of the most critical points for achieving high positioning accuracy with smartphones. Since smartphones generally contain relatively low-cost antennas, the stochastic characteristics of observations acquired from smartphones are quite different from those of geodetic GNSS receivers. Therefore, it is crucial to apply an optimal weighting scheme that is able to reflect actual stochastic characteristics of observations in smartphone positioning. In the current literature, there has been a limited number of studies that specifically analyzed the positioning performance of smartphones in terms of observation weighting approaches. In this regard, this study aims at analyzing the performance of real-time standalone positioning with smartphones on the basis of observation weighting approaches. Firstly, this study evaluates the characteristics of smartphone observations collected in the challenging environment, i.e., in the urban area and kinematic mode. Also, two fundamental weighting approaches, which are respectively dependent on elevation angle and carrier to noise ratio (C/N0), are assessed for real-time positioning performance with smartphones.

2. Method

This study includes the standalone positioning that relies on single-frequency code pseudorange observations. Basically, code pseudorange observation (P) on the ith frequency can be expressed by the following equation:

$$P_{i,r}^{s,k} = \rho_r^{s,k} + c(dt_r^s - dT^{s,k}) + T_r^{s,k} + I_i^{s,k} + c\left(b_{i,r}^s - B_i^{s,k}\right) + \varepsilon(P_{i,r}^{s,k}) \quad (1)$$

where subscript r indicates the receiver, while superscripts s and k demonstrate the GNSS index and satellite number. Additionally, ρ is the geometric range between the receive and satellite, c is the velocity of light, dt and dT are the receiver and satellite clock offsets, T is the tropospheric delay, I is the first-order ionospheric delay on ith frequency, b and B are the receiver and satellite code hardware biases, respectively and ε indicates the observation noise and multipath for the related observation.

In this study, single-frequency code observations on L1, G1, E1, and B1 frequencies are employed for GPS, GLONASS, Galileo, and BeiDou satellites, respectively. The International GNSS Service (IGS) Real-time Service (RTS) products are also used to obtain real-time satellite orbits and clock corrections. Besides, the ionospheric delay is mitigated using the ionospheric corrections provided in IGS-RTS products. On the other side, the tropospheric delay is corrected by the Saastamoinen model (1972) combined with the VMF3 (Vienna Mapping Functions 3) and GPT3 (Global Pressure and Temperature 3) model (Landskron and Böhm 2018). In this study, an extended version of PPPH is used to conduct all real-time processes (Bahadur and Nohutcu 2018).

When it comes to observation weights, two weighting approaches, which respectively rely on elevation angles and C/N0 values, are employed in this study. Traditionally, the elevation-dependent weighting method is expressed as follows:

$$\sigma_P^2 = \sigma_{P_0}^2 + \sigma_{P_0}^2 \cos\left(E^2\right) \quad (2)$$

where $\sigma_{P_0}^2$ denotes the initial observation variance, E is the satellite elevation angle and σ_P^2 represents the related observation variance. The standard deviation of code pseudorange observations is typically used as 0.3 m.

On the other hand, the C/N0 dependent weighting method can be given as follows:

$$\sigma_P^2 = \frac{\alpha\beta_L}{c/n_0}\lambda_c \quad (3)$$

where c/n_0 indicates the carrier-to-noise density calculated as $10^{(C/N0)/10}$ in dB-Hz for $C/N0$ values, λ_c is the wavelength of P- or C/A-code (29.305 and 293.05 m). α and β_L represent the dimensionless delay lock loop discriminator correlator factor and equivalent code loop noise bandwidth, which are approximated as $\alpha = 0.5$ and $\beta_L = 0.8$ Hz (Langley 1996).

3. Results and Discussion

In this section, the observation dataset utilized in the experimental tests is introduced. Afterward, the observations collected from smartphones are analyzed in several aspects. Finally, this section provides the results obtained from the experimental tests conducted for evaluating the impact of weighting approaches on the performance of real-time positioning with smartphones.

3.1. Observation dataset and analysis

In recent years, the Android GPS team has provided the benchmark dataset so that researchers can test their algorithms and positioning models with Android smartphones. This study employs the benchmark dataset collected from two different smartphones, Xiaomi Mi 8 and Google Pixel 4, placed above the dashboard of the test vehicle moving along a highway in the US San Francisco Sunnyvale on January 5, 2021. The smartphones contain GNSS receivers that can collect dual-frequency multi-GNSS observations with a sampling interval of 1 second. Besides, the dataset provides the ground truth information obtained from an external positioning system that combines the NovAtel SPAN IMU (Inertial Measurement Unit) with RTK positioning. The external coordinates can be used as a reference for assessing the positioning performance of smartphones. Figure 1 indicates the geometry of the experimental setup, including the positions of smartphones, GNSS antenna, and SPAN IMU (Fu et al. 2020).

The observations collected from two different smartphones in the kinematic environment are evaluated in several aspects. These smartphones can collect dual-frequency observations on civilian GNSS signals only. As an example, code and phase observations on L1 and L5 frequencies can be collected by smartphones for GPS satellites. In this regard, Table 1 indicates the average number of tracked satellites on the corresponding frequencies of GPS, GLONASS, Galileo, and BeiDou constellations per epoch for two smartphones.

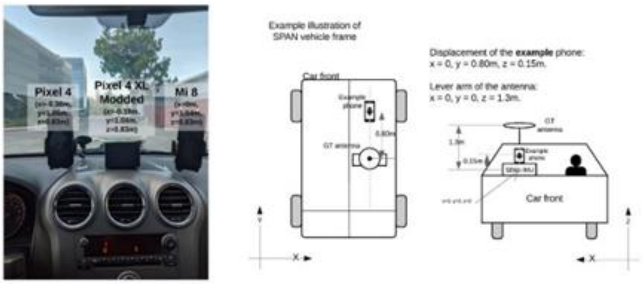

Figure 1. Geometry of the experimental setup used for the observation dataset (Fu et al. 2020).

Table 1. Average number of tracked satellites per epoch for two smartphones.

System	Frequency	Smartphone	
		MI8	PIXEL 4
GPS	L1	8.07	7.93
	L5	5.38	5.36
GLO	G1	4.28	5.80
GAL	E1	4.47	5.96
	E5	4.59	5.60
BDS	B1	3.74	2.68

To evaluate the quality of observations acquired from smartphones, C/N0 values that represent the GNSS signal strength are analyzed as a part of this study. Figure 2 illustrates the C/N0 values of specific GNSS satellites obtained from the Xiaomi Mi 8 and Google Pixel smartphones during the observation period. In this figure, the y-axis represents the C/N0 values (dB-Hz), while the x-axis represents the elevation angle of the corresponding satellite in degree. As can be seen from the figure, there is no considerable dependency between C/N0 values and satellite elevation angle, which is a very different situation from the high-grade geodetic receivers. These results show that the traditional weighting approaches which mainly rely on the satellite elevation angle can be insufficient in representing the actual stochastic characteristics of smartphone observations.

3.2. Positioning performance

The observation dataset was processed based on the elevation- and C/N0-dependent weighting approaches, separately. To evaluate the positioning accuracy, positioning errors were computed as the difference between the acquired coordinates and ground truth from the related positioning process for each epoch in the local coordinate system (North, East, and Up). The epoch-wise coordinates obtained from the external IMU system were used as the ground truth in the computation of positioning errors. Figure 3 indicates the scatter plots of three-dimensional (3D) positioning errors obtained from two weighting approaches for the Mi 8 and Pixel 4 smartphones. In addition, Table 2 shows RMS values of horizontal, vertical, and 3D positioning errors obtained from the Mi 8 and Pixel 4 smartphones with the elevation- and C/N0-dependent weighting approaches. It can be seen from the table that the C/N0-dependent weighting approach provides a better positioning performance for both smartphones. When compared with the elevation-dependent weighting approach, the C/N0-dependent weighting method improves the 3D positioning accuracy by 30.1% and 36.5% for Mi 8 and Pixel 4 smartphones, respectively.

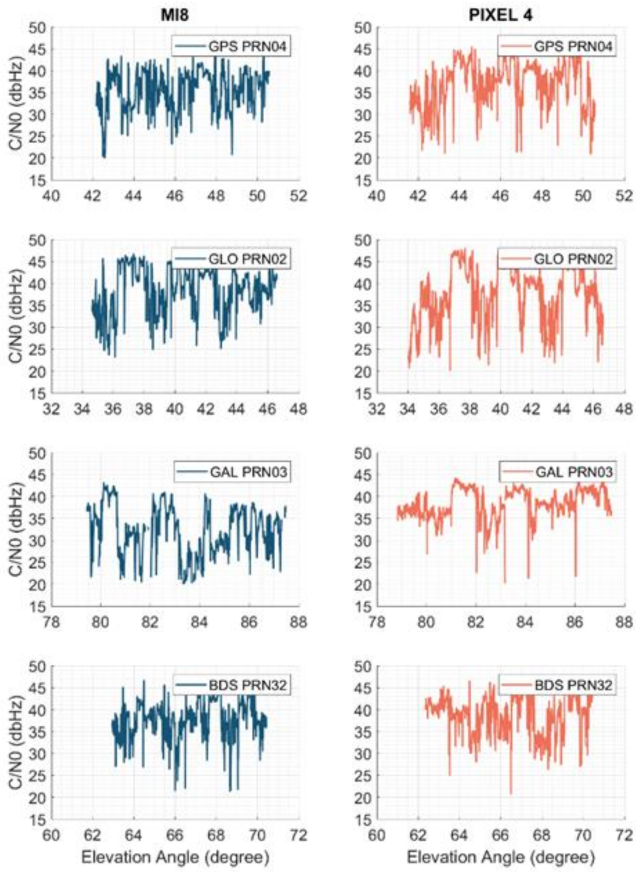

Figure 2. C/N0 values of specific GNSS satellites for Xiaomi Mi 8 and Google Pixel 4 smartphones

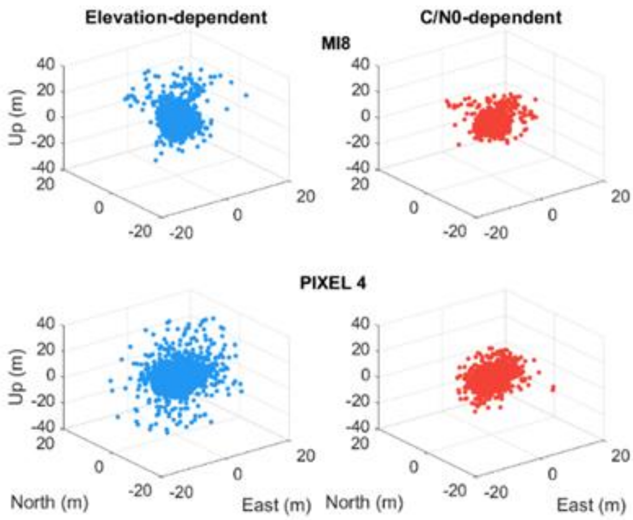

Figure 3. 3D positioning errors of Mi 8 and Pixel 4 smartphones for elevation- and C/N0-dependent weighting approaches

Table 2. RMS values of horizontal, vertical, and 3D positioning errors for Mi 8 and Pixel 4 smartphones with elevation- and C/N0-dependent weighting approach

	Weighting approach	Positioning error		
		Horizontal	Vertical	3D
MI8	Elevation	3.720	4.992	6.673
MI8	C/N0	2.902	3.231	4.663
PIXEL 4	Elevation	5.134	7.483	9.640
PIXEL 4	C/N0	3.344	4.689	6.119

4. Conclusion

This study evaluates the performance of real-time positioning with smartphone observations collected in the kinematic environment using two fundamental weighting approaches, namely elevation- and C/N0-dependent. The observation dataset of two smartphones, including Xiaomi Mi 8 and Google Pixel 4, is utilized in this study to evaluate the impact of two weighting approaches. The results revealed that C/N0 values acquired from smartphones are not significantly dependent on satellite elevation angle, which is a very different situation from the high-grade geodetic receivers. As a result, the traditional weighting approaches which mainly rely on the satellite elevation angle can be insufficient in representing the actual stochastic characteristics of smartphone observations. The experimental tests proved that the C/N0-dependent weighting approach provides considerably better positioning performance for both smartphones when compared with the elevation-dependent weighting strategy. Considering the 3D positioning errors, the C/N0-dependent weighting approach enhances the positioning accuracies of the Mi 8 and Pixel 4 smartphones by 30.1% and 36.5% in comparison with the elevation-dependent weighting approach.

References

Aggrey, J., Bisnath, S., Naciri, N., Shinghal, G., & Yang, S. (2020). Multi-GNSS precise point positioning with next-generation smartphone measurements. Journal of Spatial Science, 65(1), 79-98. https://doi.org/10.1080/14498596.2019.1664944

Bahadur, B., & Nohutcu, M. (2018). PPPH: a MATLAB-based software for multi-GNSS precise point positioning analysis. GPS Solutions, 22(4), 1-10. https://doi.org/10.1007/s10291-018-0777-z

Bahadur, B. (2022). A study on the real-time code-based GNSS positioning with Android smartphones. Measurement, 194, 111078. https://doi.org/10.1016/j.measurement.2022.111078

Fu, G. M., Khider, M. & van Diggelen, F. (2020). Android Raw GNSS Measurement Datasets for Precise Positioning. In Proceedings of the 33rd International Technical Meeting of the Satellite Division of The Institute of Navigation (2020), pp. 1925-1937

Gao, R., Xu, L., Zhang, B., & Liu, T. (2021). Raw GNSS observations from Android smartphones: Characteristics and short-baseline RTK positioning performance. Measurement Science and Technology, 32(8), 084012. https://doi.org/10.1088/1361-6501/abe56e

Geng, J., & Li, G. (2019). On the feasibility of resolving Android GNSS carrier-phase ambiguities. Journal of Geodesy, 93(12), 2621-2635. https://doi.org/10.1007/s00190-019-01323-0

GSA, European GNSS Agency (GSA) GNSS Market Report Issue 6, European GNSS Agency: Prague, Czech Republic, 2019. https://doi.org/10.2878/031762

Landskron, D., & Böhm, J. (2018). VMF3/GPT3: refined discrete and empirical troposphere mapping functions. Journal of Geodesy, 92(4), 349-360. https://doi.org/10.1007/s00190-017-1066-2

Langley, R. B. (1996). GPS receivers and the observables, in: A. Kleusberg, P.J.G. Teunissen (Eds.), GPS for Geodesy, Lecture Notes in Earth Sciences, vol. 60, Springer, Berlin.

Liu, Q., Gao, C., Peng, Z., Zhang, R., & Shang, R. (2021). Smartphone positioning and accuracy analysis based on real-time regional ionospheric correction model. Sensors, 21(11), 3879. https://doi.org/10.3390/s21113879

Odolinski, R., & Teunissen, P. (2019). An assessment of smartphone and low-cost multi-GNSS single-frequency RTK positioning for low, medium and high ionospheric disturbance periods. Journal of Geodesy, 93(5), 701-722. https://doi.org/10.1007/s00190-018-1192-5

Paziewski, J., Sieradzki, R., & Baryla, R. (2019). Signal characterization and assessment of code GNSS positioning with low-power consumption smartphones. GPS Solutions, 23(4), 1-12. https://doi.org/10.1007/s10291-019-0892-5

Paziewski, J., Fortunato, M., Mazzoni, A., & Odolinski, R. (2021). An analysis of multi-GNSS observations tracked by recent Android smartphones and smartphone-only relative positioning results. Measurement, 175, 109162. https://doi.org/10.1016/j.measurement.2021.109162

Robustelli, U., Baiocchi, V., & Pugliano, G. (2019). Assessment of dual frequency GNSS observations from a Xiaomi Mi 8 Android smartphone and positioning performance analysis. Electronics, 8(1), 91. https://doi.org/10.3390/electronics8010091

Robustelli, U., Paziewski, J., & Pugliano, G. (2021). Observation quality assessment and performance of GNSS standalone positioning with code pseudoranges of dual-frequency Android smartphones. Sensors, 21(6), 2125. https://doi.org/10.3390/s21062125

Saastamoinen, J. (1972). Contributions to the theory of atmospheric refraction. Bulletin Géodésique (1946-1975), 105(1), 279-298. https://doi.org/10.1007/BF02522083

Wang, G., Bo, Y., Yu, Q., Li, M., Yin, Z., & Chen, Y. (2020). Ionosphere-Constrained Single-Frequency PPP with an Android Smartphone and Assessment of GNSS Observations. Sensors, 20(20), 5917. https://doi.org/10.3390/s20205917

Zangenehnejad, F., & Gao, Y. (2021). GNSS smartphones positioning: Advances, challenges, opportunities, and future perspectives. Satellite Navigation, 2(1), 1-23. https://doi.org/10.1186/s43020-021-00054-y