ACHIEVING CENTIMETERS-LEVEL GPS POSITIONING ACCURACY USING A SMARTPHONE FOR MAPPING APPLICATIONS

Marcin Uradziński[1], Mieczysław Bakuła[2]

[1] University of Warmia and Mazury, Faculty of Geoengineering, Department of Geodesy, Poland;
[2] Polish Air Force University, Institute of Navigation, Poland

KEY WORDS: smartphone positioning, GNSS, GPS, centimeters accuracy, Huawei P30 Pro, phase measurements, ambiguity fixation.

ABSTRACT:

Nowadays, GNSS chips inside modern smartphones deliver high-quality code and carrier phase measurements which may be applied in various mobile applications, especially in mapping applications. In this situation, the usefulness of a professional geodetic receiver is commonly met to reach centimeters and sub-centimeter accuracies. To obtain such precise positioning results, carrier-phase measurements should be used. Therefore, we decided to check the Huawei P 30 Pro smartphone GNSS-based positioning system which may be an excellent tool to fast and accurately measure the points or details which may need to be precisely mapped with accuracies within centimeters. According to the tested smartphones' postprocessing RTKLib 2.4.3 software results, we could fix all L1 ambiguities based on GPS-only satellite constellation. After the comparison to reference fixed point position, for all 1-hour static session results, positioning errors were at centimeters level of accuracy (1-5cm). For fast static surveying mode, the best results were obtained for 30-minute sessions, where average accuracy was also at centimeters level (close to the level of a professional geodetic receiver).

1. INTRODUCTION

In recent years, a technical development environment that enables access to raw GNSS measurements has been introduced to smartphones. In the beginning, researchers using mobile satellite signal data for high-accuracy surveying purposes had no successful results in ambiguity fixing, which caused submeter positioning results [1-3]. The first significant technological breakthrough in smartphone positioning was in the year 2017 when the Broadcom company released the first dual-frequency GNSS chipset (BCM47755). Such a step was followed by other producers like Qualcomm or U-blox, who presented chipsets with multi-constellation and multi-frequency technology [4,5]. GNSS observations in smartphones suffered not only from high antenna noise but also from anomalies such as duty cycling and gradual accumulation of phase errors. Such a problem appeared with early GNSS chipsets built into smartphones, such as the Xiaomi Mi 8 [6–8]. This problem occurred when the GNSS chipset of the smartphone worked in a discontinuous way, which caused the hardware clock to be active only for a fraction of each second to support battery power saving [9,10]. Google Nexus 9 was the first smartphone that enabled the continuous collecting of GNSS observations. The research results of the static data analysis showed that the positioning accuracy ranged from below 1 m to a few decimeters depending on experimental setups for positioning based on carrier-phase observations [11,12].

Today, GNSS chips inside the latest mobile phones deliver high-quality code and carrier phase measurements which are applied in various mobile applications. To obtain the most precise positioning results, carrier-phase measurements should be used. Therefore, the use of geodetic receivers with applied advanced positioning algorithms is met to obtain centimeter and sub-centimeter positioning accuracies. Additionally, multi-frequency GNSS observations and multi-constellations allow us to apply advanced algorithms for postprocessing and even real-time (RTK) positioning techniques for smartphones [13,14]. Obtaining high positioning accuracies using GNSS technology relies on carrier phase observations and the capability to fix their ambiguities to the correct integer values [15]. So far GNSS chipsets built into mobile phones mainly provided code and phase measurements only on the single frequency L1/E1. Nowadays, developers started extracting high-quality raw measurements on various frequencies in a RINEX format (Receiver Independent Exchange Format) that was best suited for post-surveying processing and analysis. Current mobile applications such as Rinex ON or Geo++, give an opportunity to collect GNSS data and conduct numerous research in GNSS positioning. While considering carrier phase GNSS observations, one should also mention their practical applications. Mobile GNSS-based positioning system provides an excellent tool to quickly, accurately, and reliably position points of details or features which may need to be precisely mapped. Detail surveys typically require an accuracy between 1 and 10 centimeters. There are also some applications, like utility mapping, which require decimeter accuracies. Therefore, the authors of this paper focused on checking the Huawei P30 Pro smartphone performance and positioning accuracy results for the potential usefulness in mapping applications.

2. SMARTPHONE SURVEYING METHODOLOGY

To obtain a centimeter level of accuracy using carrier-phase observations, precise information on the average phase center position of the internal smartphone antenna and possible phase center variations is needed. In our previous experimental work concerning phase center determination, we conducted measurements where the smartphone was placed on the base made of the aluminum beam with a centrally positioned mandrel that allows mounting it on the leveling head which is centered over the reference point [16]. The central Huawei P30 Pro smartphone was fixed in three various positions on the aluminum base. Firstly, mounted vertically, then, lying along

the beam (parallel), and for the last option—perpendicularly to it. At the same time, for all phase-center determination measurements, two additional GNSS Javad Alpha receivers were mounted at the North-end and South-end locations of the aluminum beam. The base was equipped with a professional sensitive compass allowing the positioning of the base along the North–South line. The carrier phase measurements were collected using RINEX ON latest software and processed using commercial Topcon Tools post-processing software with reference to the closest OPNT (ASG-EUPOS network) base station located 4 km away. Based on this, the mobile phone phase center information was determined by us very precisely (millimeter level of accuracy).
For our main positioning experiment, we collected raw static data in two separate 1-hour sessions during the two following days. Based on the numerous tests conducted, to obtain the best positioning results, we decided to mount smartphones vertically (not horizontally) at a distance of 1 m from each other on the same base made of an aluminum beam with a centrally positioned mandrel (Figure 1).

Figure 1. Equipment and surveying environment

The aluminum beam pointed exact North-South direction. The first smartphone called (SMART1_OPAL), was located on the North edge, and (SMART2_BLACK) on the South edge. In both cases, smartphone displays were facing South. In the central point of the aluminum beam, the geodetic GNSS Javad Alpha receiver was positioned and acted as a positioning reference point. The Huawei P30 Pro smartphones have the possibility to collect data from GPS, GLONASS, GALILEO, and BEIDOU positioning systems. Due to the GPS and GLONASS observations only at the OPNT reference station, for the postprocessing using RTKLib v.2.4.2 software, we decided to use GPS-only observations. GPS plus GLONASS calculations were also made, but no better results were obtained than with GPS-only. Before processing the data, we prepared the example of the first-day south-located Huawei P30 Pro GPS constellation and L1 signal quality comparison in reference to the geodetic receiver using RTKLib GNSS software (Figures 2 - 5).

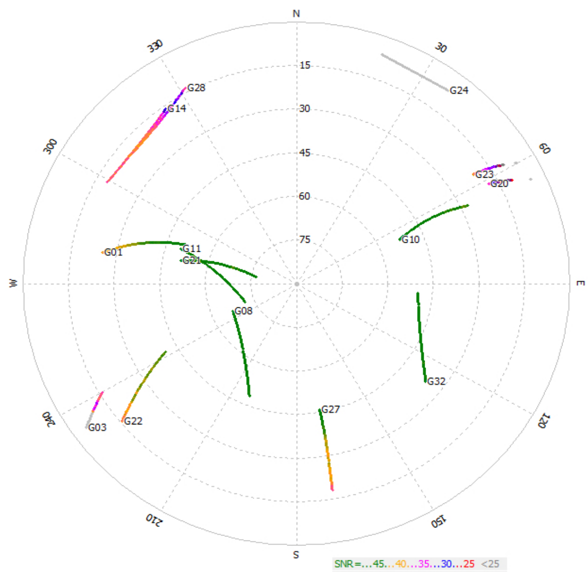

Figure 2. GPS constellation for Javad Alpha reference receiver

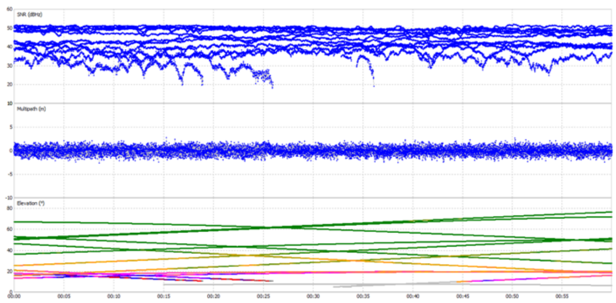

Figure 3. L1 signal quality for Javad Alpha reference receiver

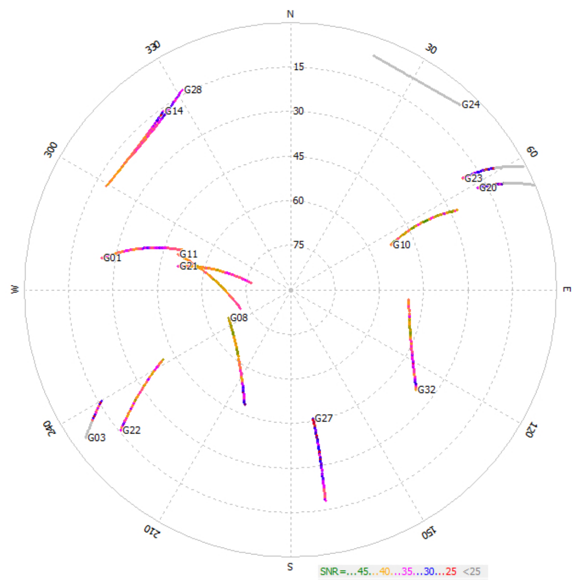

Figure 4. GPS constellation for Huawei P30 Pro smartphone (SMART2_BLACK)

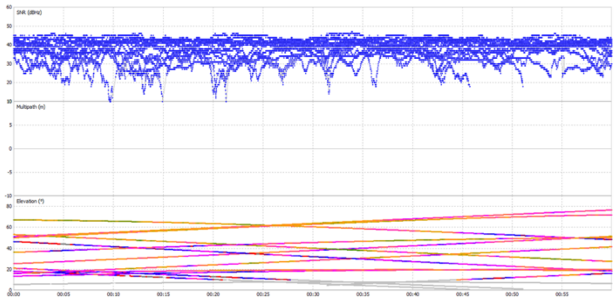

Figure 5. L1 signal quality for Javad Alpha reference receiver

Concerning the ratio of the power of the carrier phase signal to the power of noise, it should be noted that it is the most important factor depending on the class of receiver and type of antenna. There are limitations of embedded smartphone GNSS antennas addressed to the subject of low gain and low multipath elimination.

3. POSITIONING RESULTS ANALYSIS

Considering two positioning tests, in both cases, Huawei P30 Pro smartphones were mounted in a vertical position at a distance of 1 m from each other. In the central point of the aluminum beam, the geodetic GNSS Javad Alpha receiver was positioned and used for positioning results comparisons. Static coordinate results were computed based on carrier phase observations obtained from the OPNT permanent station and compared to the reference position. 1-hour sessions were divided into 15, 20, and 30-minute separate sub-sessions to check surveying results accuracy for fast static mode and ending on 1-h session. For all time intervals, the best results were obtained with GPS-only L1 carrier phase measurements, where all the ambiguities were fixed. The computation of baseline coordinates in all cases was provided by RTKLib v. 2.4.3 software. During the 1-h session, the number of observed GPS satellites did not drop below 8, and the average number was 9 satellites. Tables 1-4 present the positioning accuracy results of the first-day test.

SMART1_OPAL				SMART2_BLACK			
minutes	dx (m)	dy (m)	dh (m)	minutes	dx (m)	dy (m)	dh (m)
0-15	0.054	0.125	-0.106	0-15	0.049	0.119	-0.087
15-30	0.059	0.111	0.131	15-30	0.045	0.098	0.122
30-45	0.049	0.076	-0.124	30-45	0.052	0.059	0.098
45-60	0.041	0.072	-0.055	45-60	0.056	0.061	-0.081
min	0.041	0.072	-0.124	min	0.045	0.059	-0.087
max	0.059	0.125	0.131	max	0.056	0.119	0.122
StDev	0.008	0.026	0.117	StDev	0.005	0.029	0.112

Table 1. Coordinate differences between Javad reference receiver and Huawei smartphones for 15min sessions (day 1)

SMART1_OPAL				SMART2_BLACK			
minutes	dx (m)	dy (m)	dh (m)	minutes	dx (m)	dy (m)	dh (m)
0-20	0.039	0.104	-0.088	0-20	-0.040	0.087	-0.061
20-40	-0.027	0.079	-0.081	20-40	-0.032	0.061	-0.066
40-60	0.009	0.049	-0.058	40-60	0.031	-0.034	0.041
min	-0.027	0.049	-0.088	min	-0.040	-0.034	-0.066
max	0.039	0.104	-0.058	max	0.031	0.087	0.041
StDev	0.033	0.028	0.016	StDev	0.039	0.064	0.060

Table 2. Coordinate differences between Javad reference receiver and Huawei smartphones for 20min sessions (day 1)

SMART1_OPAL				SMART2_BLACK			
minutes	dx (m)	dy (m)	dh (m)	minutes	dx (m)	dy (m)	dh (m)
0-30	-0.021	0.053	-0.065	0-30	-0.011	0.033	-0.039
30-60	0.013	0.043	-0.041	30-60	0.033	-0.013	0.021
min	-0.021	0.043	-0.065	min	-0.011	-0.013	-0.039
max	0.013	0.053	-0.041	max	0.033	0.033	0.021
StDev	0.024	0.007	0.017	StDev	0.031	0.033	0.042

Table 3. Coordinate differences between Javad reference receiver and Huawei smartphones for 30min sessions (day 1)

SMART1_OPAL				SMART2_BLACK			
minutes	dx (m)	dy (m)	dh (m)	minutes	dx (m)	dy (m)	dh (m)
0-60	0.011	0.041	-0.044	0-60	0.013	0.027	-0.028

Table 4. Coordinate differences between Javad reference receiver and Huawei smartphones for a 60min session (day 1)

Smartphone positioning accuracy results for the second day are presented in Tables 5-8.

SMART1_OPAL				SMART2_BLACK			
minutes	dx (m)	dy (m)	dh (m)	minutes	dx (m)	dy (m)	dh (m)
0-15	-0.066	0.141	0.139	0-15	-0.049	0.111	0.103
15-30	0.021	0.193	-0.131	15-30	0.034	0.151	-0.120
30-45	-0.088	0.097	-0.221	30-45	-0.042	0.079	-0.188
45-60	0.058	0.037	-0.095	45-60	0.040	0.046	-0.081
min	-0.088	0.037	-0.221	min	-0.049	0.046	-0.188
max	0.058	0.193	0.139	max	0.04	0.151	0.103
StDev	0.070	0.066	0.153	StDev	0.048	0.045	0.124

Table 5. Coordinate differences between Javad reference receiver and Huawei smartphones for 15min sessions (day 2)

SMART1_OPAL				SMART2_BLACK			
minutes	dx (m)	dy (m)	dh (m)	minutes	dx (m)	dy (m)	dh (m)
0-20	-0.041	0.122	0.088	0-20	-0.020	0.084	0.082
20-40	-0.064	0.119	-0.081	20-40	-0.022	0.102	-0.074
40-60	0.021	0.023	-0.058	40-60	0.015	0.034	-0.041
min	-0.064	0.023	-0.081	min	-0.022	0.034	-0.074
max	0.021	0.122	0.088	max	0.015	0.102	0.082
StDev	0.044	0.056	0.092	StDev	0.021	0.035	0.082

Table 6. Coordinate differences between Javad reference receiver and Huawei smartphones for 20min sessions (day 2)

This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-525-2023

SMART1_OPAL				SMART2_BLACK			
minutes	**dx (m)**	**dy (m)**	**dh (m)**	**minutes**	**dx (m)**	**dy (m)**	**dh (m)**
0-30	-0.033	0.081	0.045	0-30	-0.016	0.064	0.058
30-60	-0.027	0.029	-0.047	30-60	0.013	0.027	-0.030
min	**-0.033**	**0.029**	**-0.047**	**min**	**-0.016**	**0.027**	**-0.030**
max	**-0.027**	**0.081**	**0.045**	**max**	**0.013**	**0.064**	**0.058**
StDev	**0.004**	**0.037**	**0.065**	**StDev**	**0.021**	**0.026**	**0.062**

Table 7. Coordinate differences between Javad reference receiver and Huawei smartphones for 30min sessions (day 2)

SMART1_OPAL				SMART2_BLACK			
minutes	**dx (m)**	**dy (m)**	**dh (m)**	**minutes**	**dx (m)**	**dy (m)**	**dh (m)**
0-60	**-0.029**	**0.047**	**-0.056**	**0-60**	**-0.017**	**0.029**	**-0.038**

Table 8. Coordinate differences between Javad reference receiver and Huawei smartphones for a 60min session (day 2)

4. CONCLUSIONS

In the conducted measurements, the mobile phones were used with the option of data recording of GPS, GLONASS, GALILEO, and BEIDOU positioning systems. This creates the possibility of tracking over 25 satellites simultaneously during the test measurements. Unfortunately, GALILEO and BEIDOU observations were not recorded at the reference station, even though the system owner informs us that such data is available for postprocessing. Therefore, only L1 frequency observations for the GPS system were used for comparative calculations in the described tests. In addition, GPS plus GLONASS calculations were made, but no better results were obtained than with GPS-only. According to the postprocessing results, we could fix all L1 ambiguities based on GPS-only satellite constellation. After the comparison to reference fixed point position, for all 1-hour static session results, positioning errors were at centimeters level of accuracy (1-5cm). For fast static surveying mode, the best results were obtained for 30-minute sessions. Generally, the accuracy of smartphone static positioning was obtained at the centimeters level which means that undoubtedly a new era has arrived for GNSS systems, where every mobile phone user will have the opportunity to obtain a position with such high accuracy. What's more, mobile phone manufacturers provide L1/L5 observations from the GPS and GALILEO systems. This creates much greater positioning options, both autonomous positioning (enabling even decimeter accuracy of autonomous positioning), as well as for static measurements and RTK techniques. However, it should be noted that the phase observations on L1 frequency are currently much worse for the tested Huawei P30 pro compared to a high-class GNSS geodetic receiver. There are some unfixed ambiguities with observations of even a few minutes which is caused by the low quality of the smartphone carrier phase observations at the moment of observation. Even when we conducted measurements in such perfect environmental conditions, the number of cycle slips, smartphone antenna noise, and multipath effect are larger as compared to a geodetic GNSS receiver. This has a direct effect on the quality of float solutions for many epochs.

REFERENCES

1. Yoon, D.; Kee, C.; Seo, J.; Park, B., 2016. Position accuracy improvement by implementing the DGNSS-CP algorithm in smartphones. Sensors (Switzerland) 2016, doi:10.3390/s16060910.

2. Banville, S.; Van Diggelen, F., 2016. Precision GNSS for everyone precise positioning using raw GPS measurements from android smart phones. GPS World 2016, 27, pp. 43–48.

3. Al Khairy, M., 2018. Snapdragon X24: World's first announced 2 Gbps LTE modem. Qualcomm, 14 February 2018. Available online: https://www.qualcomm.com/news/onq/2018/02/14/snapdragon-x24-worlds-first-announced-2-gbps-lte-modem (accessed on 12 May 2020).

4. Zhang, X.; Tao, X.; Zhu, F.; Shi, X.; Wang, F., 2018. Quality assessment of GNSS observations from an Android N smartphone and positioning performance analysis using time differenced filtering approach. GPS Solutions. 2018, 22, 70.

5. Cozzens, T., 2018. U-blox F9 platform designed for high-precision mass market. GPS World, 22 February 2018. Available online: https://www.gpsworld.com/u-blox-f9-platform-designed-for-high-precision-mass-market/ (accessed on 15 april 2023).

6. Robustelli, U.; Baiocchi, V.; Pugliano, G., 2019. Assessment of dual frequency GNSS observations from a Xiaomi Mi8 Android smartphone and positioning performance analysis. Electronics 2019, 8, 91.

7. Warnant, R.; Van De Vyvere, L.; Warnant, Q., 2018. Positioning with Single and Dual Frequency Smartphones Running Android or Later. In Proceedings of the 31st International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2018), Miami, FL, USA, 24–28 September 2018; pp. 284–303.

8. Chen, B.; Gao, C.; Liu, Y.; Sun, P., 2019. Real-time Precise Point Positioning with a Xiaomi MI 8 Android Smartphone. Sensors 2019, 19, 2835.

9. Linty, N.; Lo Presti, L.; Dovis, F.; Crosta, P., 2014. Performance analysis of duty-cycle power saving techniques in GNSS mass-market receivers. In Proceedings of the Position, Location and Navigation Symposium-PLANS 2014, Monterey, CA, USA, 5–8 May 2014; pp. 1096–1104.

10. Pirazzi, G.; Mazzoni, A.; Biagi, L.; Crespi, M., 2017. Preliminary performance analysis with a GPS+Galileo enabled chipset embedded in a smartphone. In Proceedings of the ION GNSS+ 2017, Institute of Navigation, Portland, OR, USA, 25–29 September 2017; pp. 101–115.

11. Hakansson, M., 2018. Characterization of GNSS observations from a Nexus 9 Android tablet. GPS Solutions. 2018, 23, 21.

12. Realini, E.; Caldera, S.; Pertusini, L.; Sampietro, D., 2017. Precise GNSS positioning using smart devices. Sensors 2017, 17, 2434.

13. Sui, M.; Gong, C.; Shen, F., 2022. An optimized stochastic model for smartphone GNSS positioning. Frontiers in Earth Science 2022, 10, DOI=10.3389/feart.2022.1018420

14. ElKhalea, M. F., Hendy, H. M., Kamel, A. M., Arafa I. I., Abosekeen, A., 2022. Smartphone Positioning Enhancement Using Several GNSS Satellite Selection Techniques. 2022 5th International Conference on Communications, Signal Processing, and their Applications (ICCSPA), Cairo, Egypt, 2022, pp. 1-6, doi: 10.1109/ICCSPA55860.2022.10019004.

15. Li, B., Miao, W., Chen, G., Li, Z., 2022. Ambiguity resolution for smartphone GNSS precise positioning: effect factors and performance. Journal of Geodesy 2022, volume 96, https://doi.org/10.1007/s00190-022-01652-7

16. Uradziński, M., Bakuła, M., 2020. Assessment of Static Positioning Accuracy Using Low-Cost Smartphone GPS Devices for Geodetic Survey Points' Determination and Monitoring. Applied Sciences*. 10(15):5308, https://doi.org/10.3390/app10155308*