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Recent advances and perspectives for accurate positioning with low-cost smart devices

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ABSTRACT

Nowadays, satellite-based positioning systems have become the most widely used method for fast, reliable and accurate positioning in many different areas. With this method, 3D position of fixed or moving objects can be determined in the range of meters to cm level depending on the method used and the experimental setups. Among them, when it is possible to determine the position in meters with code measurements using a single GNSS receiver, this accuracy can reach cm (even mm) levels in case the carrier phase measurements are used. With the conventional GNSS positioning approach, it is sufficient to use receivers of a few hundred USD for the first method, however, the second group that requires high accuracy should use geodetic-grade receivers with prices about 10,000 USD or more. Recently, several low-cost systems have been used as an alternative to highly expensive geodetic GNSS receivers for precise positioning. The most prominent of these are hand-held GNSS receiver, smart-phones / tablets, and OEM-type GNSS receivers, and these devices are widely used in many fields, including geodetic applications. In this study, the usability of these different mobile devices in geodetic measurements was reviewed and shared in the light of the literature.

1. INTRODUCTION

Today, satellite-based positioning techniques have become widely used tools for positioning and timing in many different areas. At the beginning, there was only NAVigation Satellite Timing And Ranging-Global Positioning System (NAVSTAR-GPS) developed by the United States Department of Defense, later operated by Russia, GLObal'na NAvigatsionnaya Sputnikovaya Sistema (GLONASS), Galileo operated by the European Union and BeiDou Navigation Satellite System (BDS) operated by the People's Republic of China, an integrated global positioning system called the Global Navigation Satellite System (GNSS) has emerged. With GNSS, depending on the method applied and the equipment used, 3D position of static or moving objects can be determined within the accuracy level of meters to cm. Some of the main features of these systems are given in Table 1.

It is routinely possible to determine the 3D position with meter-level accuracy by using the code measurements collected with a single GNSS receiver. Unfortunately, this accuracy cannot meet the requirements for many surveying applications that require high-accuracy. In this case, the carrier phase observations should also be used. While the hand-held GNSS receivers of a few hundred USD may be sufficient for the first one, the second one requires multi-frequency geodetic-grade GNSS receivers (and antennas) whose prices can reach up to USD 10,000 or even more.

Table 1. The main features of Global Positioning Systems

Parameter	GPS	GLONASS	Galileo	BDS
First Launch Date, FOC	22-Feb-78 17-Jul-95	12-Oct-82 95	21-Oct-11 -	31-Oct-00 -
Total Sat. in Constellation	32	27	30	49
Orbital Planes	6	3	3	3
Inclination with Equator	55°	64.8°	56°	55°
Coordinate Frame	WGS-84	PZ-90	GTRF	CGCS2000
Time System	GPST	UTC (SU)	GST	BDT
Signal / Frequencies (MHz)	L1(C/A): 1575.42 L1(C): 1575.42 L2(C): 1227.60 L2(P): 1227.60 L5: 1176.45	L1(C/A): 1598.0625-1609.3125 L2(C): 1242.9375-1251.6875 L2(P): 1242.9375-1251.6875 L3(OC): 1202.025	E1: 1575.42 E5a: 1176.45 E5b: 1207.14 E5 AltBOC: 1191.795 E6: 1278.75	B1l: 1561.098 B2l: 1207.14 B3l:1268.52 B1C:1575.42 B2a: 1176.45 B2b: 1207.14

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Recently, as an alternative to high-cost geodetic type GNSS receivers, hand-held GNSS receiver, Android mobile devices (i.e. smart-phones, tablets etc.), and OEM-type GNSS receiver, which allow to collect and process the raw data, have been widely used in many areas. These types of devices can perform single or multi-frequency pseudorange and carrier phase measurements and provide a significant alternative to geodetic GNSS receivers in many applications by providing positioning at different levels as post-mission and/or RTK modes.

In this study, the geodetic surveying performances of different kinds of devices that can be used as an alternative to the widely used geodetic type GNSS receivers will be reviewed.

2. BRIEF REVIEW of GNSS POSITIONING TECHNIQUE

In general, GNSS positioning is carried out in two main ways: Absolute Positioning and Relative Positioning Methods. For Absolute Positioning, it is possible to determine the position within an accuracy of a few meters, depending on the environment in which it is used, also the number and geometry of the satellites. However, the attainable accuracy of this method is not sufficient for many surveying applications.

Recent advances in satellite geodesy, data analysis and processing techniques have led to the emergence of many algorithms and approaches that make it possible to determine the position with high accuracy (cm-dm) using GNSS data collected with only a single receiver. One of these is the technique called Precise Point Positioning (PPP), which is widely used all over the world in several different applications. By using code and carrier phase observations obtained by a single GNSS receiver, PPP method performs 3D point positioning either in real-time and/or in post-mission, combines with precise orbit and clock corrections produced by mainly International GNSS Service (IGS) and others to obtain centimeter-level positioning accuracy. However, using a single GNSS receiver with PPP technique also has a disadvantage such as necessity of the long occupation time for convergence (of the order of 20 minutes or more). It is important for the ambiguity float solution to converge in order to obtain centimeter-level positioning accuracy (Rizos et al. 2021).

In the Relative Positioning Method, the coordinates of the point(s) can be determined with very high accuracy according to a reference station having known coordinates. In this method, in order to make high accurate positioning, the data collected in the field should be processed in the office with a proper GNSS data processing software. This is a major drawback of the method. It also limits the use of it in real-time applications. For such applications, a method called Real-Time Kinematics (RTK) is used. However, the prominent difficulties of the method are that there is a distance limitation between the rover receiver and its reference, it requires additional equipment for data communication and may not be used due to possible problems in data communication. Instead, with another method called Network-RTK (such as CORS-TR in Turkey), it is possible to determine coordinates of a point in real time with high accuracy in a very efficient, easy and economical way. Network-RTK method requires GSM connection and therefore the field survey is limited with the coverage area of the service provider. Some of the prominent disadvantages of this method are that the GNSS receivers to be used are relatively more expensive, the installation and operation difficulties and costs of such a system.

The methods mentioned above are compared with each other in terms of their prominent features in Figure 1.

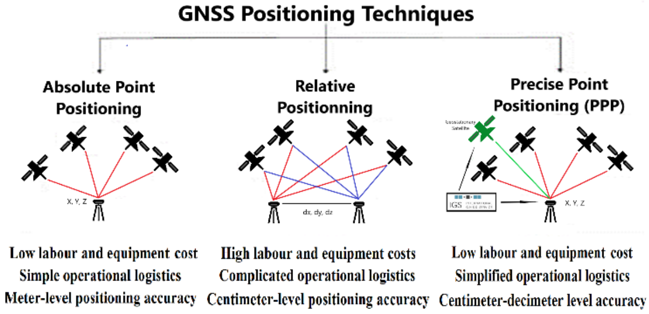

Figure 1. Comparison of GNSS positioning techniques

It should be emphasized that, in order to make high accurate positioning (i.e., within accuracy level of the cm to dm) with PPP or Relative Positioning Method, carrier phase measurements should be made together with the pseudorange measurements. However, in this case, it is required to use geodetic grade GNSS receivers (at least one for PPP and at least two for the relative method) with a unit price of USD 10,000 or more.

As an alternative to highly costly geodetic grade GNSS receivers, hand-held GNSS receivers, smart-phones/tablets and OEM-type receivers have been used in geodetic surveys as a result of developments in technology and communication. Generally, these types of systems are used today and their general performances are given below.

2.1. Positioning with hand-held GNSS receivers

Hand-held GNSS receivers have a large market for navigation, may be purchased by 100-500 USD depending on their features. At the origin, hand-held GNSS receivers perform continuously 3D positions in real-time by using only GPS satellites. Nowadays, multi-constellation hand-held receivers are available on the market.

The Department of Defense has released the latest "Global Positioning System Standard Positioning Service (SPS) Performance Standard" in April, 2020 (note that, this document can be accessed via U.S. Coast Guard Navigation Center web site, https://www.navcen.uscg.gov). The latest performance standard, for GPS SPS PVT (Position, Velocity and Time) accuracy standards are given in Table 2. As can be seen from Table 2, GPS provides global average position accuracy of 8 m (95%) for horizontal component and 13 m (95%) for vertical component; however, site environment conditions can cause severe effect on accuracy. The reason behind the limited accuracy is high level of noise that is caused by integrated low-cost GNSS antenna, in addition to satellite orbit and clock errors, ionospheric and tropospheric delays as well as multipath effects. The typical low-cost hand-held GNSS receivers can fulfill the needs of navigation users; however, geodetic positioning requires higher accuracies with geodetic type receivers.

Table 2. GPS SPS Position, Velocity and Time Transfer Accuracy Standards (as of April 2020)

Position/Time Accuracy Standard	Conditions and Constraints
Global Average Position Accuracy • ≤ 8 m 95% Horizontal Error • ≤ 13 m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Position/time solution is available
Worst Site Position Accuracy • ≤ 15 m 95% Horizontal Error • ≤ 33 m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Position/time solution is available
Global Average Velocity Accuracy • ≤ 0.2 m/sec 95% velocity error, any axis	• Defined for a position/velocity/time solution meeting the representative user conditions • Position/velocity/time solution is available
Time Transfer Accuracy • ≤ 30 ns Time Transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Time transfer solution is available

Today, some hand-held GNSS receivers can start to log raw data (pseudorange and carrier phase measurement) in RINEX format. In this case, the user can make positioning with cm-dm level of accuracy by processing the collected data. Lachapelle et al. (2018.a) investigated the GPS and GLONASS raw measurements with single frequency GNSS receiver, Garmin Rino 750 hand-held receiver. They obtained dm or better level of positioning accuracy with relative static method. PPP results produced positioning accuracies between 0.5 and 2 meters as a function of the occupation time. According to the kinematic application with the same receiver, it was possible to reach an accuracy of 2 meters (RMS) in position and 2 times lower than in height. In another research of Lachapelle et al. (2018.b), decimeter-level accuracy was obtained by processing code and carrier-phase data collected with single-frequency Garmin GPS Map66 hand-held GNSS receiver and external geodetic antenna in static and kinematic modes.

2.2. Positioning with Android Mobil Devices

In May 2016, Google introduced APIs giving access to GNSS raw measurements from Android Nougat operating system (version 7.x or 8.x). After this improvement, users will be able to log GNSS raw data. This opens the possibility to reach low-cost positioning devices for Android mobile devices including smartphones and tablets. Nowadays, almost all android devices have an integrated GNSS receiver/chip; however, the accuracy of measurements made with this type of device is much lower than it is received with geodetic receivers, and even hand-held GNSS receivers. One of the reasons for this is that the carrier-to-noise density ratios (C/N0) of smart devices are about 10 dB lower than those of geodetic receivers. Another reason is that the pseudo range measurements made in smart devices cause high levels of noise and gross errors along with the multipath caused by the internal antenna (Wang et al. 2021).

Several studies have been conducted on this topic, and very promising results have been obtained. These studies have shown that the positioning accuracy was affected from the length of the session, receiver characteristics (i.e. single or multi-frequency, multi constellation) and used antenna type. This type of devices typically provides level of a few meters accuracy and even more, depending on experimental setups and environmental conditions for navigational purposes. However, more accurate results can be obtained when carrier phase measurements are used along with the pseudo ranges. One of the important issues affecting the result here is the type of antenna used. In general, it has been seen that by processing the carrier phase data collected using device's own internal antennas, the positioning can be made with an accuracy of meters or better. It should be noted that, the GNSS measurement with smartphones/tablets etc. is closely affected by the high noise and multipath. Thus, if the code measurements are used, it is seen that the position can be determined at the order of meters. In the case of using a geodetic grade antenna, it is possible to obtain accuracies at the order of cm-dm as a result of the processing of the code and phase measurements in static mode. For kinematic positioning approach, lower accuracies are obtained (Humphreys et al. 2016; Dabove et al. 2019; Geng and Li 2019; Håkansson 2019; Lachapelle and Gratton 2019; Robustelli et al. 2019; Uradziński and Bakuła 2020; Wen et al. 2020).

In general, it can be concluded that, use of android smart devices having multi-frequency and multi-constellation GNSS receiver with an external geodetic antenna shows promising results to use them as an alternative to geodetic receivers.

2.3. Positioning with OEM-Type GNSS receivers

The use of low-cost systems, commonly referred to as Original Equipment Manufacturers (OEM) type GNSS receivers, began in the late 1990s. OEM receivers, with their accuracy, have been an important alternative to highly expensive geodetic grade GNSS receivers and have been used successfully in several surveying projects (Figure 2).

Figure 2. OEM-type GNSS receiver boards

It is possible to measure and record multi-frequency, multi-constellation pseudorange and carrier phase data with these types of receivers. However, in such systems, connections between components (e.g., board, antenna, power supply, data collection unit, etc.) have to be assembled by user. Besides, lack of easy user interfaces and the need for users to develop many stages by themselves cause such systems to be used only in certain areas. In general, OEM-type GNSS receivers with geodetic antennas can provide cm-dm level accuracy in static and kinematic modes by fixing the carrier phase ambiguities (Lu et al. 2019; Dabove et al. 2020).

3. CONCLUSION

Position data will continue to be more important in many areas and applications on future as it is today. This means that the need for accurate and fast positioning will continue to increase day by day. Therefore, the production of position data at different accuracy levels will always maintain its importance.

Today, geomatics engineers and many technicians around the world are using satellite-based positioning techniques for accurate, fast and cost-effective positioning. Traditionally high-cost geodetic receivers were required for this purpose, however, in the current situation, new type of low-cost mobile platforms like hand-held receivers, smart devices, OEM-type GNSS receivers, have been started to be used as economical alternatives. Indeed, it is possible to determine the position with dm or better level of accuracy with these type of low-cost devices (<500-1,000 USD). The use of these devices will be a serious alternative to geodetic type receivers and will decrease the necessity of geodetic receivers.

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