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Position Solution Quality Performance of Compact, Low-cost, Dual Frequency GNSS Modules

Somnath Mahato* (1), Mrinal Goswami(2) and Anindya Bose(1)
(1) The University of Burdwan, Burdwan, INDIA; email: smahato@scholar.buruniv.ac.in; abose@phys.buruniv.ac.in
(2) Integrated Test Range, DRDO, Chandipur, INDIA; e-mail: mrinal.goswami.itr@gov.in

Abstract

GNSS is used for various types of positioning applications. To enhance the quality of positioning, multiple positioning techniques are developed with solution accuracy/ precision varying between meter to mm level. Together with the costly GNSS geodetic receivers, to meet the user requirements of cost-effectiveness, compact, low-cost, single (CLS) and dual-frequency (CLD) modules are commercially available those can be used with compact, commercial patch antennas. This manuscript presents a systematic review on the positioning performance of the CLD GNSS modules for various positioning techniques- SPP, PPP, and RTK with varying baseline lengths. Based on real-time data collected from India, the results show the encouraging potential of such compact modules for GNSS based positioning. It is seen that for the same set of GPS-only data SPP provides 2-3 m solution accuracy and PPP provides mm to decimeter level accuracy for Online and Offline operations respectively. In RTK operation, while used as the Rover the module provides sub-meter solution precision up to a baseline length of 200+ km.

1 Introduction

Global Navigation satellite system (GNSS) offers precise Position, Navigation and Timing (PNT) information using satellite data. Signals from all global (GPS (USA), GLONASS (Russia), Galileo (EU), Beidou (China), and regional (QZSS (Japan), and IRNSS/ NavIC (India)) and regional (QZSS (Japan), and IRNSS/ NavIC (India)) systems are accessible for use from India, and users from the region can exploit the benefit for real-time applications.

Popularity of GNSS for real-life application development generated need for improved solution quality at affordable price. To meet these growing needs, several GNSS-based positioning methods and various types of GNSS hardware have been developed. The GNSS positioning techniques are divided into two categories- absolute positioning and relative positioning. In case of absolute positioning, the instantaneous (Single Point Positioning (SPP)) or post-processed (Precise Point Positioning (PPP)) [1], position solution values in three coordinates can be computed using a single receiver with an antenna at any location, and appropriate processing method. SPP allows rapid solution precision of 5m or less. While in case of PPP, post-processing of the locally collected data from a standalone receiver and augmentation data from additional sources, such as the International GNSS Service (IGS) [2] provide significantly better solution quality after a certain time of data collection. In case of relative positioning, (Differential GNSS (dGNSS) and Real Time Kinematic (RTK)) [1] at least two receiver-antenna combinations are used. With respect to a reference receiver (Base), one or more user receivers (Rovers) situated within a distance up to 40km can provide precise, real-time position solution utilizing code-based measurements (dGNSS) or carrier-phase based measurements (RTK). The instantaneous solution errors generated at the Base with respect to the a-priori location coordinates are transmitted over wireless links (Radio or Internet) that is used by the Rovers to process this error data together with the locally collected data to improve their solution quality [3-4]. Because of the manifold advantages RTK is a popular technique for real-life application development [5].

Expensive geodetic or special-purpose GNSS receivers are generally used for numerous PNT and non-PNT science applications. Keeping the price tag within limit for real-life application development, compact (<100 gm), inexpensive (<300 USD) GNSS modules were introduced commercially by several manufacturers. These modules can use signal from multiple GNSS constellations in single (Compact low-cost single frequency (CLS)) or multiple (Compact low-cost dual frequency (CLD)) GNSS frequencies with the associated advantages of compactness, economy and low power requirement; these modules are now used for various PNT and non-PNT applications. Few such modules can provide GNSS raw data enabling PPP, dGNSS and RTK operation.

Although the CLD GNSS modules have been explored for positioning purposes [6], a systematic study on their position solution capability in different positioning techniques is not properly explored, which is done in this manuscript. This works systematically presents the results of the positioning capability of CLD GNSS modules in SPP, PPP and short- and long-baseline RTK. The next section presents the experimental plan followed by the results and finally the conclusions are presented.

2 Experimental Schematic

An uBlox ZED F9P (F9P) CLD module [7] together with an uBlox ANN commercial patch antenna [8] is used for GNSS SPP, PPP, and as the RTK rover as shown in Figure 1 wherein the data processing schematic is also shown. The

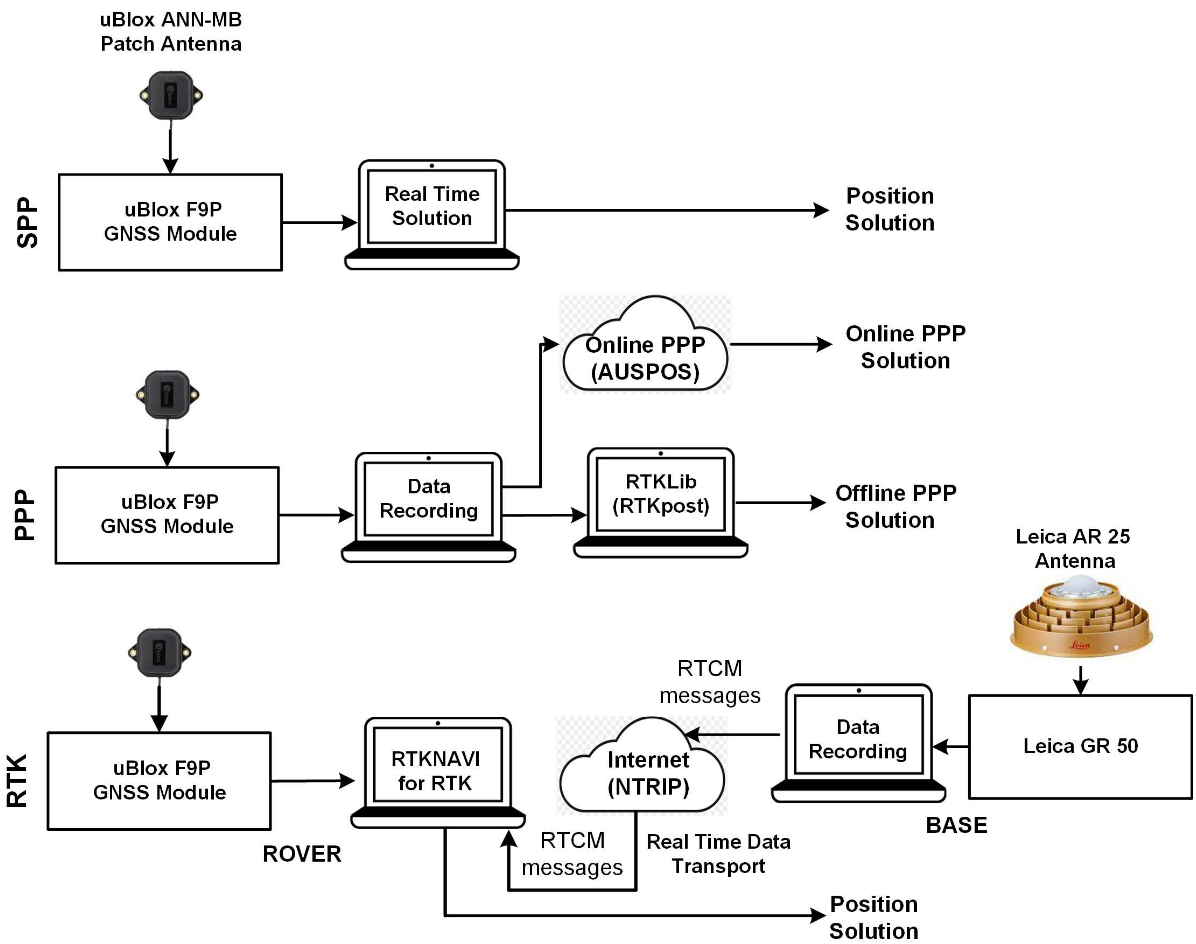

Figure 1. Experimental configuration of SPS, PPP and RTK using compact GNSS module

total cost of the hardware is less than 380 USD and open-source GNSS data processing software is used in the work.

For SPP, data from the F9P-patch antenna (placed in an open-sky condition) combination is directly collected to a computer using the u-center software from uBlox [9] on 12 February 2021. The computer also supplies power to the F9P module and records SPP solution data. Data is collected for 24 hours in GPS dual-frequency operation @1Hz, this dataset is also used for PPP solution quality analysis as described below.

For PPP, same real-time, dual frequency, GPS raw dataset (in *.ubx* format) @1Hz is used. This raw data is first converted into Receiver INdependent Exchange (RINEX) [10] format using the 'RTKCONV' utility of the RTKLib, a popular, open-source, GNSS data processing software tool [11]. The GPS RINEX dataset for 24 hours is processed using the 'RTKPOST' utility of RTKLib package to obtain 'Offline' PPP solution. Following settings of RTKPOST are used for the processing: masking angle 10^o, ionofree LC ionosphere correction, Saastamoinen Troposphere correction, broadcast satellite ephemeris/ clock, continuous integer ambiguity resolution in WGS 84 datum. The same dataset (used for SPP and Offline PPP) is used to obtain 'Online' PPP solution using the Natural Resources Canada (NRCan) online PPP utility [12] after 15 days of the data logging to use IGS final products for PPP. The GPS RINEX data collected for 24 hours @1Hz is uploaded to the site and the 'Online' PPP solutions are received back by email. These three exercises help to understand the positioning capability of the F9P CLD GNSS module w.r.t the same dataset collected in the same environmental condition. This 'Online' PPP solution is used as the reference coordinate (RC) of the antenna for solution quality analysis in SPP.

RTK requires a Base station to generate the error messages; at GNSS Laboratory Burdwan (GLB), The University of Burdwan, India, a Base station facility is created using a Leica GR50 multi-GNSS, survey grade receiver together with an AR25 geodetic antenna as shown in Figure 1 [13]. The precise location of the Base station is determined using the online PPP service provided by NRCan. The Base station transmits error messages in Radio Technical Commission for Maritime Services (RTCM) format using Network Transport of RTCM via Internet Protocol (NTRIP) service. A uBlox F9P with a uBlox patch antenna connected with a computer running RTKNAVI utility of RTKLib is used as the user receiver or Rover at various distances from the Base location as shown in Figure 2. RTCM messages from the Base are received at the Rover end using the GSM network. At the Rover location, the RTKNAVI utility uses local data from the F9P module and RTCM data received from the Base NTRIP caster to provide real-time precise RTK positioning solutions. Figure 2 shows the locations of the Rover w.r.t the Base locations together with the various Base-Rover distances; the Base is shown as green circle while the Rover locations are shown in red. It is to be noted that the SPP and PPP experiments have been performed at the same Base location. As shown in Figure 2, the Base-Rover combination is evaluated over the baseline lengths of 1 km, 22 km, 40 km, 50 km, 100 km, 135 km, and 220 km. For each Rover location, 1 hour GPS data is collected @1Hz. The findings of the SPP, PPP, RTK positioning performances are discussed in the following subsection.

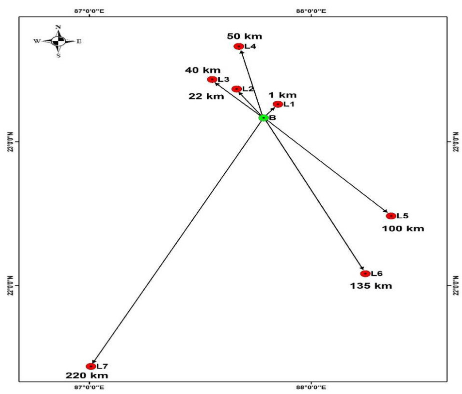

Figure 2. RTK experiments using F9P CLD GNSS module at various baseline length; the green dot represents the Base and red dots represent Rover locations.

3 Results

In this work, performance evaluation of F9P CLD GNSS module used with a commercial patch is conducted for GNSS SPP, PPP, and RTK in short to long baseline lengths.

To examine the performance of SPP and RTK, the 2 and 3-dimensional (2D, 3D) precisions parameters are calculated in terms of Distance Root Mean Square (2DRMS), Circle of Error Probable (CEP) for 2D, and Spherical Error probable (SEP), and Mean Radial Spherical Error (MRSE) for 3D as described in [14].

Table 1 shows the SPP and PPP (Offline and Online) solution qualities provided by the F9P CLD GNSS module against the same dataset. The 2D and 3D solution accuracy in SPP w.r.t the RC calculated earlier, lies between 2-3m as shown in Table 1. The results again confirm the findings presented in [15]. So, SPP using CLD GNSS modules is a very convenient and cost-efficient method of real-time geolocation when the offered solution quality is sufficient for the users.

Table 1 also shows the PPP solution quality in Offline and Online operation. Online PPP provides solution accuracy in the order of few mm (95% confidence level) in the horizontal coordinate and in centimeter-level for the vertical coordinate. This solution quality is comparable to those provided by the higher-cost, multi-constellation, multi-frequency geodetic receivers [16]. For obtaining online PPP solution, the users need to wait for some time, till the proper IGS products are not available. Whereas, the

Table 1: SPP and PPP performances offered by compact GNSS module (uBlox F9P) in GPS operation

SPS (m)		**2DRMS**	2.897
		CEP	1.348
		SEP	2.746
		MRSE	2.988
PPP (m)	**Online**	**Latitude**	0.004
		Longitude	0.003
		Altitude	0.010
PPP (m)	**Offline**	**Latitude**	0.014
		Longitude	0.013
		Altitude	0.018

'Offline' PPP using 'RTKPOST' provides faster PPP solution, though the solution quality is one order inferior, always lying between 10-20 centimeters. Therefore, for PNT and non-PNT GNSS applications, where very high quality, non-real-time position solutions are required, the CLD modules can meet the user requirements similar to the geodetic GNSS receivers, using only a single GNSS module saving the associated infrastructure cost and system complexity.

Table 2. Short to long-distance RTK performances offered by compact GNSS modules (uBlox F9P) as Rover in GPS mode

Baseline Distance (km)	**Solution precision values (m)**			
	2DRMS	**CEP**	**SEP**	**MRSE**
1	0.053	0.087	0.093	0.121
22	0.287	0.254	0.207	0.242
40	0.584	0.523	0.562	0.582
50	0.444	0.417	0.321	0.376
100	0.677	0.628	0.597	0.605
135	0.829	0.81	0.802	0.843
220	0.997	0.968	0.948	0.989

Table 2 shows the position solution quality provided by the F9P CLD module used as Rovers at different baseline distances [16]. In this case, the solution precision values are calculated following [14], as these are calculated w.r.t the average position solutions. For short baseline lengths up to around 50km, solution precision less than 50 cm both for 2D and 3D is obtained. For higher baseline lengths, the solution quality slowly degrades with increasing distance, but even for the baseline distance of more than 200 km, the 2D and 3D precision is within 1 m in GPS-only operation [16]. It is to be noted that, in this exercise, a single Base is used together with the low-cost module for RTK; real-time sub-meter position solution is achievable here reducing the overall infrastructure cost. For many real-time applications, therefore, this compact module based GNSS RTK would a good choice where decimeter-level solution quality is sufficient for the users.

4 Conclusions

This work presents the results on the applicability of the compact, low-cost, dual-frequency GNSS modules for the common GNSS-based positioning techniques. Using such a module with a commercial patch antenna, solution qualities in SPP, Offline and Online PPP, and RTK for varying baseline distances have been studied. It is seen that for the same set of GPS-only data, SPP provides 2-3 m solution accuracy, PPP provides mm to decimeter level accuracy for Online and Offline operations respectively. In short to long baseline RTK, while used as the Rover, the module always provides sub-meter solution precision. It is also witnessed that, the performance of such modules in SPP and PPP is comparable to those provided by the geodetic receivers. Therefore, exploiting the advantages of cost, size, power requirement and ease of use, the CLD GNSS modules have immense potential to cater to the need for users with varying solution quality requirements. Future work in this work would be to explore the performance of such module in hybrid-constellation operation.

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