



Potential of GNSS Post Processing Kinematic (PPK) Technique for Test Range Surveying Applications using Compact, Low Cost GNSS Modules

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Abstract

The evolution of multiple global and regional GNSS constellations over the last two decades has transformed the positioning, navigation, and timing (PNT) technology unprecedentedly by introducing an unmatched combination of precision, accuracy, convenience, and confidence. Various methods and techniques like use of dual frequency, ionospheric error-free standard positioning service (SPP/SPS), real time kinematic (RTK), and precise point positioning (PPP) have increased the level of accuracies and precision in both static and dynamic operations. This study explores the potential of dual frequency Post Processing Kinematic (PPK) RTK positioning for test range applications using compact, low cost, dual frequency (CLD), multi-constellation GNSS modules. The results show centimeter-level solution accuracy; the results would be useful in enhancing the confidence of using such systems for various applications where real time wireless connectivity between the Base and Rover is not available, or in cases where the real time connectivity between the RTK Base and Rover poses cyber security threats.

1. Introduction

Global Navigational Satellite System (GNSS) has paved the way for myriads of application both for the civilian and military users. The capabilities of professional users have been boosted through the adoption of GNSS positioning techniques by enhancing the accuracy levels from a few meters to sub-centimeter level. Positioning with carrier phase-based measurements has increased the accuracy in comparison to the code-based measurements. There are various GNSS-based positioning techniques like Single Point Positioning (SPP/ SPS), PPP (Precise Point Positioning), differential GNSS (DGNSS) and Real Time Kinematic (RTK) [1]. In SPP/ SPS, quick meter level position solution precision is achieved globally using a standalone GNSS receiver. While PPP uses post processing of data from a standalone receiver and other sources to provide much improved solution quality after a longer period. DGNSS and RTK are differential positioning techniques where more than one receiver is used; one is configured as the 'Base' and the one or more is/ are configured as the "Rover(s)". A Rover uses streamed correction data from the Base to provide instantaneous

precise position solution. Both the DGNSS and RTK techniques require a wireless communication channel to send the measurement from the Base to the Rover(s). The communication channel is established either by using a radio frequency (RF) link that has limited coverage and higher cost involvement or by using the Internet for transportation of data in Radio Technical Commission for Maritime Services (RTCM) format [2]. In case of the later, Network Transport of RTCM via Internet Protocol (NTRIP) is frequently used to provide real-time RTK service [3-4] with the advantages of cost, enhanced reach, and ease of use. DGNSS involves code-based measurements and offers decimeter-level precision solution for a few tens of km baseline distances between the Base and Rover. For more demanding applications, carrier phase based RTK is used that offers one order of better solution quality [5].

For calibration process of various sensor stations, survey is very important in Test Ranges. In pre-GNSS era, survey of stations was done by optical theodolites. With the GNSS as an additional source of trajectory, users started comparing this data with the accuracies of the sensors like Electro-Optical Tracking System (EOTS) and RADARS. After the removal of Selective Availability (SA) in May 2000 from the GPS signal, and with the introduction of the differential GPS (DGPS) concept, all the stations are calibrated using DGPS as the reference. There was additional improvement in the accuracy of the reference trajectory to the order of few meters for the calibration of the test ranges [6]. The differential GNSS positioning technique uses code-based positioning; for higher accuracy requirements, carrier-phase based RTK was established to be a more promising technique offering one order of solution quality improvement. Usually, geodetic grade, costly and bulky receivers are used for GNSS positioning applications including the RTK. Currently, compact, multi-GNSS enabled, dual frequency receiver modules are commercially available whose SPP/ SPS, PPP and RTK solution qualities are comparable to that of the geodetic receivers with the clear advantages of cost, size and power requirements. From India, there are some studies done on RTK performance comparison of geodetic and low-cost receivers [7-8]. Geodetic receivers generally use the vendor-developed algorithm to calculate RTK solution, while an open-source GNSS data processing software,

RTKLib has been used for the low-cost receivers that provide submeter level RTK precision. [9].

In case of Test Range applications, implementation of RTK system have major restrictions primarily in terms of the online Base-Rover wireless connectivity for the RTCM message transmission. Use of unsecured RF link for such communication involves the risk of eavesdropping and limited coverage. To implement the NTRIP-based RTK system, real-time Internet connectivity is required, which is also prone to cyber security threats. Also, in some locations, where the internet connectivity is not available at the Rover end, RTK cannot be implemented there. In many situations, there may be loss in connectivity due to long baseline distance/ poor internet service at the Rover location and the RTK performance degrades. In such scenarios, the best solution may be offline RTK. Post Processing Kinematic (PPK) positioning is a method of correcting and improving the precision of positioning solution data derived from GNSS constellations using the basic Base-Rover configuration, but without the need for a real-time connectivity. Here, the Rover collects the GNSS data without the need of the real-time connection together with the Base station that simultaneously collects the GNSS data for the same GNSS constellation. Unlike normal RTK, which broadcasts GNSS position corrections to the Rover in real-time, in PPK, the position solutions for the Rover are calculated through post-processing the Base and Rover data together those are concurrently collected after the data collection mission is completed [10-11]. PPK offers some flexibility over conventional RTK in terms of security and coverage area, and therefore can be employed in more challenging environments like Test Ranges within the constraint of no-real time solution availability. The user must wait for completion of the data collection campaign and post-processing to obtain the Rover coordinates. With the PPK, it is possible to perform different types of data post-processing to reduce the error. Since the PPK system doesn't require GCP (Ground Control Points), it is suitable to cater quiet large areas [10]. Research work have been performed to compare the possibility of using the PPP-Ambiguity resolution and PPK method in precise positioning of the aircrafts using two different software, RTKLib and gLAB [9, 11], but not much work is found on the use of commercially available compact, low-cost, GNSS modules for PPK work both as Base and Rover, especially in India, that is presented in this work.

This novel study presents the performance evaluation of the PPK RTK technique for Indian Test Range through (i) the use of compact, low-cost, dual frequency (CLD) GNSS modules *both at Base and Rover* ends exploiting the benefits of overall infrastructure cost, size and power reduction and (ii) use of multi-constellation hybrid GNSS operation. The exercise is carried out without the need for real-time wireless network connectivity between the Base and Rover to maintain the cyber security aspects for strategic applications. Experimental configuration, results and discussions are sequentially presented in the subsequent sections.

2. Experimental Setup and Methodology

In this effort, a compact, low-cost, dual frequency uBlox ZED F9P multi-GNSS receiver module (Price ~210 USD) [12] is used as the Base together with a Skytraq low-cost Survey Grade (price ~USD 120) antenna [13] installed on the rooftop of a building at Integrated Test Range (ITR) under open sky environment. The precise location of this Base station is obtained using offline PPP service [9] using 24hrs GPS+GLONASS data logged @1Hz rate. Another setup of uBlox ZED F9P module and a uBlox ANN patch antenna (~ USD 65) is used at the Rover end. At both the ends, the GNSS module is connected to a computer over USB which also supplies the DC power to the module. Both the uBlox ZED F9P modules are configured to provide raw data (.ubx format) in hybrid, multi-constellation GPS (L1 and L2)+Galileo (E1 and E5)+QZSS (L1) operation [12]. Concurrent data is collected at the Base and Rover end in hybrid-GNSS mode (GPS+Galileo+QZSS) for 1 hour @1Hz for multiple Rover locations with varying baseline distances. Care has been taken so that data is collected concurrently at the two ends; the small mismatch in common time span of data collection is taken care of by the post-processing software. The schematic of the data logging configuration of the low-cost PPK RTK system is shown in Figure 1. After the 1-hour data collection campaign is over for a particular Rover location, data collected at both the Base and Rover ends are taken together for further post-processing.

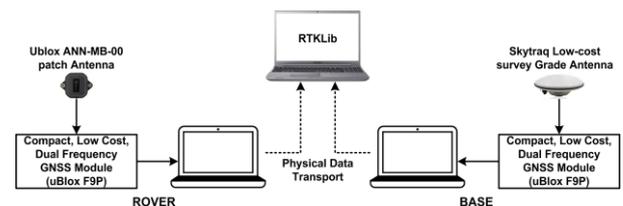


Figure 1. Schematic diagram of Post Processing Kinematic (PPK) using compact, low-cost GNSS modules at Base and Rover

GNSS data together from the Base and Rover is post-processed using RTKLib, an open source, popular GNSS data processing software [14] for PPK solution. The .ubx raw files from both the Base and Rover GNSS modules are converted into Receiver Independent Exchange Format (RINEX) files using the RTKCONV utility of RTKLib. The converted files of both Base and Rover are provided as the input for post processing in RTKPOST, another utility available in RTKLib. The data is then processed, the navigation solution for Rover location is obtained, and results are found out for multiple Rover locations. The results on PPK performance are discussed in the next section.

3. Results and Discussion

Here, the experiment is conducted for short-baseline length (<40 km) PPK performance evaluation. Figure 2 shows the 4 Rover locations (marked in red) and the Base station

Rover locations and distance from the Base	SPS/ SPP (GPS+Galileo+QZSS) (m)				PPK (GPS+Galileo+QZSS) (m)				Fix (%)	Float (%)
	2D		3D		2D		3D			
	2DRMS	CEP	SEP	MRSE	2DRMS	CEP	SEP	MRSE		
100 m (L1)	1.895	1.366	0.963	1.340	0.0131	0.0257	0.0103	0.0157	91.1	8.9
476 m (L2)	1.782	1.325	0.867	1.214	0.0144	0.0060	0.0250	0.0396	84.1	15.9
1 km (L3)	1.450	1.188	0.802	1.274	0.0503	0.0210	0.0343	0.0407	24.0	76.0
1.84 km (L4)	1.944	0.811	1.413	1.707	0.1418	0.0957	0.157	0.5613	9.9	90.1

(green). GNSS data @1 Hz for 1 hour each in SPS and PPK in hybrid, multi-constellation GNSS operation is collected from all the 4 locations. To examine the performance of PPK RTK using compact, low-cost modules both at Base and Rover, the 2 and 3-dimensional (2D, 3D) precisions parameters, standard deviation of solutions and Peak to Peak deviations in East, North, and Up directions are calculated with respect to the reference coordinates calculated using offline PPP using RTKLib [9] for each of the Rover location. For comparison, standalone SPP/ SPS solutions in the same hybrid mode is also considered.

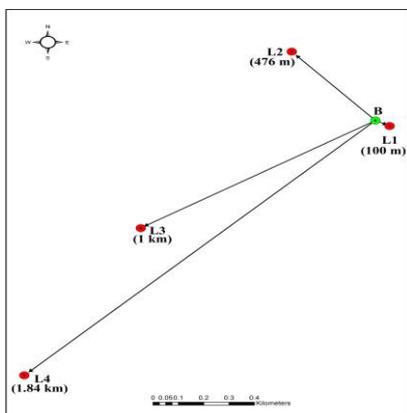


Figure 2. Different Rover Locations at Test Range Site; Base Location is marked in green and Rover locations are marked in red

Table 1 shows the position solution quality provided by the low-cost, compact Rover operating at different baseline distances in terms of Distance Root Mean Square (2DRMS), Circle of Error Probable (CEP), Spherical Error probable (SEP) and Mean Radial Spherical Error (MRSE) calculated following [14] w.r.t the PPP coordinates, so the results show the solution accuracy. The 2D and 3D position solution accuracy at the Rover end lies in centimeter level in hybrid GPS+Galileo+QZSS operation. Comparison of the PPK 2D and 3D accuracy with those obtained from SPP/ SPS clearly shows the improvement and advantage of the PPK. For example, for different baseline lengths, the 2DRMS SPS values of ~1.5m improves excellently to few cm to sub 2cm in PPK. Like normal RTK, the offline PPK RTK also provides two types of solutions- *Fix* and *Float* [7-8]. Here the *Fix* and *Float* solution percentage for different baseline lengths have also been studied for multi constellation hybrid operation.

From this study it is understood that clear environment for

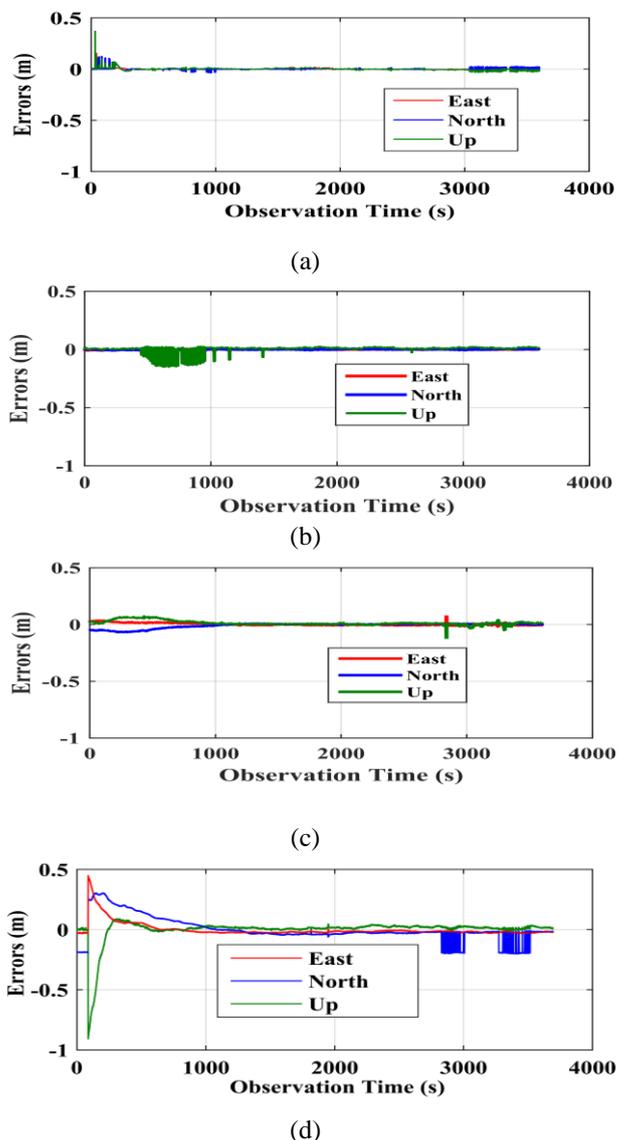


Figure 3. ENU error plots for different Rover locations (a) L1 (b) L2 (c) L3 (d) L4

the antenna placement, and common set of satellite availability at both the ends are important factors to obtain high level precision in position solution. Figure 3 shows the East (E), North (N) and Up (U) position error plots for the 4 Rover locations. It is seen that the solutions take some time to converge and therefore, for real-time applications, before the actual data collection, some time (~10-15 minutes) is to be provided after powering up the systems. Due to the low cost of the Rover, multiple Rover systems

at different locations can be used simultaneously for overall survey time efficiency.

4. Conclusions

The present study investigates the potential of cost-efficient PPK technique for precise positioning using compact, low-cost, dual frequency multi-GNSS modules both at Base and Rover ends without the need for real-time connectivity in contrast to normal RTK. The study results show that centimeter level position solution accuracy can be achieved using this offline RTK method using hybrid GNSS operation. But the drawback of this technique is the non-availability of real time position solution at Rover end. From network connectivity requirements, and most importantly network-related security issues in case of military applications, PPK is a promising candidate for surveying in strategic areas like Test Ranges, and in areas where connectivity and/ or security are important issues to consider. As there is no requirement to have real-time connectivity between the Base and Rover, and the position quality is adequate for many applications, PPK can be used for civilian and defense applications. Further research in this regard would be performance comparison of multi-GNSS and single-constellation PPK, long baseline PPK and dynamic PPK.

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