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Investigations into the quality of Kinematic PPP in open-sky using final-product APPS free online GPS-alone service

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Abstract

The Global Positioning System (GPS) delivers precise, continuous, and worldwide positioning and timing information based on satellite observations. Nevertheless, reliance on a single GNSS constellation is constrained by satellite geometry and signal availability, which may degrade positioning robustness, particularly in kinematic applications. This limited-scale study investigates the performance of kinematic Precise Point Positioning (PPP) using the free online Automatic Precise Positioning Service (APPS). The APPS platform processes alone GPS observation data and employs state-of-the-art GPS PPP algorithms developed by the NASA Jet Propulsion Laboratory to generate precise positioning solutions. The analysis was conducted under open-sky conditions to eliminate the influence of multipath effects. Dual-frequency GPS data were collected at ten spatially distributed fixed stations in Libya, each observed continuously for 24 hours. The datasets were processed in both static and kinematic PPP modes. Static PPP solutions were adopted as reference coordinates for evaluating the accuracy of the kinematic results. The findings indicate that GPS-alone kinematic PPP processed via APPS provides continuous positioning solutions; however, the achieved accuracy is limited. The Average Absolute Error (AAE) reached 0.42 m, 0.175 m, and 0.485 m in the Easting (E), Northing (N), and Height (H) components, respectively. Corresponding Maximum Average Errors (MAE) were 2.2 m in E, 1.5 m in N, and 2.3 m in H, while the Root Mean Square Errors (RMSE) were 0.50 m, 0.21 m, and 0.31 m for E, N, and H, respectively. Moreover, the proportion of kinematic epochs exhibiting absolute errors exceeding 5 cm in the horizontal components and 10 cm in the vertical component amounted to 64% in E, 38% in N, and 45% in H. Overall, the results demonstrate that the kinematic PPP solutions produced by APPS are comparatively unstable and exhibit lower precision and reliability when contrasted with other free online PPP services, such as CSRS-PPP, which are capable of achieving centimeter-level accuracy in kinematic mode even when relying solely on GPS observations.

Keywords: GPS; Precise Point Positioning (PPP); APPS; Kinematic Positioning; Open Sky

1. Introduction

Global Navigation Satellite Systems (GNSS), notably the Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS), are satellite-based positioning infrastructures that enable the estimation of instantaneous position and velocity through passive ranging observations [1–3]. GNSS operates continuously and independently of weather conditions, delivering precise real-time positioning and timing services on a global scale [4]. These systems are based on satellite constellations broadcasting signals on two principal frequencies, modulated with Coarse/Acquisition (C/A) and Precise (P) codes [5,6]. Such signals enable GNSS receivers to generate pseudo-range and carrier-phase measurements, which form the basis of contemporary navigation, mapping, and geodetic applications [7]. The positioning accuracy attainable with GNSS is governed by several factors, including satellite geometry, atmospheric propagation effects, and receiver-related characteristics [2,3].

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Positioning solutions derived from code-based measurements generally achieve meter-level accuracy, which is sufficient for applications with modest precision requirements, such as vehicular navigation [8,9], unmanned aerial vehicle (UAV) operations [10,11], and the production of low-accuracy ortho-mosaics and digital elevation models [12]. Conversely, high-precision applications, including geodetic control networks, deformation monitoring, and precision engineering, demand centimeter-level accuracy. Such accuracy can be realized through advanced processing strategies, most notably Differential GNSS (DGNSS) and Precise Point Positioning (PPP) [2,3,5].

DGNSS improves positioning precision by utilizing simultaneous observations from a reference station with known coordinates and a rover receiver located at an unknown position [13]. Through the formation of single, double, or triple differenced observations, many common error sources, such as satellite clock biases and ionospheric delays, are substantially mitigated [14,15]. Dual-frequency DGNSS configurations are capable of achieving millimeter-level accuracy, whereas single-frequency implementations typically provide decimeter-level precision at a significantly reduced cost [15]. Despite its high accuracy, the applicability of DGNSS is limited by the necessity of a nearby reference station, thereby restricting its effectiveness over large spatial extents or in remote regions [2,3].

Precise Point Positioning constitutes a globally applicable alternative that enables high-accuracy positioning without reliance on local reference stations [2,3]. PPP exploits precise satellite orbit and clock products, commonly supplied by the International GNSS Service (IGS), in conjunction with rigorous modeling of atmospheric, relativistic, and geophysical effects. Under favorable observation conditions, PPP can achieve centimeter-level accuracy in both static and kinematic modes, although it generally requires a longer convergence time compared with DGNSS. Among the available online PPP platforms, the Automatic Precise Positioning Service (APPS) is one of the most widely utilized free services, supporting both static and kinematic datasets and delivering coordinate solutions referenced to the GRS80 geodetic reference frame. APPS processes alone GPS observation files and employs state-of-the-art GPS PPP algorithms developed by the NASA Jet Propulsion Laboratory. Users may submit dual-frequency RINEX observation files, after which the system automatically applies precise satellite ephemerides, clock corrections, and atmospheric models to produce final positioning solutions.

The performance of kinematic PPP is affected by numerous factors, including the number of tracked satellites, multipath conditions, satellite constellation geometry, GNSS antenna type and quality [16], ionospheric and tropospheric modeling approaches, and the quality of the precise satellite orbit and clock products (ultra-rapid, rapid, or final) [2,3]. This limited-scale study assesses the performance of kinematic PPP using the APPS free online service with final precise ephemerides. The analysis is conducted under open-sky conditions to eliminate the influence of multipath effects. Dual-frequency GPS observations were collected at ten well-distributed fixed stations, each observed continuously for 24 hours, and processed in both static and kinematic modes. Static PPP solutions were adopted as reference coordinates for evaluating the accuracy of the kinematic results.

This research is motivated by the need for further investigation, as much of the existing literature evaluates kinematic PPP performance without fully isolating the impact of multipath effects. Additionally, many previous studies assess kinematic PPP accuracy by comparison with DGNSS-derived coordinates obtained from real-time or post-processed kinematic measurements. Such comparisons may introduce additional uncertainties, given that DGNSS solutions themselves can be influenced by multipath, unfavorable satellite geometry, extended baseline lengths, or height discrepancies between reference and rover stations. The outcomes of this study will be extended in future work to examine the effects of multipath-rich environments, the integration of kinematic PPP with MEMS-based inertial navigation systems, and vision-based navigation techniques. Future research will also focus on enhancing kinematic PPP performance in drone-based surveying applications to improve the accuracy of exterior orientation parameters for aerial imagery, thereby reducing processing time in automated image-matching workflows. Further details on related research conducted at Benghazi University concerning drone-based surveying and the enhancement of automatic image matching for vision-based navigation are available in [11], [12], and [17–21].

2. Objectives and methodology

The dataset employed in this study was obtained through the Engineering Consultancy Office of Benghazi University and originates from multiple projects conducted across different regions of Libya. Ten independent datasets were collected using a dual-frequency GNSS receiver operating in static mode under clear open-sky conditions, with each observation session lasting 24 consecutive hours. For each site, the acquired observations were initially processed using APPS in static mode with final precise products to derive high-accuracy reference coordinate solutions. The same datasets were subsequently reprocessed in kinematic mode. The resulting kinematic solutions were evaluated by comparison with their corresponding static reference coordinates to quantify positioning performance. The assessment metrics included the Average Absolute Error (AAE), the Root Mean Square Error (RMSE) of the residuals, the Maximum

Absolute Error (MAE), and the percentage of outlier epochs exceeding predefined thresholds of 5 cm in the horizontal components (Easting and Northing) and 10 cm in the vertical component (Height). The use of observation points that are spatially well distributed throughout Libya enables an investigation of the influence of station location and satellite geometry on the accuracy and stability of the derived positioning results.

3. Results and discussion

The final statistically analyzed result for all sites are illustrated in table (1), including: AAE, RMSE, MAE, and percentage of epoch solutions that excides 5 cm in E & N, and 10 cm in H for all sites. Then, sample of the quality of E, N, H, 2D & 3D differences from one site are shown in figures (1), (2), (3), (4) & (5), respectively.

Table 1 Average quality of APPS kinematic solution of all Sites

GNSS Type	**GPS - Alone**		
Component	Easting	Northing	Height
AAE	42 cm	17.5 cm	48.5 cm
MAE	2.2 m	1.4 m	2.3 m
RMSE	50 cm	21.5 cm	31.5 cm
% Outlier > 5 cm in (E & N) & > 10 cm in H	64%	38%	45%

Figure 1 2D Quality of GPS-alone APPS kinematic solution

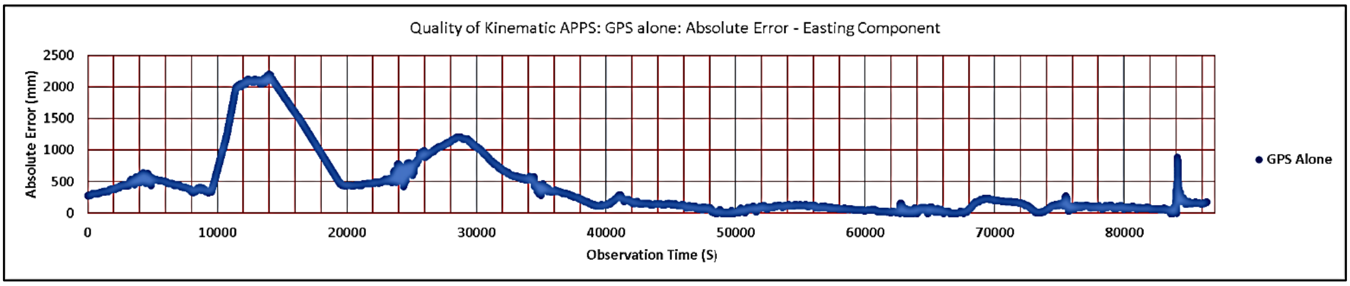

Figure 2 Easting Quality of GPS-alone APPS kinematic solution

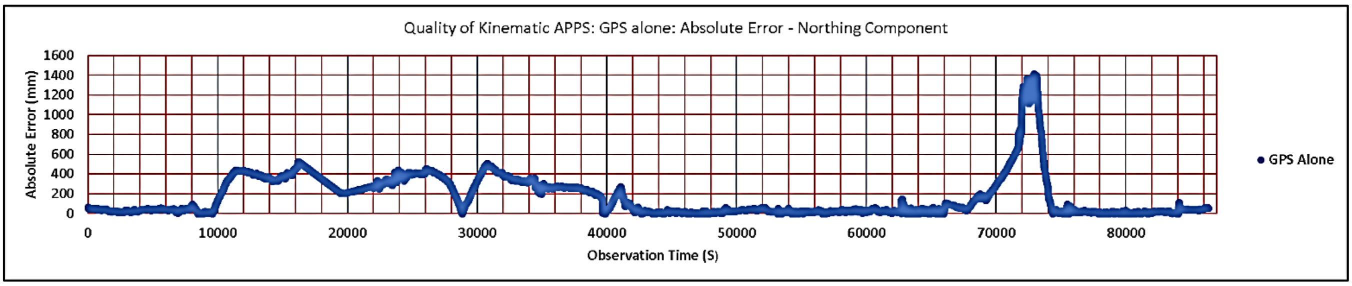

Figure 3 Northing Quality of GPS-alone APPS kinematic solution

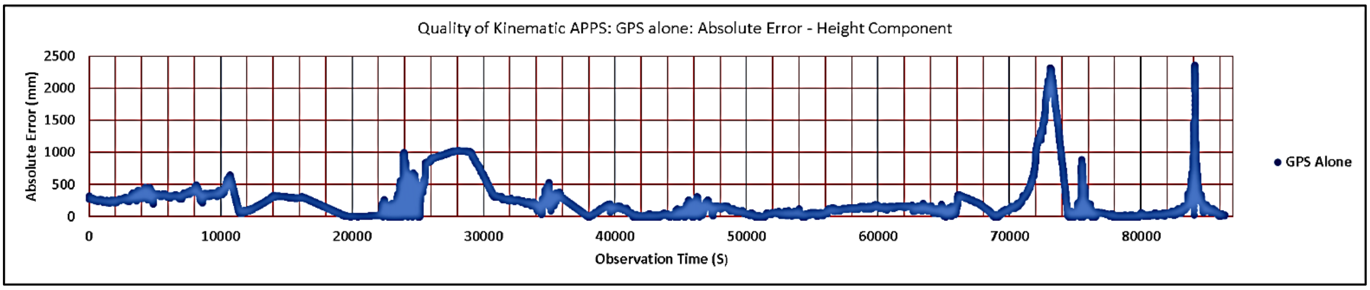

Figure 4 Height Quality of GPS-alone APPS kinematic solution

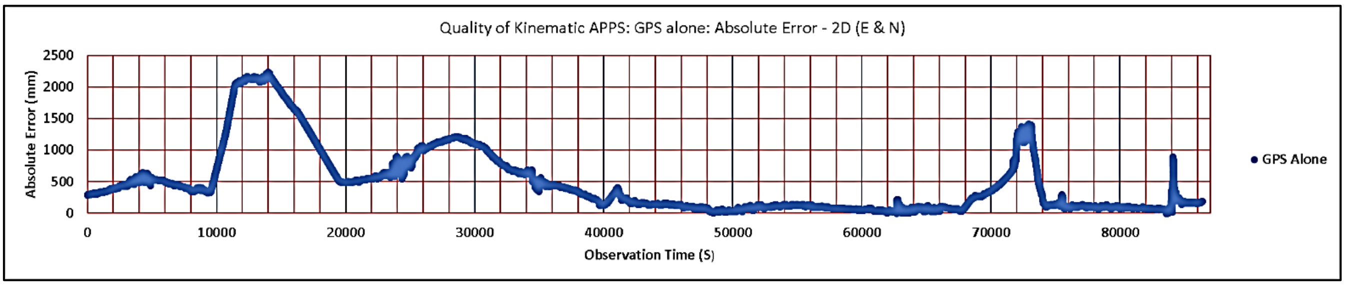

Figure 5 2D (E & N) Quality of GPS-alone APPS kinematic solution

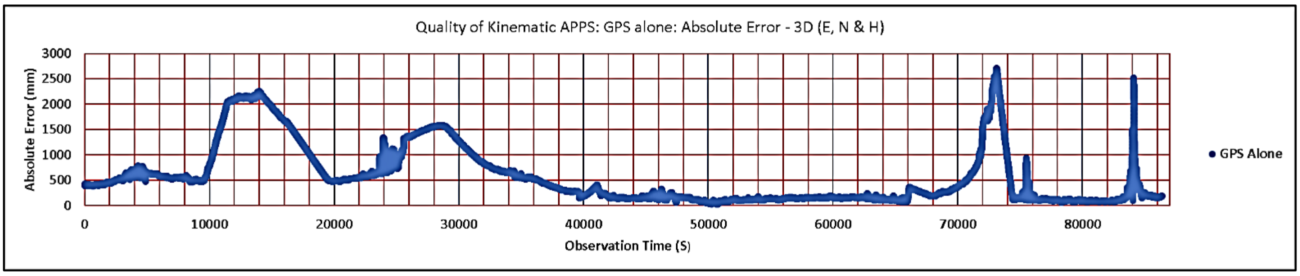

Figure 6 3D (E, N & H) Quality of GPS-alone APPS kinematic solution

The results show that GPS-alone kinematic PPP using APPS can provided continuous solution with AAE of (0.42m, 0.175m & 0.485m), MAE of (2.2m, 1.5m & 2.3m) and RMSE of (0.5m, 0.21 m & 0.31m) in (E, N & H), respectively. The percentage of kinematic epoch solutions, which are bigger than 5 cm in E & N, and 10 cm in H, is (64%, 38% & 45%) in (E, N & H), in this order. The results show that the provided kinematic solutions are relatively unstable, imprecise and weak compared with other free online services, namely: CSRS-PPP, where quality of a few centimeters can be obtained in kinematic mode even via GPS-alone solution. Such imprecise results can be avoided using multi satellite constellations, which can enhance the robustness of the PPP solution and improves the consistency and reliability of GPS-alone kinematic PPP solutions. Such imprecise results can be attributed to the limited number of available one satellite constellation, weak dilution of precision (DOP) and bad estimation of the ionospheric and tropospheric delays. The other significant advantage of increasing the number of satellites is increasing the degree of free-dome in observations, which helps for deleting all observations that include high-residuals without effecting the quality of solution. The other important benefit of increasing the number of satellites is the ability of dispensing satellites with very low-cut of angle which tend to be noisy signal as it passes throughout longer atmosphere than the signals with high-cut of angles.

4. Conclusion

This study examines the effectiveness of kinematic Precise Point Positioning (PPP) when processed using the free Automatic Precise Positioning Service (APPS). The APPS platform is limited to GPS-alone observation files and implements high-level GPS PPP processing strategies developed by the NASA Jet Propulsion Laboratory. All analyses were carried out under ideal open-sky conditions in order to fully exclude multipath interference. Dual-frequency GPS measurements were acquired at ten geographically well-distributed fixed locations, with continuous observation sessions of 24 hours per station. The collected datasets were processed in both static and kinematic PPP modes, where the static solutions were treated as benchmark coordinates for evaluating kinematic performance. The outcomes reveal that GPS-alone kinematic PPP solutions generated by APPS are continuous in time but exhibit modest accuracy. The mean absolute positioning errors were 0.42 m in Easting, 0.175 m in Northing, and 0.485 m in Height. Maximum observed absolute errors reached 2.2 m, 1.5 m, and 2.3 m in the Easting, Northing, and Height components, respectively. In addition, the Root Mean Square Errors (RMSE) were 0.50 m for Easting, 0.21 m for Northing, and 0.31 m for the vertical component. A substantial proportion of kinematic epochs exceeded the adopted accuracy thresholds of 5 cm in the horizontal directions and 10 cm in height, accounting for 64% in Easting, 38% in Northing, and 45% in Height. These results indicate that the kinematic positioning solutions provided by APPS is relatively unstable and imprecise when compared with other freely available PPP services, such as CSRS-PPP, which is capable of delivering centimeter-level accuracy in kinematic applications, even when operating with GPS-alone observations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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