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(Research Article)

Performance Evaluation of Kinematic PPP Using Qinertia Cloud: GPS vs. GPS+GLONASS

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Abstract

This study evaluates the performance of kinematic Precise Point Positioning (PPP) using the Qinertia Cloud free online service under two processing strategies: GPS-alone and combined GPS+GLONASS, in open-sky environments with negligible multipath effects. Dual-frequency GNSS observations were collected from ten well-distributed fixed stations across Libya, each observed continuously for 24 hours. Both static and kinematic processing modes were applied, with the 24-hour static PPP solution adopted as the reference for accuracy assessment The results demonstrate that both strategies provide continuous positioning solutions at the level of a few centimeters. However, the integration of GLONASS enhances positioning performance. The Root Mean Square Errors (RMSEs) in the East, North, and Height components are reduced from approximately 2.5 cm, 4 cm, and 6.5 cm for GPS-only solutions to about 2 cm, 1.5 cm, and 2 cm, respectively, when GPS and GLONASS are combined. Furthermore, the multi-constellation approach substantially decreases the proportion of gross errors - defined as errors exceeding 5 cm in the horizontal components and 10 cm in the vertical component - from 8%, 5%, and 5% to 2%, 1%, and 1% in the East, North, and Height components, respectively. Additional improvements are observed in the maximum absolute errors, which decrease from 13 cm, 22 cm, and 30 cm to 5 cm, 13 cm, and 17 cm in the respective components. Overall, the findings confirm that the Qinertia Cloud free online service can deliver reliable kinematic PPP solutions under open-sky conditions using GPS-only observations, while the inclusion of GLONASS improves accuracy and reliability, making it more suitable for high-precision kinematic applications.

Keywords: GPS; GLONASS; Precise Point Positioning (PPP); Qinertia Cloud; Kinematic Positioning; Open Sky

1. Introduction

Global Navigation Satellite Systems (GNSS), including the Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS), provide continuous, all-weather positioning, navigation, and timing services worldwide through satellite-based passive range measurements [1]. GNSS receivers utilize signals transmitted on dual frequencies, modulated with Coarse/Acquisition (C/A) and Precise (P) codes, to derive pseudo-range and carrier-phase observations [2], which form the basis of modern navigation, mapping, and geodetic applications [3]. The achievable positioning accuracy depends on several factors, including satellite geometry, atmospheric conditions, and receiver performance [4]. While code-based positioning typically provides meter-level accuracy suitable for low-precision applications such as vehicle navigation [5] and UAV-based mapping [6,7], high-precision applications, such as geodetic control, deformation monitoring, and precision engineering, require centimeter-level accuracy [8], achievable through advanced techniques such as Differential GNSS (DGNSS) and Precise Point Positioning (PPP) [9].

DGNSS improves positioning accuracy by utilizing simultaneous observations from a reference station with known coordinates and a rover receiver at an unknown location [10]. Through single, double, or triple-differencing, many

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common error sources, including satellite clock errors and ionospheric delays, are significantly mitigated [11-14]. Dual-frequency DGNSS can achieve millimeter-level accuracy, while single-frequency solutions typically provide decimeter-level precision at lower cost [15]. However, its applicability is limited by the requirement for proximity to reference stations, reducing its effectiveness over large or remote areas [16].

PPP offers a globally applicable alternative that eliminates the need for local reference stations by relying on precise satellite orbit and clock products, typically provided by the International GNSS Service (IGS) [17], along with rigorous modeling of atmospheric and geophysical effects. Under favorable conditions [18], PPP can achieve centimeter-level accuracy in both static and kinematic modes [19], although it generally requires a longer convergence time compared to DGNSS [20]. Among available processing platforms, Qinertia Cloud is a widely used online PPP service that supports both static and kinematic processing and provides solutions in the International Terrestrial Reference Frame (ITRF2020). The platform allows users to upload dual-frequency RINEX observations and automatically applies precise ephemerides, clock corrections, and atmospheric models to generate final positioning solutions.

The performance of kinematic PPP is influenced by several factors, including satellite availability, constellation configuration, multipath effects, antenna characteristics, atmospheric modeling, and the quality of precise satellite products (ultra-rapid, rapid, or final) [21]. Although numerous studies have evaluated kinematic PPP performance, many do not fully isolate the impact of multipath or rely on DGNSS-derived coordinates as reference solutions, which may themselves be affected by baseline length, satellite geometry, and environmental conditions. Consequently, uncertainties may be introduced in the assessment of PPP accuracy.

This study aims to evaluate the performance of kinematic PPP using dual-frequency observations under controlled open-sky conditions, where multipath effects are negligible. Particular emphasis is placed on quantifying the improvement achieved by integrating GLONASS observations with GPS. Unlike previous studies, the evaluation is based on high-quality static PPP solutions as reference coordinates, enabling a more reliable assessment of kinematic accuracy. Furthermore, the study focuses on analyzing the reduction of outliers and overall solution stability when adopting a multi-constellation approach using final precise ephemerides within the Qinertia Cloud free online service.

The datasets used in this study were obtained from the Engineering Consultancy Office at the University of Benghazi and originate from multiple projects across Libya. Ten datasets were collected using dual-frequency GNSS receivers under open-sky conditions, with each station observed continuously for 24 hours. The observations were first processed in static mode using final precise products to establish reference coordinates, which were further validated using high-accuracy national DGNSS control points. Subsequently, the same datasets were processed in kinematic mode under two strategies: GPS-only and combined GPS+GLONASS. The resulting kinematic solutions were evaluated against the static reference using performance metrics including mean error, maximum absolute error, and Root Mean Square Error (RMSE) in the East, North, and Height components. Finally, a statistical analysis of all datasets was conducted to assess overall performance, mitigate the influence of outliers, and provide representative accuracy indicators across different geographic locations. The future research will also include enhancing the quality of kinematic PPP in drone-based surveying to increase the accurate determination of exterior orientation parameters for aerial imagery, which can play a significant role to reduce processing time in automatic image matching workflows. Further details regarding related research efforts conducted at Benghazi University for evaluating drone-based surveying, enhancing automatic image matching for vision-based navigation, integrating navigation systems can be found in [22-26].

2. Results and Discussion

Table (1) includes the Average Absolute Error (AAE), RMSE of residual, maximum absolute Error (MAE) in (E, N & H) and percentage of outliers (more than 5 Cm in E & N and 10 Cm in H) for all sites. Then, sample of the 2D quality of E, N, H, are shown in figures (1), (2), (3), respectively.

Table 1 Quality of Kinematic PPP Using QINERTIA CLOUD Free Online Service: GPS Vs. GPS + GLONASS

GNSS Type	**GPS - Alone**			**GPS + GLONASS**		
Component	**Easting**	**Northing**	**Height**	**Easting**	**Northing**	**Height**
AAE	2 Cm	2.2 Cm	4 Cm	2 Cm	1.2 Cm	2.3 Cm
MAE	13 Cm	22 Cm	30 Cm	5 Cm	13 Cm	17 Cm
RMSE	2 Cm	4 Cm	6.5 Cm	2 Cm	1.5 Cm	2 Cm

% Outliers	8%	5%	5%	2%	1%	1%

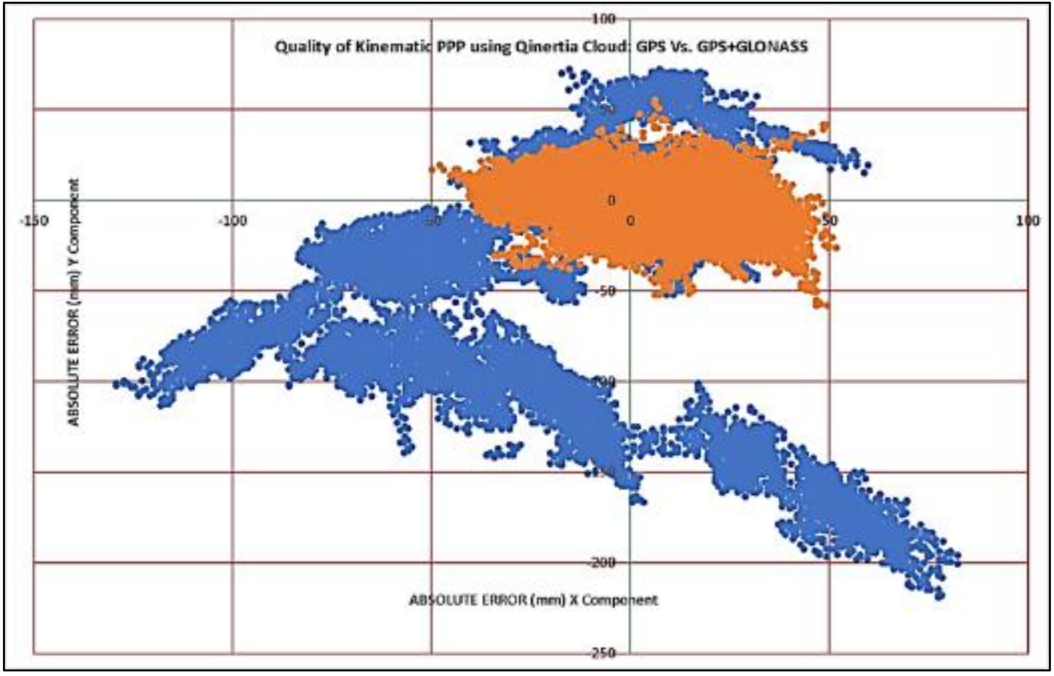

Figure 1 2D Quality (E & N): GPS-alone Vs. GPS+GLONASS

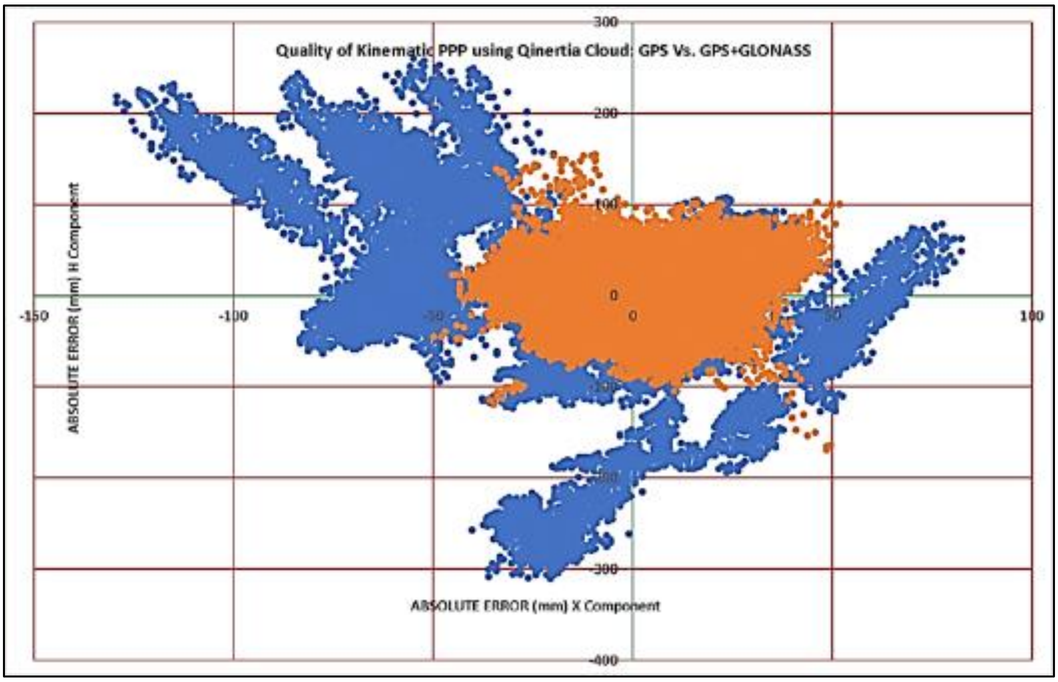

Figure 2 2D Quality (E & H): GPS-alone Vs. GPS+GLONASS

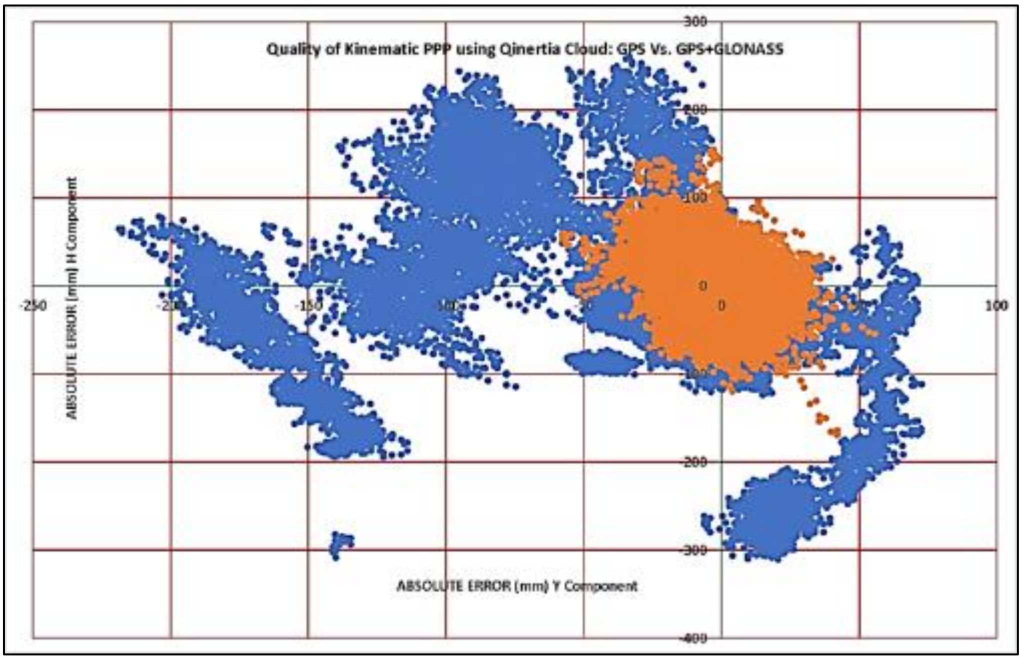

Figure 3 2D Quality (N & H): GPS-alone Vs. GPS+GLONASS

The results demonstrate that both GPS-only and combined GPS+GLONASS processing strategies can provide reliable kinematic PPP solutions with centimeter-level accuracy. However, the integration of GLONASS observations leads to a clear improvement in positioning performance. The Root Mean Square Errors (RMSEs) in the East, North, and Height components are reduced from approximately (2 cm, 4 cm, and 6.5 cm) for GPS-only solutions to about (2 cm, 1.5 cm, and 2 cm), respectively, when GPS and GLONASS are combined. Furthermore, the multi-constellation approach significantly enhances solution robustness by reducing the proportion of gross errors - defined as errors exceeding 5 cm in the horizontal components and 10 cm in the vertical component - from (8%, 5%, and 5%) to (2%, 1%, and 1%) in the East, North, and Height components, respectively. Additional improvements are observed in the maximum absolute errors, which decrease from (13 cm, 22 cm, and 30 cm) under GPS-alone processing to (5 cm, 13 cm, and 17 cm) when GLONASS observations are included.

These improvements can primarily be attributed to the increased number of tracked satellites and the resulting enhancement in satellite geometry. Improved geometry leads to lower dilution of precision (DOP) values, thereby strengthening the positioning solution, particularly during periods of limited GPS satellite availability. In addition, a more favorable satellite distribution improves the estimation of ionospheric and tropospheric delays, contributing to overall accuracy. Another important advantage of multi-constellation processing is the increased redundancy in the observation equations. This provides a higher degree of freedom, enabling more effective detection and exclusion of observations with large residuals without degrading solution quality. Moreover, the availability of a larger satellite set allows the exclusion of low-elevation satellites, whose measurements are typically noisier due to longer atmospheric signal paths. This further enhances the robustness and precision of the kinematic PPP solutions.

In comparison with other free online PPP services, such as PPP-WIZARD and APPS, the performance of Qinertia Cloud, particularly under GPS-alone processing, remains competitive, and is comparable to that of CSRS-PPP. This may be attributed to the reliance of modern PPP algorithms on sufficient observation redundancy, which is more effectively achieved through multi-constellation GNSS integration. Indeed, the use of multiple GNSS constellations has become standard practice, while reliance on a single system is increasingly uncommon. Overall, the findings confirm that the Qinertia Cloud free online service can provide continuous and accurate kinematic PPP solutions suitable for most engineering applications. Nevertheless, the integration of GLONASS significantly enhances observation redundancy, satellite geometry, and the ability to mitigate low-quality measurements, resulting in improved accuracy and reliability.

3. Conclusion

This study evaluated the performance of kinematic Precise Point Positioning (PPP) using the Qinertia Cloud free online service under two processing strategies: GPS-only and combined GPS+GLONASS, based on dual-frequency observations collected from ten well-distributed stations across Libya under open-sky conditions. The use of high-quality static PPP solutions as reference coordinates enabled a reliable and consistent assessment of kinematic positioning accuracy. The results confirm that Qinertia Cloud is capable of delivering continuous kinematic PPP solutions with centimeter-level accuracy using GPS-only observations. However, the integration of GLONASS observations significantly enhances overall performance. Notable improvements were observed in terms of RMSE, maximum absolute error, and reduction of gross errors across all coordinate components. These enhancements are primarily attributed to increased satellite availability, improved satellite geometry, and higher observation redundancy, which collectively contribute to better error modeling and more robust positioning solutions. Furthermore, the multi-constellation approach improves the reliability of the solution by enabling more effective detection and mitigation of low-quality observations, particularly those associated with poor geometry or low satellite elevation angles. The findings also indicate that Qinertia Cloud provides competitive performance compared to other free online PPP services, even under GPS-only processing. Overall, the integration of GLONASS with GPS significantly improves the accuracy, stability, and reliability of kinematic PPP solutions, making the approach more suitable for high-precision engineering and geodetic applications. Future work will extend this analysis to more challenging environments, including multipath-affected conditions, and will investigate the integration of PPP with MEMS-based inertial navigation systems and vision-based techniques to further enhance positioning performance in dynamic applications.

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