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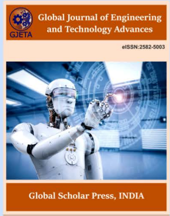

(RESEARCH ARTICLE)

Investigations into the quality of final-product dual-frequency kinematic PPP in open sky using CSRS-PPP free online service: GPS Vs. GPS + GLONASS

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Abstract

The Global Positioning System (GPS) provides accurate, continuous, and global positioning and timing information through satellite-based observations. However, single-system configurations are limited by satellite geometry and signal availability, which can affect positioning reliability in dynamic environments. This study evaluates the performance of Kinematic Precise Point Positioning (PPP) using the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service under two configurations: GPS-only and GPS combined with GLONASS in open sky where the effect of multipath is non-existent. Dual-frequency observations were collected on 10 well-distributed fixed points for 24 hours each and processed in both static and kinematic modes. The static PPP results were used as the reference to assess the accuracy of kinematic solutions. The results show that integrating GLONASS with GPS improves in average the consistency and reliability of GPS alone kinematic PPP solutions by nearly 13% in Easting, 15% in Northing, and 21% in Height. Also, the integrated solutions help to reduce the percentage of gross errors in GPS alone kinematic PPP solutions and enhancing positional precision by nearly 15% in Easting, 21% in Northing, and 18% in Height. Although the improvement in overall average accuracy is marginal, the overall stability of the solution demonstrates the advantage of multi-constellation PPP processing.

Keywords: GPS; GLONASS; Precise Point Positioning (PPP); CSRS-PPP; Kinematic Positioning; Open Sky

1. Introduction

The Global Navigation Satellite Systems (GNSS), such as Global Positioning System (GPS) & Russia's Global Navigation Satellite System (GLONASS) are satellite-based navigation and positioning system that enables the determination of instantaneous position and velocity through passive range measurements [1]. GNSS operates continuously in all weather conditions, providing high-accuracy, real-time position and time information globally [2]. GNSS relies on a constellation of satellites transmitting two primary frequencies each modulated with Coarse/Acquisition (C/A) and Precise (P) codes [3]. These signals allow receivers to determine pseudo-range and carrier phase observations, which form the foundation for modern navigation and surveying applications [4]. GNSS positioning accuracy depends on several factors, including satellite geometry, atmospheric delays, and receiver quality [3]. Code positioning typically achieves an accuracy of a few meters, sufficient for low-precision applications such as vehicle navigation [5] [6], drones [7] [8] or creating unprecise ortho-mosaic images & digital elevation models [9]. However, advanced applications such as geodetic control, deformation monitoring, and precision engineering require centimeter-level accuracy, which can be achieved through techniques like Differential carrier phase GNSS (DGNSS) and Precise Point Positioning (PPP) [3].

DGNSS improves positioning accuracy by using simultaneous observations from a known base station and an unknown rover receiver [10]. By forming single, double, or triple differenced measurements, many common GPS errors, such as satellite clock offsets and ionospheric delays are mitigated [11]. Dual-frequency DGNSS systems can achieve millimeter-

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level accuracy, while single-frequency systems offer decimeter-level precision at significantly lower cost [12]. Despite its effectiveness, DGNSS requires proximity to a reference station, limiting its global applicability.

PPP is a global alternative processing technique that achieves high accuracy without local reference stations. It utilizes precise satellite orbit and clock products, typically provided by the International GNSS Service (IGS), along with detailed models for atmospheric and relativistic effects. PPP can achieve centimeter-level accuracy in both static and kinematic modes but generally requires a longer convergence time compared to DGNSS. The Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service, developed by Natural Resources Canada (NRCan), is one of the most widely used platforms for PPP processing. It supports both static and kinematic data and provides coordinate solutions referenced to the International Terrestrial Reference Frame (ITRF). Users can upload RINEX data from single- or dual-frequency GNSS receivers, and the system automatically applies precise satellite ephemerides, clock corrections, and atmospheric models to produce high-quality results.

The quality of the kinematic PPP depends on many factors, including number of satellites, the surrounding multipath environment, satellite constellations, GNSS antenna type & quality [13], models of ionospheric and tropospheric delays, and the type of precise satellite ephemeras (Ultra-rapid, rapid or final). This study aims to investigate the advantages of integrating GLONASS with GPS in Kinematic PPP using dual frequency observations in open-sky. This investigation focuses on the results of online CSRS-PPP free service using final ephemeris. This point needs more studying as the majority of previous research carried out the investigations without canceling out the effect of multipath. Also, this study concentrates mainly on the improvement of outliers that can be obtained by adding GLONASS to GPS. This can help to give a clear review about the advantages of utilizing GLONASS with GPS away from multipath effects, bad dilation of precision and low-quality satellite ephemeras using ultra-rapid and rapid products. This study will be followed by a number of studies that investigate the effect of multipath effect, the quality of integrating Kinematic PPP with MEMS-based INS & vision navigation, and utilizing Kinematic PPP in drone-based surveying for determining the exterior orientation parameters of each aerial image precisely, which plays a significant role in reducing the processing time of automatic image matching beside the other commonly used techniques. For more information about the efforts made at the University of Benghazi for enhancing automatic image matching for vision-based navigation, the reader is referred to [14] - [18].

1.1. Objectives & Methodology

The data used in this study has been collected via Benghazi University Engineering consultancy office from different projects in different parts of Libya. 10 sets of data have been obtained using a dual-frequency GNSS receiver operating in static mode and in clear open-sky for 24 continuous hours for each point. The collected data for each site were first processed using the CSRS-PPP service in static mode with final product to establish a reference coordinate solution. Subsequently, the same dataset was processed in kinematic mode under two configurations: (1) GPS-only, and (2) GPS + GLONASS. Each kinematic solution was compared against the static reference solution to compute positioning quality, including average error, standard deviation, and maximum deviation in East, North, and Height components. The results of the 10 sites then have been statistically analyzed to deal with outlier results and obtain the final results. Using data from such well distributed points across Libya may help to investigate the effect of point location and satellite distribution on the final results in terms of accuracy and stability.

2. Results & Discussion

The individual results of each point and the final statistically analyzed result for all sites are illustrated in table (1). The table includes the Average Absolute Residual (AAR), Route Mean Square Error (RMSE) of residual in E, N, H, max absolute error, percentage of outliers (more than 3 sigma) for all sites. Then, sample of the quality of E, N, H, 2D & 3D differences in GPS alone & GPS + GLONASS from one site are shown in figures (1), (2), (3), & (4), respectively.

Table 1 (E, N & H) average quality of all Sites

GNSS Type	AAR E mm	RMSE E mm	MAX AR E mm	% of E Outliers	AAR N mm	RMSE N mm	MAX AR N mm	% of N Outliers	AAR H mm	RMSE H mm	MAX AR H mm	% of H Outliers
GPS	5.88	6.11	34.5	12.05	6.97	6.89	44.21	17.61	17.64	14.84	80.23	21.31
GPS+GLONASS	5.17	5.46	25.31	10.42	6.03	5.79	30.18	14.44	14.52	9.04	63.02	18.34

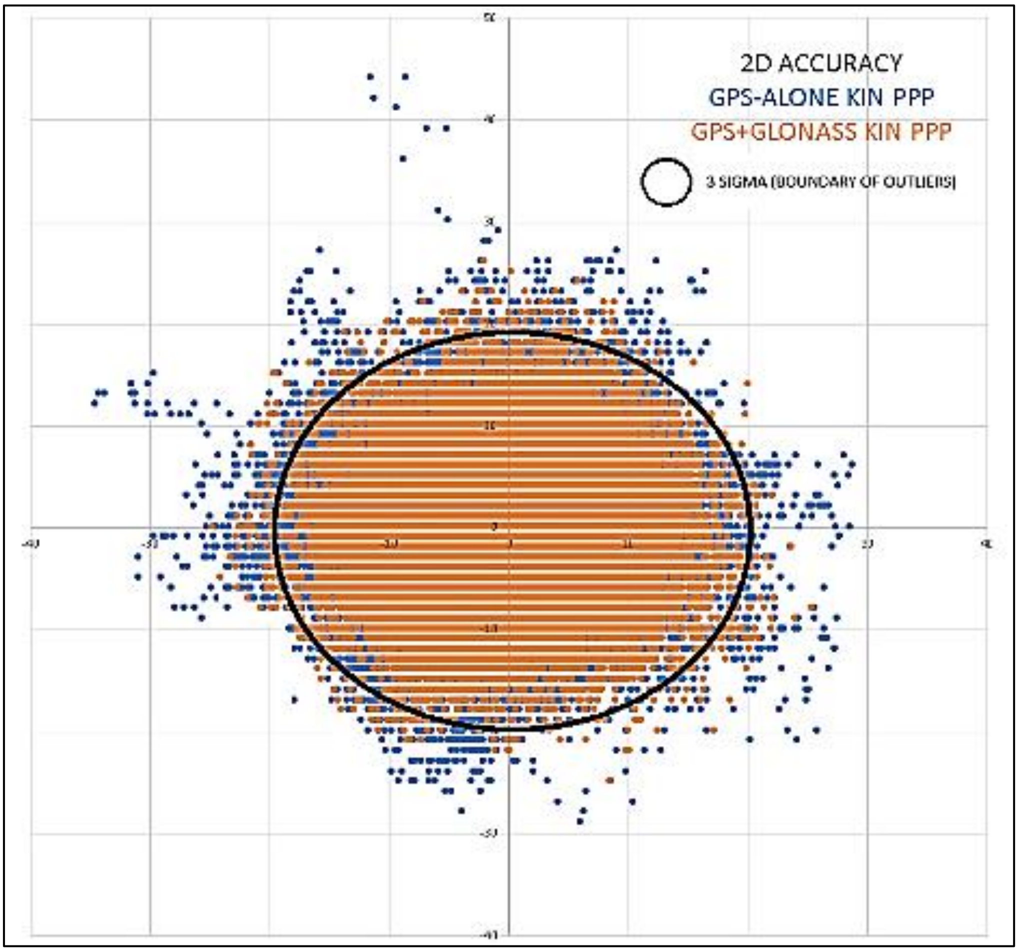

Figure 1 2D Quality: GPS-alone Vs. GPS+GLONASS

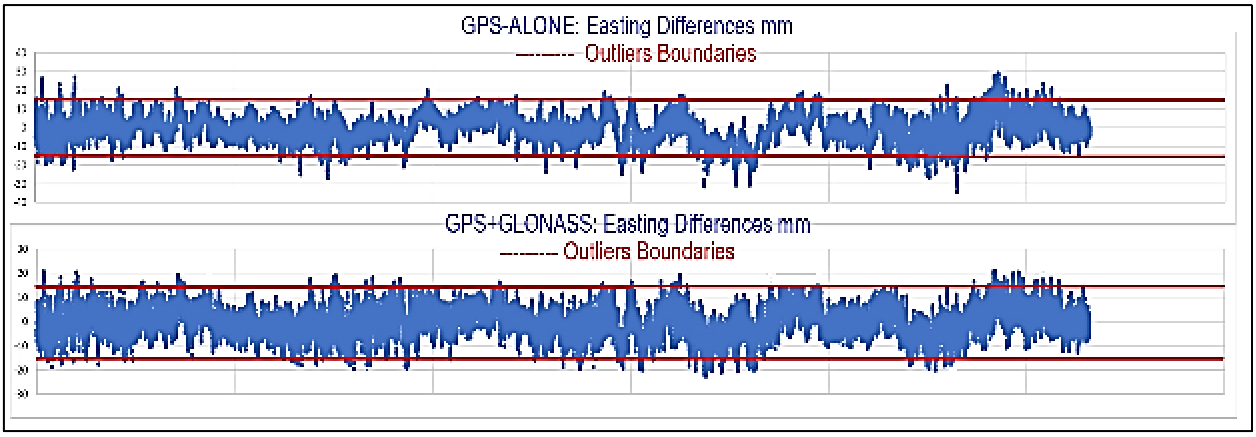

Figure 2 Easting Quality: GPS-alone Vs. GPS+GLONASS

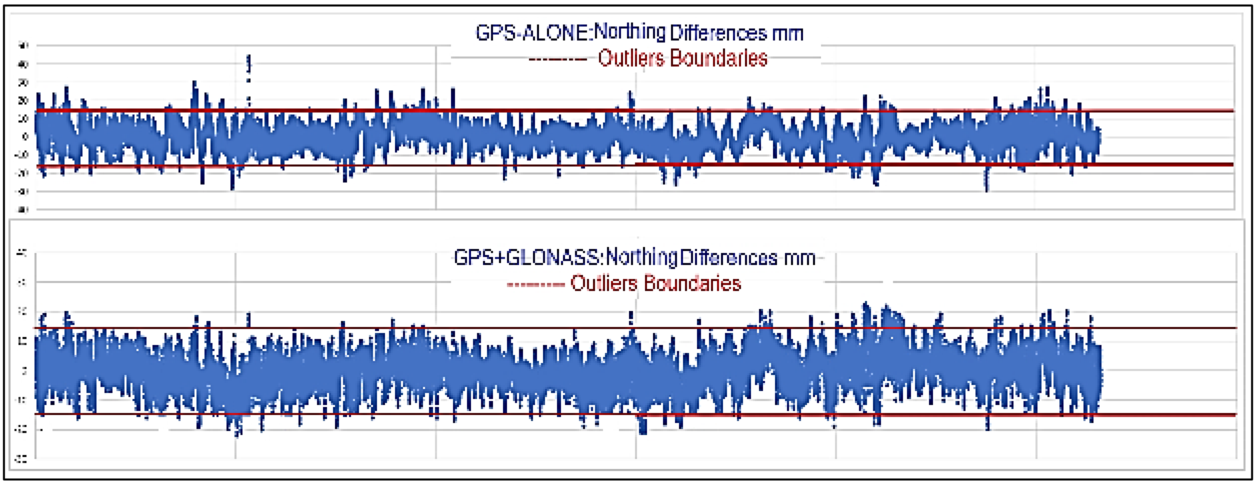

Figure 3 Northing Quality: GPS-alone Vs. GPS+GLONASS

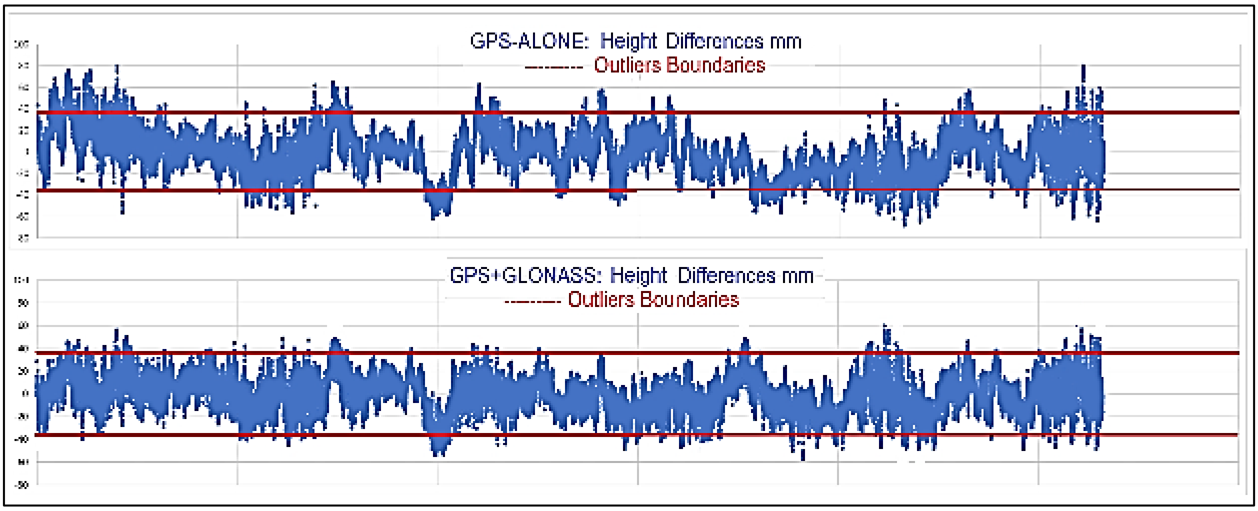

Figure 4 Northing Quality: GPS-alone Vs. GPS+GLONASS

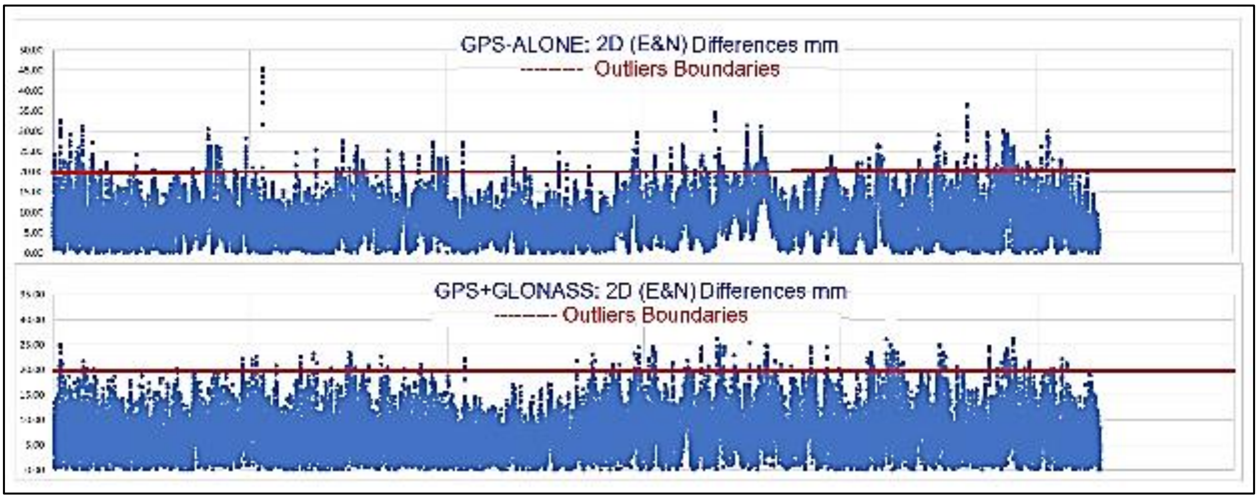

Figure 5 2D (E & N) Quality: GPS-alone Vs. GPS+GLONASS

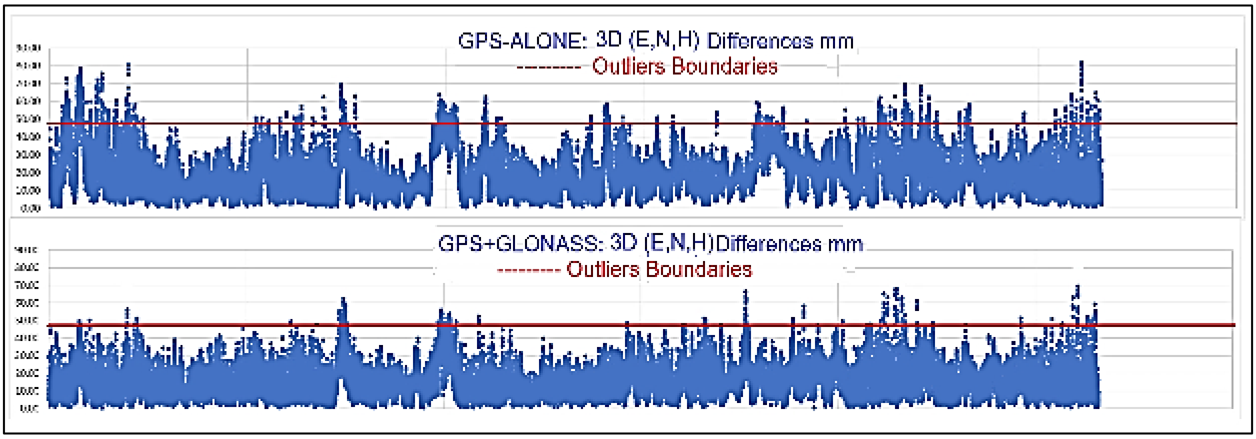

Figure 6 3D (E, N & H) Quality: GPS-alone Vs. GPS+GLONASS

The results indicate that the addition of GLONASS satellites enhances the robustness of the PPP solution and improves the consistency and reliability of GPS-alone kinematic PPP solutions by nearly 13% in Easting, 15% in Northing, and 21% in Height in average. Also, the integrated solutions help to reduce the percentage of gross errors and enhancing positional precision by nearly 15% in Easting, 21% in Northing, and 18% in Height in average. The max size of gross errors is also reduced when integrating GLONASS with GPS observations as shown from the table. These improvements can be attributed to the increased number of available satellites and improved satellite geometry, particularly during periods of reduced GPS satellite visibility, which contribute to better dilution of precision (DOP). The well-distributed satellite geometry can also help the ionospheric and tropospheric models for better estimation of 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. In summary, although the improvement of integrating GLONASS with GPS in Kinematic PPP in the average absolute accuracy is marginal, this helps to a good extend to reduce the outliers and as a consequence, providing more stable and reliable results.

3. Conclusion

This study investigates the impact of integrating GLONASS observations with GPS in kinematic PPP using the CSRS-PPP service under open-sky conditions with final precise ephemerides. Dual-frequency GNSS data were collected at ten spatially well-distributed reference stations, each observed continuously for 24 hours, and processed in both static and kinematic modes. Static PPP solutions were employed as the ground truth to evaluate the accuracy of the corresponding kinematic solutions. The results demonstrate that incorporating GLONASS with GPS enhances the consistency and reliability of kinematic PPP performance compared to GPS-only processing. On average, improvements of approximately 13% in Easting, 15% in Northing, and 21% in Height were achieved. Moreover, the integrated GPS+GLONASS solutions significantly reduced the occurrence of gross positioning errors and improved precision by about 15%, 21%, and 18% in Easting, Northing, and Height, respectively. Although the enhancement in absolute positioning accuracy remains moderate, the integration of GLONASS notably mitigates outlier effects and contributes to more stable and reliable kinematic PPP results. These findings highlight the benefit of multi-constellation PPP solutions in improving the robustness of kinematic positioning. Future research should extend this analysis to include other Global Navigation Satellite Systems (GNSS) such as Galileo and BeiDou and assess their contribution to kinematic PPP performance under more challenging observation environments.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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