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# Accuracy improvement techniques in Precise Point Positioning method using multiple GNSS constellations

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The future Global Navigation Satellite Systems (GNSS), including modernized GPS, GLONASS, Galileo and BeiDou, offer three or more signal carriers for civilian use and much more redundant observables. The additional frequencies can significantly improve the capabilities of the traditional geodetic techniques based on GPS signals at two frequencies, especially with regard to the availability, accuracy, interoperability and integrity of high-precision GNSS applications. Furthermore, highly redundant measurements can allow for robust simultaneous estimation of static or mobile user states including more parameters such as real-time tropospheric biases and more reliable ambiguity resolution estimates.

This paper presents an investigation and analysis of accuracy improvement techniques in the Precise Point Positioning (PPP) method using signals from the fully operational (GPS and GLONASS), as well as the emerging (Galileo and BeiDou) GNSS systems. The main aim was to determine the improvement in both the positioning accuracy achieved and the time convergence it takes to achieve geodetic-level (10 cm or less) accuracy. To this end, freely available observation data from the recent Multi-GNSS Experiment (MGEX) of the International GNSS Service, as well as the open source program RTKLIB were used.

Following a brief background of the PPP technique and the scope of MGEX, the paper outlines the various observational scenarios that were used in order to test various data processing aspects of PPP solutions with multi-frequency, multi-constellation GNSS systems. Results from the processing of multi-GNSS observation data from selected permanent MGEX stations are presented and useful conclusions and recommendations for further research are drawn.

As shown, data fusion from GPS, GLONASS, Galileo and BeiDou systems is becoming increasingly significant nowadays resulting in a position accuracy increase (mostly in the less favorable East direction) and a large reduction of convergence time in PPP static and kinematic solutions compared to GPS-only PPP solutions for various observational session durations. However, this is mostly observed when the visibility of Galileo and BeiDou satellites is substantially long within an observational session.

In GPS-only cases dealing with data from high elevation cut-off angles, the number of GPS satellites decreases dramatically, leading to a position accuracy and convergence time deviating from satisfactory geodetic thresholds. By contrast, respective multi-GNSS PPP solutions not only show improvement, but also lead to geodetic level accuracies even in 30° elevation cut-off.

Finally, the GPS ambiguity resolution in PPP processing is investigated using the GPS satellite wide-lane fractional cycle biases, which are included in the clock products by CNES. It is shown that their addition shortens the convergence time and increases the position accuracy of PPP solutions, especially in kinematic mode. Analogous improvement is obtained in respective multi-GNSS solutions, even though the GLONASS, Galileo and BeiDou ambiguities remain float, since information about them is not provided in the clock products available to date.