# Precise Point Positioning with high-quality and low-cost GNSS data

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## I. Introduction

The concept of Precise Point Positioning (PPP, Präzise Einzelpunktbestimmung) is quite simple: The user position is calculated with the most accurate satellite orbits, clocks, and biases available, and the positioning process utilizes exact correction models and sophisticated algorithms (Fig. 1 and 2).

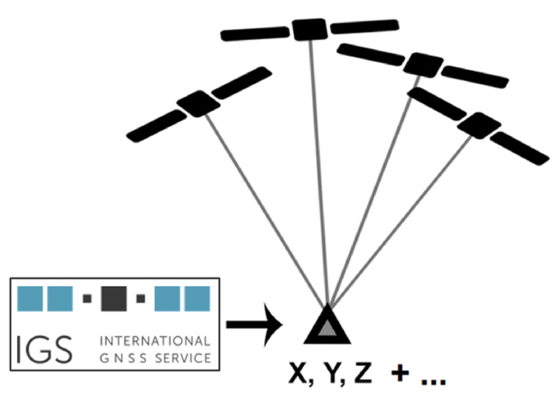


Fig. 1: Principle of PPP

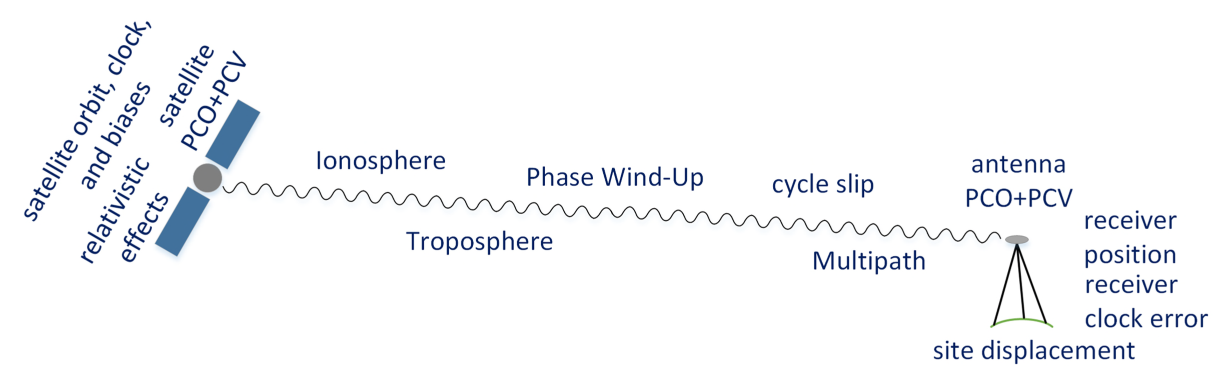


Fig. 2: Error sources relevant for PPP

Therefore, PPP can be seen as a strongly enhanced version of Single Point Positioning (SPP), but PPP exploits multi-frequency and multi-GNSS code and phase observations. The applied precise satellite products (orbits, clocks, and biases) can be obtained, for example, from the International GNSS Service (IGS). This technique allows the calculation of a highly accurate, undifferenced, and absolute position.

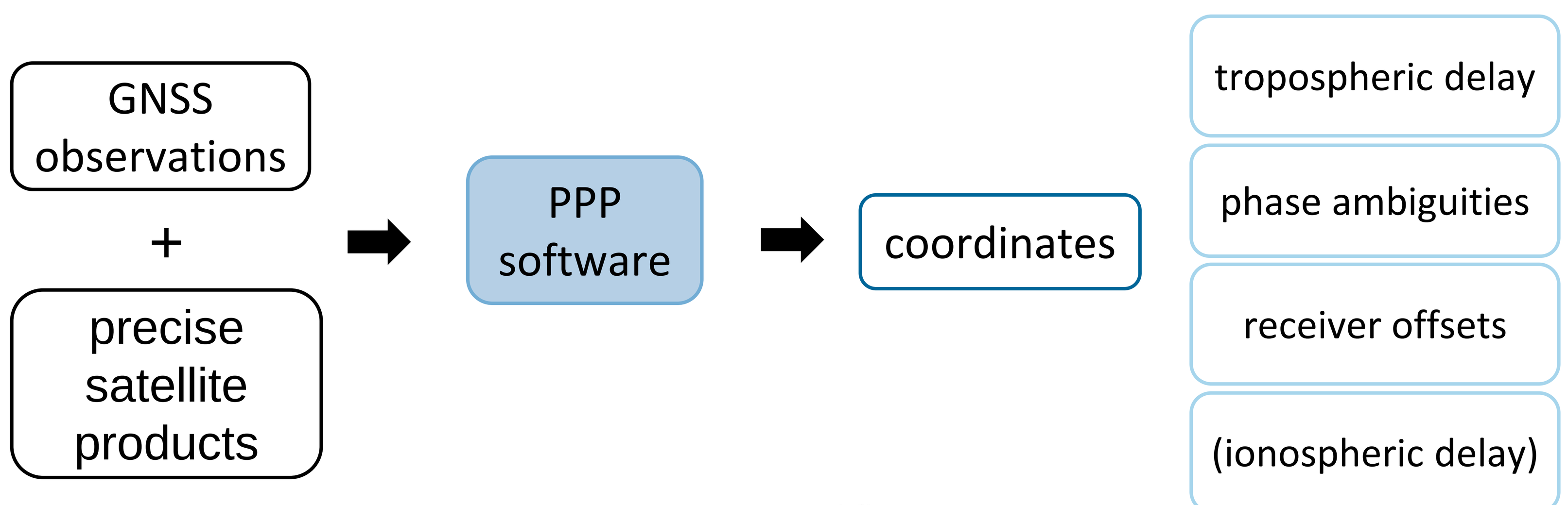


Fig. 3: Basic PPP workflow

Usually, a Kalman Filter is used to estimate the coordinates and additional parameters (Fig. 3). After a particular convergence time, a coordinate accuracy at the centimeter-level is achieved for the float solution (Fig. 4, left part). In the long term, even millimeter accuracy is possible. The apparent convergence time is the major drawback of PPP.

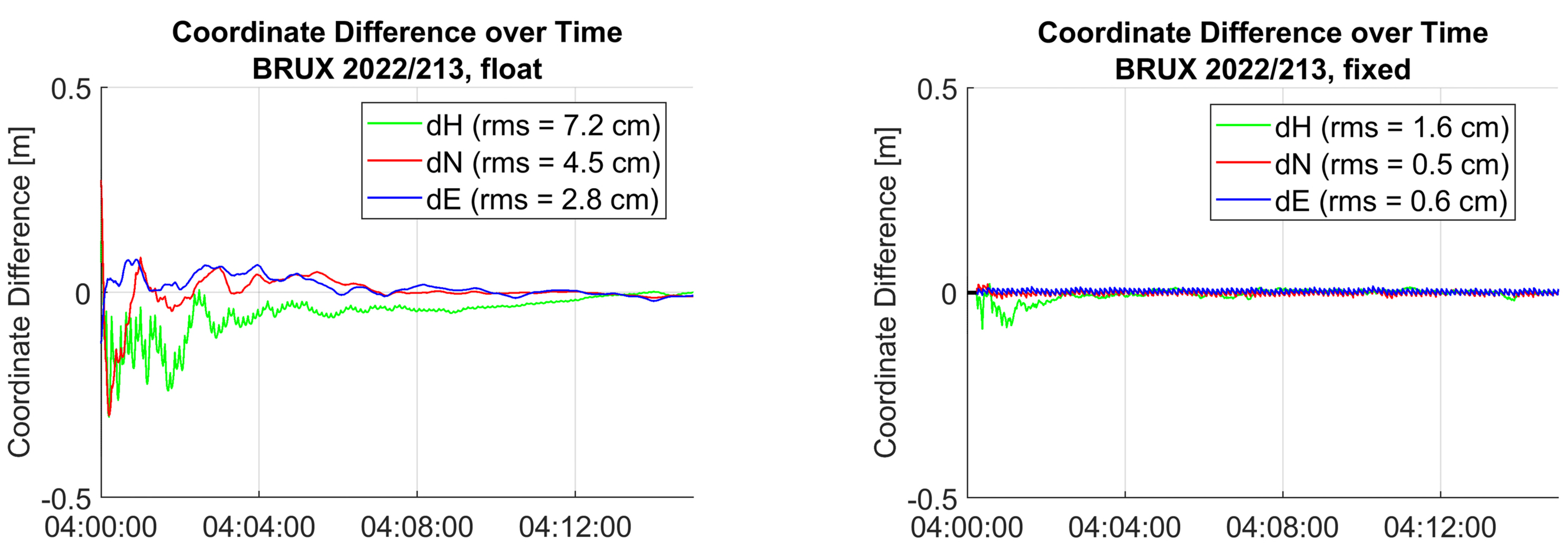


Fig. 4: Exemplary float and fixed coordinate solution

Reducing the convergence time of PPP is a major topic in scientific research to make PPP more competitive against other (relative) high-precision GNSS positioning techniques. Importantly, researchers have found ways to fix ambiguities in PPP (Fig. 4, right part), called PPP-AR. This reduces the convergence time considerably and is the key to the highest accuracy in PPP.

Since the used satellite orbits, clocks, and biases are globally valid, a worldwide homogeneous positioning quality is feasible. Furthermore, the same data has to be transmitted to every user without any restrictions or knowledge (e.g., approximate user position) and so data communication is required only in one direction. Therefore, PPP has advantages in terms of costs and computational efficiency.

## II. Open Source Software

The open-source Matlab software package raPPPid is the PPP module of the Vienna VLBI and Satellite Software. VieVS PPP can process up to three frequencies from all four globally working GNSS (GPS, GLONASS, Galileo, and BeiDou) in various PPP models. Contrary to most other PPP software, raPPPid supports PPP-AR for GPS, Galileo, and BeiDou with different available satellite products and shows outstanding user-friendliness thanks to its graphical user interface (GUI) and documentation (e.g., wiki).

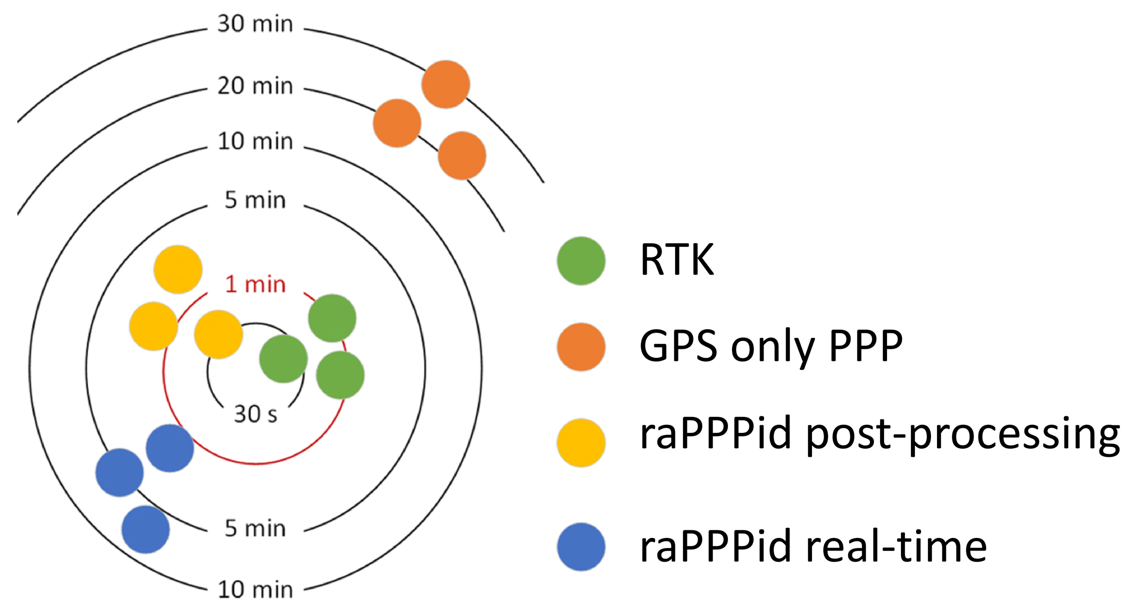


Fig. 5: Typical convergence times

TU WIEN VieVS Vienna VLBI and Satellite Software

github.com/TUW-VieVS/raPPPid

vievswiki.geo.tuwien.ac.at/en/raPPPid

In particular, raPPPid achieves remarkable convergence times (Fig. 4 and 5) and can handle high-quality to low-cost GNSS observations due to a flexible program structure, various options, and highly adaptable processing settings. VieVS PPP accepts the most common file formats of the GNSS community and supports parallel processing of multiple observation files. The processing results are available in various output formats. Finally, the user can choose from an extensive plot section to illustrate the results, convergence period, quality of the observations and models, and satellite geometry.

## III. Smartphone PPP

Since Android 7.0 in 2016, everyone can access the raw GNSS measurements tracked by Android smartphones. Now the smartphone's GNSS observations can be used directly to estimate the user position with specialized self-developed algorithms and correction data. Typically, smartphones are equipped with simple, cost-effective GNSS chips and antennas. Therefore, they provide challenging, low-quality GNSS measurements, mainly on a single frequency.

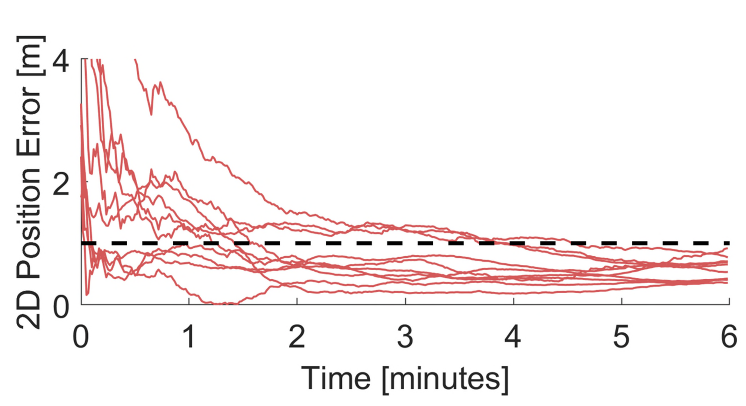


Fig. 6: Horizontal position error achieved with a Google Pixel 7 and raPPPid

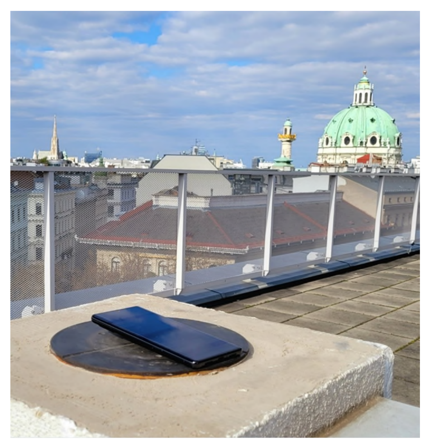

Fig. 7: Smartphone test setting

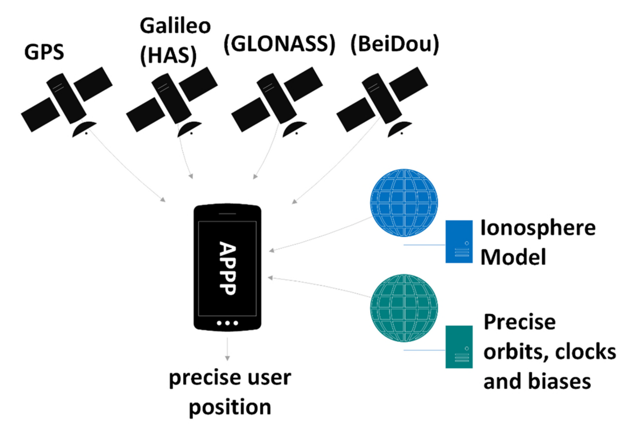


Fig. 8: Project APPP

However, raPPPid flawlessly processes the GNSS measurements logged with smartphones and typically achieves a 2D position accuracy around the one-meter level or below (Fig. 6). Note that these results are achieved under good conditions (Fig. 7), but in real-time settings. On this basis, we are developing an Android application within the FFG research project APPP (Fig. 8).

### Further Reading

Glaner MF (2022) Towards instantaneous PPP convergence using multiple GNSS signals. PhD Thesis, TU Wien

Glaner MF, Weber R (2021) PPP with integer ambiguity resolution for GPS and Galileo using satellite products from different analysis centers. GPS Solut 25(3):102. https://doi.org/10.1007/s10291-021-01140-z

Hohensinn R, Stauffer R, Glaner MF, Herrera Pinzón ID, Vuadens E, Rossi Y, Clinton J, Rothacher M (2022) Low-Cost GNSS and Real-Time PPP: Assessing the Precision of the u-blox ZED-F9P for Kinematic Monitoring Applications. Remote Sensing 14(20):5100. https://doi.org/10.3390/rs14205100

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