Title:
Fast and reliable multi-GNSS precise point positioning with integer ambiguity resolution

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Name of Academic Institution: Delft University of Technology

Level of study or work: PhD thesis
(Bachelor thesis, master, research, project, etc.)

Information about you (and your team): Dimitrios is a Global Navigation Satellite Systems (GNSS) scientist, with a demonstrated experience in Precise Point Positioning (PPP) and Real-Time Kinematic (RTK) positioning algorithm development. Dimitrios currently works as a Radio Navigation Engineer at the European Space Agency (ESA) supporting the Galileo 2nd Generation development and the Galileo High Accuracy Service. He received his PhD degree in Geodesy and GNSS from Delft University of Technology in 2022, under a Marie Skłodowska-Curie fellowship, with his research focusing on fast and reliable multi-GNSS precise point positioning with integer ambiguity resolution.

Area of interest
(Identifying the problem, explain why it is important and the current relevance of the topic, up to 250 words)

PPP is a GNSS processing method that provides single-receiver users with high positioning accuracy anywhere on the globe, without the explicit dependence on reference receivers. Although PPP delivers highly accurate positioning results, a relatively long timespan is needed to achieve them. This long convergence time is mainly due to the presence of carrier-phase ambiguities and ionospheric delays, and can be significantly reduced if one can do away with these unknown parameters using integer-estimation and external corrections, respectively. The integer ambiguity resolution-enabled variant of PPP, namely PPP-RTK, is the GNSS positioning mode that can deliver ambiguity-resolved parameter solutions on the basis of single-receiver user data and state-space corrections, which include satellite orbits, satellite clocks and satellite hardware biases. Despite being able to recover the integer-nature of user ambiguities, a considerable observational time span of 30-60 min is still needed to integer-resolve the ambiguities with sufficiently large success rate in the presence of ionospheric delays, which cannot compete with that achieved with RTK over short baselines. Next to the rapid centimetre-level convergence that is of top priority to the users, positioning reliability is critical as well. The commonly used practice in PPP-RTK to neglect the correctional uncertainty may lead to incorrect ambiguity fixing but, most importantly, leads to a sub-optimal quality description of the user coordinates. Obviously, the PPP-RTK user positioning convergence and reliability are still open problems that act as a barrier to the technology's large-scale adoption for demanding real-time positioning applications, such as surveying.

Approach to the problem

(Describe your methodology or technology and how it will solve the problem you identified, up to 300 words)

To overcome the identified limitations, this thesis focused on a framework accommodating the main enablers of fast convergence and methods to obtain reliable positioning quality description.

The first method utilizes ionospheric information from regional multi-scale networks to aid the user model in increasing its redundancy, thus allowing for faster PPP-RTK ambiguity resolution. An extensive formal analysis revealed that this is not possible when using the current ionosphere models. To overcome this, a methodology was introduced that uses the slant ionospheric delays directly as estimated from the PPP-RTK network processing and predicts the corrections at the user's location. It was analytically demonstrated how the user's model needs to be extended to its ionosphere-weighted variant to incorporate these corrections and their associated quality.

As an alternative to the ionospheric corrections augmentation, which has the stringent requirement of operating a dense network infrastructure, the approach of integrating multi-GNSS multi-frequency data was analyzed for improving the PPP-RTK convergence time. A consolidated framework was developed to extend the PPP-RTK network and user models to their multi-constellation multi-frequency variants. An extensive performance analysis of globally distributed user stations showed the impact of the increased number of satellites and frequencies on the ambiguity resolution and positioning performance, also highlighting the impact of the frequency spacing.

Finally, the effects of a misspecified user stochastic model on the reported Kalman-filter precision and the data quality control mechanisms was analyzed. The impact of neglecting the correctional uncertainty on the PPP-RTK user ambiguity resolution and positioning performance was empirically evaluated for nonzero correction latencies. Two methods to reconstruct the stochastic contribution of the corrections via limited amount of information from the correction provider were developed so as to properly weight the user corrected data and achieve close-to-optimal performance even for high latencies.

Results, conclusions and next steps

(Present your research results and conclusions of your study, up to 250 words)

First, a strategy was proposed to predict the ionospheric corrections at the user's location, per satellite and per epoch. Real-data experiments showed that near-instantaneous convergence to the sub-decimetre level is feasible when the corrections are provided from 115 km spaced networks. The analysis of multi-scale networks demonstrated the presence of a linear relationship between the convergence time and the inter-station spacing.

Further, the analysis on the integration of multi-GNSS multi-frequency data in the absence of ionospheric corrections concluded that the satellite and frequency redundancy work in tandem in improving the PPP-RTK performance, with the former being the main contributor. Another key finding was that frequency separation aids ambiguity resolution to a larger extent than the number of frequencies. It was shown that centimetre-level positioning errors can be reached within 3 min when using Galileo+GPS multi-frequency data, thereby demonstrating that almost-instantaneous PPP-RTK without atmospheric corrections is possible.

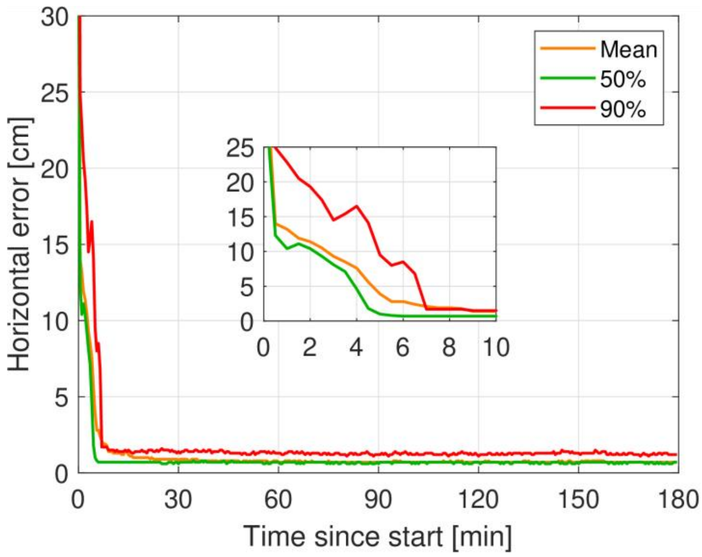

Fig. 1: Convergence of the Galileo+GPS multi-frequency PPP-RTK positioning errors

Finally, emphasis was placed on the performance degradation when the PPP-RTK correctional uncertainty is neglected. Experimental results showed that the neglected uncertainty leads to reduced ambiguity success rates (77.5% for GPS) and misleading positioning-quality description. The developed methods led to success rates above 95% and realistic positioning precision description, even for high correction latencies.

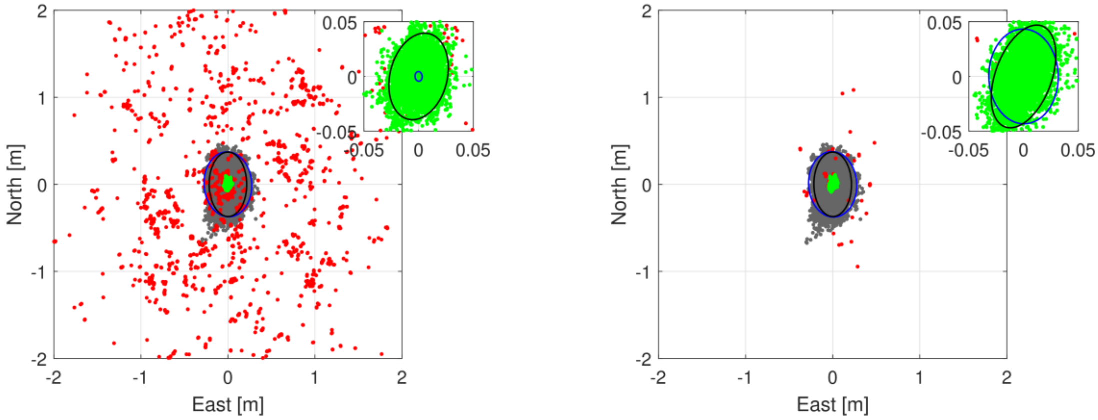

Fig. 2: Instantaneous GPS L1/L2 PPP-RTK positioning errors using deterministic (left) and stochastic (right) corrections

Addressing 'the extent to which the fusion of GNSS and signals of opportunity (LEO) improves the PPP-RTK performance' is a topic of future work.

References

(Additional information, publications, or links, up to 200 words)

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