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EDITORIAL

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Editorial

High-precision multi-constellation GNSS: methods, selected applications and challenges

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In recent years, significant advances have been made in the field of global navigation satellite systems (GNSS) algorithms and technological developments and new applications. Currently, with multi-constellation and multi-frequency signals supported with cutting-edge processing algorithms aiming at error mitigation and aiding sensor integration, we are able to obtain a position with high reliability, accuracy and continuity. Moreover, these advances have led to a significant growth in the number of GNSS applications to new areas of geoscience and engineering. Since GNSS technology has already proved its high applicability, now it can be considered as a reliable tool in such demanding applications as geodesy, geodynamics, ionosphere and troposphere sensing, surveying, civil engineering, metrology, deformation monitoring and many others.

This special feature of *Measurement Science and Technology* aims to bring together research works that advance the state-of-the-art in high-precision GNSS algorithms and applications by combining selected original contributions describing innovations, identifying potential applications, characterizing current limitations and advantages and demonstrating future perspectives. This collection of papers contains nine invited papers, which, in our opinion, contribute significantly to the subject.

Toward a goal of enhancement of GNSS positioning, several papers in this special feature deal with the development of new observation processing algorithms and correction models. The paper by Psychas *et al* (2019) presents a detailed analysis of the ionospheric corrections supporting precise GNSS positioning with the PPP-RTK method. The authors determined a prerequisite precision of the correction model which meets the requirements of fast and reliable PPP-RTK solution. As a result of these investigations, the authors have proposed an optimal methodology for providing ionospheric corrections on the basis of permanent GNSS network processing.

The above contribution is completed by the next paper of this special feature by Cai *et al* (2019). This research report assesses the impact of the ionospheric delay on precise GNSS positioning. Specifically, the authors analyzed the impact of second- and third-order ionospheric delays on the performance of multi-constellation precise point positioning. The authors reported negligible influence of higher-order ionospheric delays during low ionospheric activities. Contrarily, during active ionosphere periods, this error cannot be omitted since its value may reach up to several centimeters.

The paper by Gao *et al* (2019) deals with the subject of integration of multi-constellation signals in GNSS RTK positioning. The core of this paper is devoted to the tight combination of the GPS and GLONASS observables. As accurately reported by the authors, such approach forces not only modelling of differential inter-system biases, but also handling the issue of the different wavelengths of GLONASS satellites.

To follow on advances in GNSS relative positioning, Tu *et al* (2019) introduced an original algorithm for processing of double-differenced observations formed between different signal frequencies (e.g. L1 and L2 of GPS). The methodology developed by the authors takes advantage of the parametrization of an inter-frequency bias to recover the integer nature of phase observation ambiguities. The authors have proved the high stability of the modelled bias, hence it is possible to consider it as a constant parameter in the estimation process. With the proposed methodology it is feasible to enhance ambiguity resolution success rate, especially under poor observing conditions.

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Error mitigation in the most demanding GNSS applications was investigated in Špánik *et al* (2019). This paper faces the problem of the detection and modelling of multipath, which is a prerequisite in many high-precision GNSS applications such as metrology, distance measurements or urban canyon positioning. The authors followed initial studies recently conducted by Strode and Groves and illustrated in previous papers, and investigated selected issues of the method based on a comparison of the signal-to-noise ratio of actual observables with the reference functions derived from measurements collected in a low-multipath environment. These researches led to the elaboration of an alternative methodology and its application to multi-constellation signals.

Recent advances in low-cost GNSS receiver hardware and their rapidly growing number induce their application to novel areas of the industry. At the same time, these developments demand new efficient data processing methods. In this view, the paper by Khodabandeh and Teunissen (2019) provides a review of the current state-of-the-art in distributed estimation. As an original contribution, the authors proposed to decentralize GNSS data processing and hence distribute the computational load across a network of receivers to solve the problem of low computational capacity. Bar Yossef *et al* (2019) presented a performance assessment of a new low-cost L1/L2c receiver board. With the series of conducted experiments, the authors demonstrated the high applicability of the receiver measurements not only to pedestrian navigation and precise positioning but also to atmospheric sounding, specifically to water vapor determination.

The application of GNSS measurements to atmospheric sounding was also discussed in the paper by Jarmołowski *et al* (2019). The paper describes the methodology for regional total electron content modelling based on precise point positioning and least-squares collocation method. The authors argued a clear advantage from such an approach over well-known and widely applied spherical harmonic expansion, spherical splines or ordinary Kriging interpolation methods.

An important contribution to GNSS applications and at the same time to this special feature was made by Xu *et al* (2019). The authors extended the current knowledge in the field of GNSS rotational seismology. This open-access paper focuses on the application of high-rate multi-constellation GNSS observables to attitude determination. The results revealed noticeable differences between single constellation solutions and point out significant benefits from integrated multi-GNSS solution, which corresponds with reference inertial measurements. The experiment's results have also justified the high applicability of both high-rate PPP and relative solution to measure rotatory motions.

We would like to express our gratitude to the authors for their contributions to this special feature of *Measurement Science and Technology*. We expect that their investigations will make a noticeable impact in the subject of GNSS positioning and applications. We would also like to offer a very special word of thanks to the anonymous and voluntary reviewers. With their professional reviews it was feasible to guide the authors in substantial improvement of the submitted manuscripts. Last but not least, we are grateful to the publishers, editors and entire Editorial Board of *Measurement Science and Technology* for their professional support.

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