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Investigation of some selected strategies for multi-GNSS instantaneous RTK positioning

Jacek Paziewski *, Pawel Wielgosz

University of Warmia and Mazury in Olsztyn, Poland

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Abstract

It is clear that we can benefit from multi-constellation GNSS in precise relative positioning. On the other hand, it is still an open problem how to combine multi-GNSS signals in a single functional model. This study presents methodology and quality assessment of selected methods allowing for multi-GNSS observations combining in relative kinematic positioning using baselines up to tens of kilometers. In specific, this paper characterizes loose and tight integration strategies applied to the ionosphere and troposphere weighted model.

Performance assessment of the established strategies was based on the analyses of the integer ambiguity resolution and rover coordinates' repeatability obtained in the medium range instantaneous RTK positioning with the use of full constellation dual frequency GPS and Galileo signals. Since full constellation of Galileo satellites is not yet available, the observational data were obtained from a hardware GNSS signal simulator using regular geodetic GNSS receivers. The results indicate on similar and high performance of the loose, and tight integration with calibrated receiver ISBs strategies. These approaches have undeniable advantage over single system positioning in terms of reliability of the integer ambiguity resolution as well as rover coordinate repeatability.

Keywords: GNSS; Precise relative positioning; Galileo; GPS; Inter system bias; RTK

1. Introduction

Integration of multiple GNSS system observations is nowadays the crucial issue in the development of precise positioning algorithms. Combined multi-GNSS positioning has undeniable advantage over standard single GNSS system utilization in terms of accuracy, reliability, availability and convergence of position solution as presented in Cellmer et al. (2013), Paziewski et al. (2013), Odolinski et al. (2015) and Gao et al. (2015). Multisystem positioning is especially beneficial in obstructed environments (Teunissen et al., 2014; He et al., 2014). What is more, with the launch of new GNSS systems – Galileo and BDS – and modernization of the existing ones, it is possible to utilize not only multi-GNSS but also multi-frequency (triple and quadruple) observations. As studies show, this approach may be beneficial for precise relative positioning performance (Hernandez-Pajares et al., 2003; Cao et al., 2008; Montenbruck et al., 2013; Li et al., 2013; Paziewski and Wielgosz, 2014; Zhang and He, 2015). Number of new signal frequencies gives also opportunity for development of new ambiguity resolution algorithms (Ji et al., 2013). On the other hand, the use of multi-frequency and multi-GNSS observations can increase ambiguity resolution computational problem due to large number of observables and parameters. Studies has been carried out to resolve this issue by partial ambiguity resolution (Cao et al., 2007; Parkins, 2011; Li et al., 2015; Gao et al., 2015).

* Corresponding author.
E-mail address: jacek.paziewski@uwm.edu.pl (J. Paziewski).

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The benefit from using multiple GNSS observations in relative positioning is quite obvious. One important advantage is that in case of low number of observed satellites of each system, the capability to resolve of inter system DD ambiguities allows for single-epoch ambiguity resolution. Nevertheless, the optimal approach for combining such observations is still an open problem. Multi-GNSS integration in relative positioning may be performed in several ways such as loose and tight approach (Zhang et al., 2003; Julien et al., 2004). Overlapping frequencies in GNSS systems support creating double-differences using mixed observations from different satellite systems. This approach is commonly termed as tight integration. In specific, this geometry-based relative observational model utilizes a single reference satellite for observations from all the GNSS systems. This model forces taking into account differential receiver inter system biases (ISB). The ISB is the difference between receiver hardware delays for different GNSS observations that is present both in carrier-phase and pseudorange data (Torre and Caporali, 2014). Detailed research concerning inter system biases calibration and utilization in precise relative multi-GNSSS positioning has been recently carried out. Initial research concerning between GPS and Galileo-IOV inter system bias modelling were carried by Montenbruck et al. (2011). Detailed methodology for receiver ISB estimation may be found in Odijk and Teunissen (2013) and Paziewski and Wielgosz (2015). These studies revealed that phase and pseudorange ISB are present when different types of multi-GNSS receivers are used over a processed baseline (Paziewski et al., 2015; Odijk et al., 2016). On the contrary, when homogenous receivers are utilized, the DD observations are free from the influence of these types of biases. What is more, the stability of the ISB time series indicates on possibility of calibration of these biases and a priori correcting of multi-GNSS observations.

In case of lack of coinciding frequencies in multi-GNSS relative positioning, the integration may be performed in so-called loose combining (LC) approach. This strategy can be applied relatively easily for integration of observations from individual GNSS systems with different carrier phase frequencies. In this method, functional model utilizes separate pivot satellites for each GNSS system which decreases potential number of double-differenced observables. On the contrary, number of the unknown parameters is also lower with respect to tight combining (TC) approach with parametrized ISBs due to absence of the unknown ISB parameters.

This study investigates and compares performance of both general approaches for combining of multiple GNSS observations in precise geometry-based relative positioning. This analysis is based on utilization of full constellation Galileo and modernized GPS satellites (with L5 signals available). Since full constellation of Galileo satellites is not yet available, the observational data were obtained from a hardware GNSS signal simulator (Spirent) using regular geodetic GNSS receivers. This scenario may characterize presumable future performance of real full constellation GPS + Galileo positioning enhanced by multi-GNSS satellite geometry. However, it cannot precisely describe future positioning accuracy since signals acquired by GNSS receivers are simulated. On the other hand, this scenario may be applied in order to distinguish between examined strategies (Li et al., 2013). Quality assessment of both strategies was based on dual frequency instantaneous L1 + L5 RTK (Real Time Kinematics) positioning. The processing was performed using both single and multi-baseline solutions, since the number of baselines has important influence on the number of unknowns in the tested strategies. Here, the multi-GNSS relative positioning was performed baselines under 100 km with modified ionosphere-weighted model. Most of the existing studies concerning multi-GNSS signal combining are based on single and short baselines without atmospheric delays parametrization using real data and thus limited number of Galileo satellites (Shi et al., 2013; Deng et al., 2014; Odijk et al., 2014, 2016). Indeed, there are few research concerning multi-GNSS relative positioning taking into account parametrization of atmospheric delays (Odolinski et al., 2014, 2015).

The paper is arranged as follows. In the following section, a brief description of both methodologies for multi-GNSS data combining in precise relative positioning is characterized. The experiment design, observational data and positioning results in terms of ambiguity resolution and coordinate domains are described in Section 3. Finally, a summary is given in the last section.

2. Multi-GNSS precise relative positioning

In this contribution a comparative performance assessment of strategies combining GPS + Galileo observations in relative kinematic satellite positioning are presented. In specific, results from tight and loose integration were compared to those obtained from single GNSS system at medium baselines which served as benchmark. At the beginning we present functional models of tight and loose integration in geometry based relative positioning with parametrized slant ionospheric delays (SID) – ionosphere weighted model. In the second part of this section, the adjustment model is derived and presented. The ionosphere weighted model was applied and modified here for utilization of multi-GNSS data in selected schemes since this model is said to be one of the most effective approach for medium and wide range RTK positioning. The geometry-based model with estimated double-differenced (DD) ionospheric delays has been often utilized for single system observations at medium range baselines up to several tens of kilometers (Paziewski, 2016). The fundamentals of ionosphere parametrization in relative positioning may be found in Bock et al. (1986), Schaffrin and Bock (1988) and Teunissen (1997). Further developments of this approach were also made by Bock et al. (2000), Odijk (2002), Julien et al. (2004), Kashani et al. (2007), Wielgosz