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Multi-GNSS real-time clock estimation using the dual-thread parallel method

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Abstract

The development of Global Navigation Satellite System (GNSS) promotes multi-GNSS real-time precise point positioning (PPP) which raises a strong demand for real-time precise clock products. The increase of navigation systems and satellites leads to an extremely large number of observations, ambiguities and other unknowns, which makes the traditional undifferenced (UD) clock estimation method much time-consuming. We need processing of high computation efficiency for multi-GNSS real-time clock estimation. To satisfy the demand of multi-GNSS real-time clock estimation, we introduce a dual-thread parallel algorithm that consists of two threads with difference computation efficiency. The slow thread runs the traditional UD method and updates all the parameters of satellite and receiver clock, ZTD and ambiguity at a rather low rate. The fast thread runs a reduced UD method to update satellite clocks in real-time, in which the ZTDs and ambiguities are corrected with the latest estimates from the slow thread. Multi-GNSS observations of 75 stations are collected from DOY 200 to 230, 2015 to test the proposed algorithm. The dual-thread parallel method requires an average time of 2 s at each processing epoch, which is much faster than the traditional UD method. The multi-GNSS clock solutions of the introduced method exhibit good agreement with the WUM final products, with the RMS better than 0.2 ns, which is comparable to that of the UD method. Multi-GNSS kinematic PPP tests based on the clock solutions verify the introduced method further. The clock solution of the parallel method is precise enough to support real-time multi-GNSS PPP, which is comparable to the UD method and better than the ED method.

Keywords: Multi-GNSS; Real-time clock estimation; Real-time PPP

1. Introduction

Real-time precise orbit and clock products of Global Navigation Satellite System (GNSS) are essential and prerequisite for real-time precise point positioning (PPP) (Zumberge et al., 1997). Unlike precise orbit that can be predicted with high precision, the precise clock should be estimated in real-time for the real-time applications. Actually, the satellite clock is usually estimated from real-time observations of a ground network (Ge et al., 2012; Zhang et al., 2011), which will be broadcasted to the real-time positioning users (Kouba and Héroux, 2001; Zhang et al., 2018). With the advent of multi-GNSS, estimation real-time precise clock for all the available systems is one of the crucial issues in GNSS real-time precise data processing.

There are a few real-time clock estimation methods which fall into three classes based on the observation models they adopt, i.e. the undifferenced (UD) method, epoch-differenced (ED) method, and mixed-differenced (MD) method (Ge et al., 2012). In 2007, Zhang et al estimate the near real-time orbit and clock by filtering the ED observations (Zhang et al., 2007). Mervart et al estimate the GPS

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real-time clock only using the ED phase observations (Mervart et al., 2008). In 2008, Hauschild and Montenbruck estimate the GPS real-time clock based on the UD observation model. The real-time clock is used in precise orbit determination of low Earth orbit satellite successfully (Hauschild and Montenbruck, 2009). In order to densify the clock correction to support high-rate data processing, researchers of Center for Orbit Determination in Europe (CODE) uses the UD model to estimate the 5-min interval precise clock and the ED observation model to densify the low-rate clock resulting in the 1 Hz clock (Bock et al., 2009a). In the same year, Bock et al apply this MD model to near real-time precise clock estimation for near real-time precise orbit determination of low Earth orbit satellites (Bock et al., 2009b). To improve computation efficiency, Zhang et al introduce a strategy that runs the UD and ED methods in two threads to generate the low rate clock and high rate clock change respectively. The high rate clock change is used to densify the absolute clock (Zhang et al., 2011). Ge et al proposed a MD method in 2012 using both the UD pseudorange observations and ED phase observations. The ambiguity parameters are eliminated in the ED model, so it exhibits high efficiency (Ge et al., 2012). In 2013, Laurichesse et al processed the UD observations using Kalman filter to generate near real-time precise orbit and clock products simultaneously. Because of the abundant unknown parameters, this method works so slow that the clock correction is updated with a rather low rate (Laurichesse et al., 2013). Overall, all the aforementioned methods have advantages and disadvantages. Among them, ED method eliminates all ambiguity parameters and preserves only satellite clock, receiver clock and tropospheric delay by differencing observations between consecutive epochs. Because of limited unknowns, the ED method is characterized by the high computation efficiency. The UD method estimates real-time clock based on the UD ionosphere-free code and carrier phase observations, which is more rigorous than the ED method and contributes to rather more precise clock solutions (Ge et al., 2012; Hauschild and Montenbruck, 2009). What's more, estimating ambiguity parameters makes it possible to fix ambiguity and resolve satellite hardware delay in further processing. The MD method is a trade-off between computation efficiency and solution accuracy.

Recently, a few international GNSS service (IGS) analysis centers (ACs), such as BKG, CNES, ESA and GFZ, have been working on generating real-time precise clock products (Dow et al., 2009). Actually, there are nearly 30 different real-time clock products mounting on the IGS caster, most of which are updated every 5 s, and a very few every 10 s. All the products contain real-time clock correction of GPS, while only 4 products include that of GLONASS. There are very few official products for the emerging GNSSs yet, such as the CNES real-time product. Statistically, all real-time clock products of different ACs exhibit comparable precision of about 0.2 ns. Fig. 1 presents the precision of some real-time GPS clock products generated by the IGS ACs with respect to the IGS final precise clock product. All the real-time clock corrections are received and saved as .clk files using the BKG Ntrip Client (BNC) software from DOY 300 to 360, 2015. As it is shown, most of the real-time clock products are better than 0.2 ns, which are helpful to the real-time precise positioning applications. The products of CNES, GFZ and IGS exhibit better accuracy and stability than that of BKG and ESA.

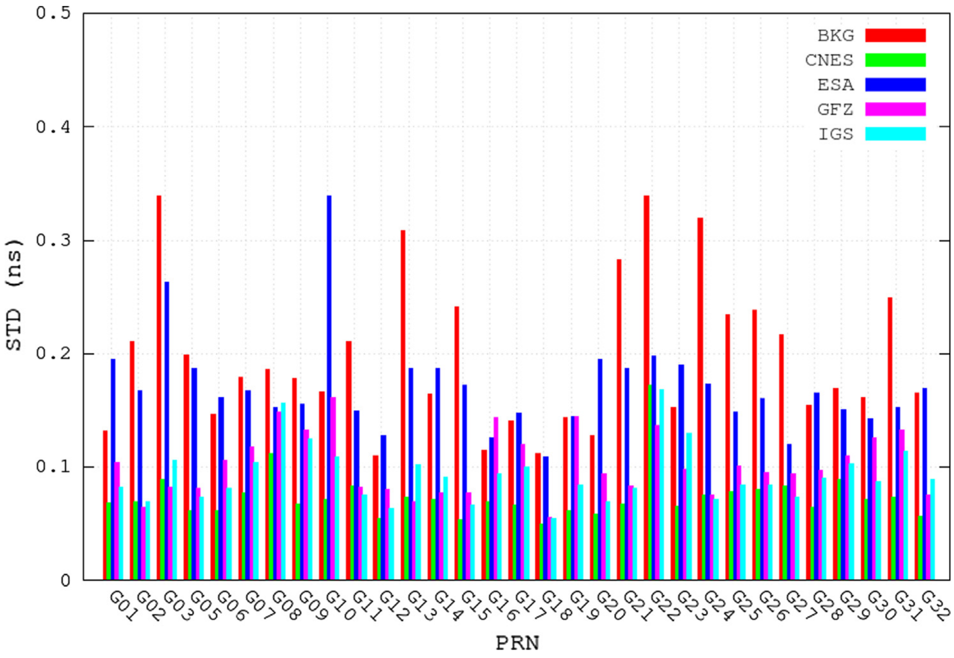

Fig. 1. Precision of real-time GPS clock products of 5 IGS ACs.

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