Improved PPP for time and frequency transfer and real-time detection of GNSS satellite clock frequency anomalies

Abstract

The aims of this PhD work were 1) to improve the performance of time and frequency transfer using upgraded GNSS PPP algorithms, and 2) to enable the real-time detection of GNSS satellite clock frequency anomalies for positioning and timing applications.

PPP is a state-of-the-art GNSS technique for precise time and frequency transfer, and its time solution has a statistical uncertainty of 100 ps over one day. In recent years, this classic PPP technique has shown some limitations when used to compare atomic clocks of the highest quality. The main limiting factor of PPP time transfer is the time discontinuity at the boundary of the computation batch, which could be more than 1 ns in extreme cases. During the PhD work, the Atomium PPP, which was originally developed by the Observatoire royal de Belgique, has been upgraded in order to improve its performance on time and frequency transfer. In the first part of the dissertation, three main updates to the current Atomium PPP are introduced: 1. adding Galileo signals to the PPP computation; 2. adding a constraint to the receiver clock; 3. new PPP algorithms with integer ambiguity resolution. The experiments carried out demonstrate that the Galileo + GPS PPP improves the short-term stability of the time transfer (in general by 20%-10% from 5 min to 2.5 hours interval) in the daily batch; the constrained PPP can be used to measure the H-maser with very good short-term stability, while it also shows its advantages in providing continuous time solution and retrieving clock measurements in extremely noisy environments; the integer ambiguity PPP shows improved time transfer frequency stabilities at mid and long-term (reaching 10^{-16} at 2 to 10 days averaging), and it also provides more accurate frequency transfer with monthly frequency offset within $\pm 2 \cdot 10^{-16}$.

The second part of the work focuses on developing the methods for producing real-time GNSS satellite clock frequency measurements, which are used for frequency anomaly detection. It has been reported in the experiment that a frequency jump of size $7.5 \cdot 10^{-13}$ in a GNSS satellite clock could cause accumulated errors of some meters to the calculated position or tens of ns divergence in the time solution if it is not detected within several hours. Current studies into these satellite clock frequency jump detections are based on post-processed measurements, which can not be used for real-time applications. The new method that we propose in this work can provide the frequency measurements of the GPS and Galileo satellite clocks in real-time using the carrier phase observations from a global ground station network. The test results

show that the precision of the frequency measurements obtained by the new method is comparable to the post-processed measurements, and that a satellite clock frequency jump as small as 5×10^{-13} could be detected within 30 min by the frequency jump detector using the related frequency measurements. In addition, in order to keep the measurement redundancy and to double check the detected jump, alternative methods are also proposed to provide the same kind of real-time frequency measurements.

Furthermore, it is currently in progress the integration of all the software developed into the DEMETRA project, which is a European project designed to provide time services to the specific users. The DEMETRA time monitoring service has been providing improved daily time solutions with the upgraded Atomium PPP software, while the GPS + Galileo PPP will soon be used instead of the GPS-only PPP to provide an hourly solution. The function of the real-time GNSS satellite clock frequency anomaly detections will be added to the DEMETRA time integrity service in future work.