Assessment of NAVCAST Precise Orbit and Clock Products for Real-Time GPS/Galileo PPP

Abdelsatar ELMEZAYEN and Ahmed EL-RABBANY, Canada

Key words: NAVCAST, PPP, kinematic.

SUMMARY

Precise point positioning (PPP) is a popular GNSS technique, due mainly to its ability to provide precise navigation solution using a standalone GNSS receiver. In 2018, a new real-time service, NAVCAST, which provides real-time precise orbit and clock products for the GPS and Galileo constellations, was launched. Galileo GNSS system has recently completed a total of 24 healthy satellites, which makes it possible to rely on it, along with GPS, to provide accurate positioning for a wide range of real-time applications. In this paper, a PPP algorithm is adopted to assess the potential positioning accuracy of the real-time GPS/Galileo PPP, which makes use of the NAVCAST real-time products. Two different land vehicular tests were conducted in Toronto, Canada, for that purpose. The German Federal Agency for Cartography and Geodesy (BKG) NTRIP client (BNC) software was used to process the GPS/Galileo observations in the real-time mode. It is shown that a sub-decimeter positioning accuracy can be achieved in an open sky environment. In addition, a sub-decimeter horizontal positioning accuracy and a meter-level vertical positioning accuracy can be achieved in the combined urban and sub-urban environment.

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1. ABSTRACT

Precise point positioning (PPP) is a popular GNSS technique, due mainly to its ability to provide precise navigation solution using a standalone GNSS receiver. In 2018, a new real-time service, NAVCAST, which provides real-time precise orbit and clock products for the GPS and Galileo constellations, was launched. Galileo GNSS system has recently completed a total of 24 healthy satellites, which makes it possible to rely on it, along with GPS, to provide accurate positioning for a wide range of real-time applications. In this paper, a PPP algorithm is adopted to assess the potential positioning accuracy of the real-time GPS/Galileo PPP, which makes use of the NAVCAST real-time products. Two different land vehicular tests were conducted in Toronto, Canada, for that purpose. The German Federal Agency for Cartography and Geodesy (BKG) NTRIP client (BNC) software was used to process the GPS/Galileo observations in the real-time mode. It is shown that a sub-decimeter positioning accuracy can be achieved in an open sky environment. In addition, a sub-decimeter horizontal positioning accuracy and a meter-level vertical positioning accuracy can be achieved in the combined urban and sub-urban environment.

2. INTRODUCTION

Conventional real-time kinematic (RTK) positioning has traditionally been one of the most widely used GNSS technique within the Geomatics community (El-Rabbany 2006). In RTK, a user can routinely achieve centimeter-level positioning accuracy, which makes it the standard choice for precise navigation applications such as machine automation, surveying, and mapping. Precise point positioning (PPP) technique, on the other hand, provides positioning accuracy at the centimeter-level in static mode and at the decimeter-level in postprocessed kinematic mode, respectively, using a single GNSS receiver (Kouba 2015, Rabbou and El-Rabbany 2015). To meet the growing need for accurate real-time PPP, several GNSS services have been made available, including the IGS real-time service (RTS). The IGS-RTS provides GPS-only or GPS+GLONASS real-time precise orbit and clock corrections. Real-time PPP was assessed in static and kinematic modes using GPS-only (Elsobeiey and Al-Harbi 2016), GPS+GLONASS (Krzan and Przestrzelski 2016), GPS+GLONASS+BeiDou (Abdi et al. 2017), and GPS+GLONASS+Galileo+BeiDou (Li et al. 2016).

In October 2018, Spaceopal GmbH, the prime contractor responsible for the Galileo operations, launched a new real-time GNSS high accuracy positioning service known as NAVCAST (Spaceopal 2018). This service provides real-time orbit and clock corrections for the GPS and Galileo satellite systems. A real-time GPS/Galileo PPP algorithm is adopted and used in this paper, which makes the use of the NAVCAST real-time orbit and clock products. Two different ground vehicular tests were conducted in Toronto, Ontario, Canada to assess the potential positioning accuracy of the real-time GPS/Galileo PPP solution. The processing strategy used in the BNC software is presented in the following section. Subsequently, the

NAVCAST real-time correction streams is described. Field trials and analysis of the results are then presented. Finally, some concluding remarks are drawn in the final section.

3. PROCESSING STRATEGY USED IN THE BNC SOFTWARE

The new version of BNC software, v2.12.9, is used in this study due to its ability to process multi-constellation GNSS observations in Rinex 3.03 format, combining real-time orbit and clock corrections with broadcast ephemeris in real-time mode (Stürze et al. 2016). To mitigate the bulk of ionospheric delay, the un-differenced ionosphere-free (IF) linear combinations of GPS and Galileo pseudorange and carrier phase observations are formed and employed as described in Equations (1) to (4) (Rabbou and El-Rabbany 2015).

$$P_{IF}^{G} = \rho^{G} + b_{r}^{G} - c \times dt_{s}^{G} + m_{w}^{G} \times zwd^{G} + \varepsilon_{PIF}^{G} \quad (1)$$

$$\Phi_{IF}^{G} = \rho^{G} + b_{r}^{G} - c \times dt_{s}^{G} + m_{w}^{G} \times zwd^{G} + N_{IF}^{G} + \varepsilon_{PIF}^{G} \quad (2)$$

$$P_{IF}^{E} = \rho^{E} + b_{r}^{G} - c \times dt_{s}^{E} + m_{w}^{E} \times zwd^{E} + ISB + \varepsilon_{PIF}^{E} \quad (3)$$

$$\Phi_{IF}^{E} = \rho^{E} + b_{r}^{G} - c \times dt_{s}^{E} + m_{w}^{E} \times zwd^{E} + N_{IF}^{E} + ISB + \varepsilon_{PIF}^{E} \quad (4)$$

Where, G and E refer to GPS and Galileo, respectively; ρ^{G} , ρ^{E} are the geometric range between the receiver and corresponding satellite for GPS and Galileo, respectively; $b_{r}^{G} = c \times dt_{r}^{G}$; c is the speed of light; dt_{r}^{G} is the GPS receiver clock error, which includes the GPS IF linear combination of the receiver code hardware delay; dt_{s}^{G}, dt_{s}^{E} are the GPS/Galileo satellite clock errors, which include the GPS/Galileo IF linear combination of the satellite code hardware delay; *zwd* is the zenith wet delay; m_{w} is the wet mapping function; N_{IF}^{G} and N_{IF}^{E} are the non-integer IF ambiguity terms for GPS and Galileo, respectively; *ISB* refers to the inter-system bias between the Galileo and GPS satellite systems, which equals the difference between the GPS and Galileo IF linear combination of satellite code hardware delay; ε refers to the multipath effect and un-modeled errors. GPS satellite clock correction includes the IF linear combination of the L1/L2 satellite code hardware delays, while Galileo satellite clock correction includes the IF linear combination of the E1/E5a satellite code hardware delays (Afifi and El-Rabbany 2016). To be consistent with the GPS satellite clock corrections, the IF linear combination of pseudorange observations are corrected by DCB_{P1-C1}. Additionally, the zenith dry component of the tropospheric delay is accounted for using the Saastamoinen model. In BNC software, the extended Kalman filter (EKF) is implemented to estimate the state vector, which includes three coordinates, receiver clock error, zenith wet tropospheric delay, ISB, and non-integer ambiguities for the tracked satellites (Abdi et al. 2017).

4. DESCRIPTION OF NAVCAST REAL-TIME STREAM

NAVCAST GNSS PPP service was announced by Spaceopal on October 29, 2018 (Spaceopal 2018). NAVCAST products include GPS/Galileo precise orbit and clock corrections that are broadcasted every 30 and 5 seconds, respectively. The only requirement to use this service is to register through the Spaceopal website (https://spaceopal.com/navcast/). The BNC software, which is available through the BKG website (BKG. 2019), can be used to combine the NAVCAST corrections, broadcast ephemeris, and GNSS observations to provide the PPP solution in real time. The main specifications of the NAVCAST correction streams are summarized in Tables 1 and 2.

Table 1. CLKA0_DEU mount point specifications (www.navcast.spaceopal.com)

Reference point	APC	
Reference frame	ITRF2008	
Format	RTCM_3.1	
Satellites constellations	GPS + Galileo	
RTCM messages	Constellation	Orbit and clock corrections
	GPS	1057, 1058
	Galileo	1040, 1041
Caster IP: port/ NTRIP version	navcast.spaceopal.com: 443 / 2s	

Table 2. BCEP0_DEU1 mount point specifications (www.navcast.spaceopal.com)

Reference point	APC BCEP0_DEU1-BCE	
Format	RTCM_3.3	
Satellites constellations	GPS + Galileo	
RTCM messages	Constellation	Navigation
	GPS	1019
	Galileo	1044, 1045
Caster IP: port/ NTRIP version	navcast.spaceopal.com: 443 / 2s	

5. LAND VEHCULAR FIELD TRIALS AND RESULTS ANALYSIS

To assess the accuracy of the real-time GPS/Galileo PPP, two kinematic land vehicular trials were conducted in Toronto, Canada. The first trajectory lasted for about forty minutes and included combined urban and suburban areas with several overpasses, as shown in Figure 1. Raw GPS L1/L2 and Galileo E1/E5a pseudorange and carrier phase measurements were collected using Trimble R9s geodetic receivers. NAVCAST real-time products were acquired using the BNC software through NTRIP. GPS/Galileo observations along with the pre-saved NAVCAST corrections and broadcast ephemeris were then processed in the real-time mode using the BNC software. The reference solution was obtained from the carrier-phase-based differential GNSS (DGNSS) solution, which was created using Trimble Business Centre (TBC) software. One of Cansel's GNSS permanent network (CAN-NET) in the Toronto area, TORO, was used as the reference station.

Figure 1: First field trial trajectory, Toronto, Ontario, Canada

Figures 2 shows the positioning errors in the east, north, and up directions. As can be seen, in general the positioning errors show a consistent behavior in all directions. The jumps in the positioning errors in Figure 2 refer to the parts where the PPP solution started to re-converge after complete GNSS outages, which occurred while the vehicle was passing under several bridges.

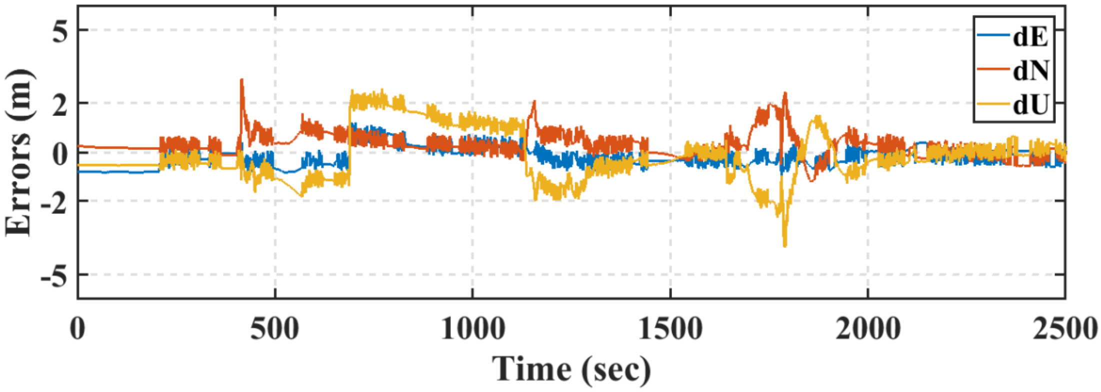

Figure 2. Positioning errors in the east (dE), north (dN), and up (dU) directions for the first trial

The second trajectory lasted for about twenty minutes and included a combined open sky and urban areas with one overpass, as shown in Figure 3. Raw GPS L1/L2 and Galileo E1/E5a pseudorange and carrier-phase measurements were collected using Trimble R9s geodetic receiver. Similar to the first field trial, GPS/Galileo observations along with the pre-saved NAVCAST corrections and broadcast ephemeris were processed in the real-time mode using the BNC software. The reference solution was obtained from the carrier-phase-based differential GNSS (DGNSS) solution, which was created using Trimble Business Centre (TBC) software. RIHI station, which is one of Cansel's GNSS permanent network (CAN-NET) in the Toronto area, was used as the reference station. As shown in Figure 4, the positioning errors for the GPS/Galileo PPP solution are within ±1m in all directions, except for the part that is directly after GNSS outage. The jump in Figure 4 refers to the part where the PPP solution started to re-converge after a complete GNSS outage, which occurred while the vehicle was passing under a bridge.

Figure 3: Second field trial trajectory, Toronto, Ontario, Canada

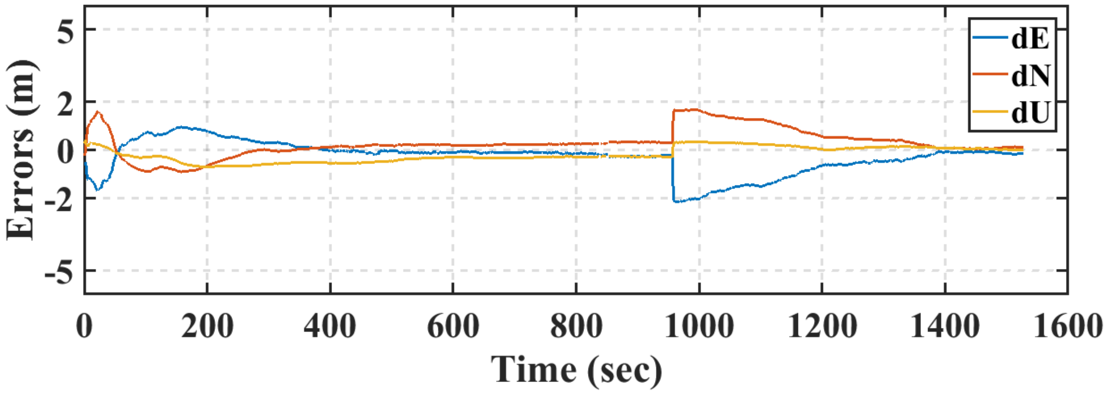

Figure 4. Positioning errors in the east (dE), north (dN), and up (dU) directions for the second trajectory

Table 3. Mean and RMS for the East, North, and Up components for the kinematic tests

Trajectory	dE (m)	dN (m)	dU (m)

	mean	RMS	mean	RMS	mean	RMS
First	0.224	0.457	0.288	0.574	0.189	0.998
Second	0.288	0.374	0.281	0.367	0.185	0.439

The RMS of the real-time GPS/Galileo PPP solutions for both field trials are presented in Table 3. The overall positioning accuracy for the first trial is 0.457m, 0.574 m, and 0.998 m in the east, north, and up directions, respectively. The corresponding RMS values for the second trial are 0.374 m, 0.367 m, and 0.439, respectively. The positioning accuracy for the second trial is better than the corresponding accuracy for the first trial, which is expected as the second trial was carried out in an open sky environment.

6. CONCLUSIONS

In this paper, the BNC software was adopted and used for real-time kinematic GPS/Galileo PPP. NAVCAST real-time orbit and clock products were used to simulate the real-time scenario. Two different field trials were carried out and the obtained PPP results were compared to the carrier-phased-based DGNSS counterparts. It was shown that a sub-decimeter-level positioning accuracy is achievable in real time in an open-sky environment. However, the real-time PPP accuracy deteriorates to a sub-decimeter- and a meter-level in the horizontal and vertical directions, respectively, when driving in a combined urban and suburban environment.

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BIOGRAPHICAL NOTES

Abdelsatar Elmezayen obtained his B.Sc. and M.Sc. degrees in Civil Engineering from the Department of Civil Engineering, Tanta University, Egypt. At present, Abdelsatar is a PhD candidate, Geomatics Engineering, Civil Engineering Department, Ryerson university, Canada. His research focuses on multi-sensor integration for precise navigation.

Ahmed El-Rabbany obtained his PhD degree in GPS Satellite Navigation from the Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. At present, Dr. El-Rabbany is a full professor at Ryerson University, Toronto, Canada, where he leads research projects in the areas of satellite navigation and multi-sensor integration for mobile indoor/outdoor mapping.

CONTACTS

Abdelsatar Elmezayen
PhD candidate, Civil Engineering Department, Ryerson University
350 Victoria street, Toronto, Canada
Tel. +(416)979-5000, ext. 4623
Email: abdelsatar.elmezayen@ryerson.ca