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Evaluation of EPOS-RT for Real-time Deformation Monitoring

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Abstract

With the development of the EPOS-RT software system at GFZ, various tests have been performed to target some high precision applications such as real-time network deformation monitoring and that of based on real-time PPP (Precise Point Positioning). The paper provides an overview of the main features of the EPOS-RT software and focuses on the software performance assessment. The case studies of real-time detection of the well controlled station motion, using a network with stations separated by distances between 123 Km and 482 Km, show kinematic position accuracy at 7 mm in horizontal components and better than 2.5 cm in vertical component. Results from analysing real earthquake dynamics have demonstrated some unique features of the system and its capability of attaining mm accuracy in real time.
Keywords: EPOS-RT, precise point positioning, real-time deformation monitoring

1 Introduction

Real-time kinematic (known as RTK) positioning is widely used in local and regional scales (e.g. Bock et al 2000, Rizos 2003, Rocken et al 2004). The major restriction of the state-of-art network RTK systems, including its latter developments, e.g. VRS (Virtual Reference System), is its rather short reference station spacing, usually in the range of 100 Km or less. With future generation GNSS signals, the distance may be doubled (Feng and Li, 2008). PPP (Zumberge et al, 1997) based positioning strategies may overcome this problem, regardless of dual or triple frequency signals. As an implementation of this idea, a newly developed software package, named EPOS-RT, has been developed at GFZ. This paper provides the performance assessment of EPOS-RT for real-time network deformation monitoring. The main features of EPOS-RT software are outlined in Section 2. Three case studies of real-time detection of well controlled station motion and real-time monitoring of real earthquake deformation in terms of seismic wave propagation are detailed in sections 3 and 4.

2 EPOS-RT Software

The EPOS-RT software as more systematically described by Ge et al 2008, 2009; Chen et al 2008, 2009 was on the initiative of Maorong Ge and a collective effort from all co-authors at GFZ. For real-time data analysis, the Square Root Information Filter (SRIF, Bierman 1977) is used. In pre-processing, the so-called "Bancroft solution" (Bancroft 1985) is implemented to perform a pseudorange based coordinate estimation and to correct for the receiver clock "msec-jump" of phase observation for some type of receivers (Zhang et al 2007). To get the best accuracy from ambiguity resolution, the strategy developed at GFZ, which selects the double difference ambiguities according to their probability of being fixed, (Ge et al 2005) is implemented and the LAMBDA method (Teunissen 1995) is used.

EPOS-RT applies the un-difference epoch-wise processing strategy and it is ready to fulfil the multi-functional performance, such as:

- real-time / post-mission processing
- static / kinematic / dynamic positioning
- high spatial & temporal resolution solution
- multi-technique & multi-system integrated solution

Using the same software, two real-time processing procedures are supported. The first one is the so called "real-time network monitoring" by running EPOS-RT in "RT network" mode (Fig. 1a), and the other is "PPP based positioning service" by running EPOS-RT in "RT Clock" and "RT PPP" mode in parallel(Fig. 1b). In both strategies, three parts are included: data communication and interface, processing kernel, and product service. Different types of data, file-based or real-time streaming (via internet), are supported in data communication. Depending on different input configuration file, processing kernel (SRIF) applies three processing modes, i.e. SRIF(NET) for network solution, SRIF(Clk) for satellite clock estimation, and SRIF(PPP) for PPP solution at single site.

In the network monitoring (Fig. 1a) we use a regional network, where several reference stations are fixed and satellite clocks, station tropospheric parameters, ambiguities together with "rover" clocks and kinematic coordinates are estimated by SRIF(NET). In PPP based positioning service (Fig. 1b), the processing is done in two stages. Firstly, real-time epoch by epoch satellite clocks are estimated by SRIF(Clk) based on a reference network, where reference stations are fixed. The clocks are disseminated together with real-time (or predicted) orbits to the users who calculate its precise position thereafter by SRIF(PPP). This paper focuses on the network monitoring capabilities of EPOS-RT. In the following, we present some examples of the detection of precisely controlled station motion and monitoring a highly dynamic deformation sequence caused by a real earthquake to show the performance of EPOS-RT software.

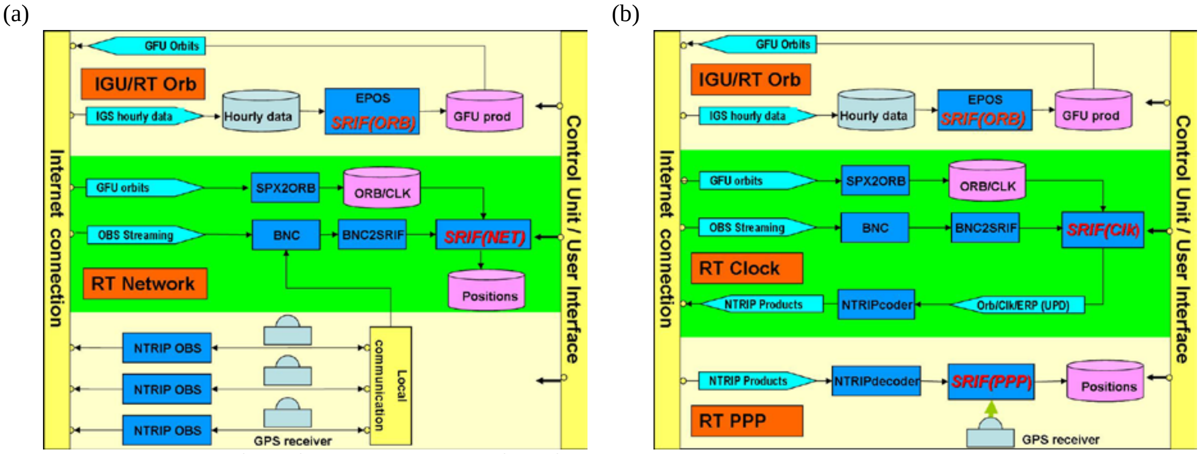

Fig. 1 (a) Structure and data flow of the network solution for deformation monitoring by running EPOS-RT in "RT network" solution mode. (b) Structure and data flow of the PPP based positioning service by parallelly running EPOS-RT in the "RT Clock" and "RT PPP" mode. In both cases, the estimated (RT) or predicted (IGU) orbits are fixed.

3 Real-time deformation monitoring

To evaluate the performance of EPOS-RT, two on-site real-time tests were carried out on the roof of building A17 located at GFZ. In the first test, horizontal motion was monitored, where one experiment station (A17B, Rover 1 in Fig. 2) was set up on a horizontal linear table with scale panel (Fig. 2, front) to read the distances between the current and initial positions. Another station (A17D, Rover 2 in Fig. 2) was installed with its position precisely adjustable and the height changes can be recorded by scale panel. Station A17D was used to perform a vertical motion test.

In both tests, real-time data sampled at 1 Hz were streamed using NTRIP protocol (Gebhard et al 2003, Weber et al 2005). In the real-time data processing, GNSS orbits and Earth Rotation Parameters (ERPs) from GFZ's Ultra rapid solution (GFU) were used as fixed parameters; clock biases of satellites and stations and kinematic coordinates of rovers were estimated at each epoch. For the ambiguity resolution, LAMBDA method was used at time interval of every 20 minutes after the initial 30 minutes.

Fig. 2 The experiment field at GFZ, where Rover 1 (A17B) was set up on the horizontal linear table with scale panel to read the distances between the current and initial positions, and Rover 2 (A17D) was equipped with the device capable of adjusting the antenna height and recording the height changes

3.1 Horizontal vibration motion

We performed 3 scenarios of controlled horizontal motion using A17B on 28 July, 2009. The range of the motion is from -20 cm to 20 cm (Fig. 2). In the first scenario, we moved the rover along the linear table from its initial position (central point) towards north-west direction to the stop point in N-W (track1). Afterwards the rover was moved towards opposite direction to the stop point in S-E (track2). In the third scenario, we moved the rover back to its initial positions (track3).

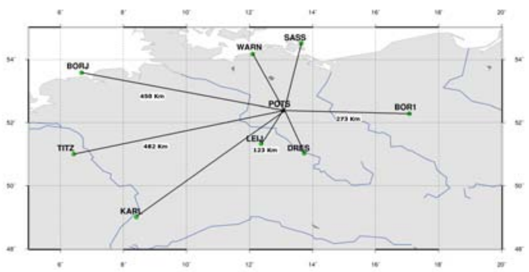

Fig. 3 Illustration of the real-time stations used in the experiment and the lengths of the baselines from the used reference stations to experiment kinematic stations in Potsdam, where POTS stands for A17B and A17D

Data analysis was performed in two different strategies. In the first strategy (L3 solution), the network showing in Fig. 3 was used, where the 8 EUREF stations (only BORJ,TITZ,LEIJ and BOR1 have real-time streams during the test) were fixed and only A17B was treated as a kinematic station. In this strategy, we had the shortest baseline of 123 Km and network mode processing was set with tropospheric parameters were set up and estimated in Piece-Wise-Constant (PWC) mode at interval of 1 hour using the combined L3 observables. In the second strategy (L1 solution), the IGS reference station POTS at GFZ, several meters away from A17B, was used as the reference station. Due to the short distance, tropospheric parameters were not estimated and data analysis was carried out with GPS L1 observations only.

Fig. 4 shows the kinematic coordinate changes of A17B in real-time relative to its initial coordinates by implementing different processing strategies. In Fig. 4, accuracy better than 1 cm in horizontal component and better than 2.5 cm in vertical component is achieved. By comparing the two solutions, we see the vertical precision is 3 times worse in L3 solution, where the existence of tropospheric parameters degrades the results. In L3 solution, a drift around 1.5 cm exists after we return to the initial position in track3. In all 3 scenarios, we held the station for few minutes when the stop positions were reached to test for coordinate repeatability. In general, L3 solution has a bigger repeatability than L1 solution, and in both case we see that N-S component has a worse repeatability than that in E-W component, which can be clearly explained from the network configuration. In Fig. 3, we have 3 reference stations in N-S direction while in E-W direction only LEIJ is available.

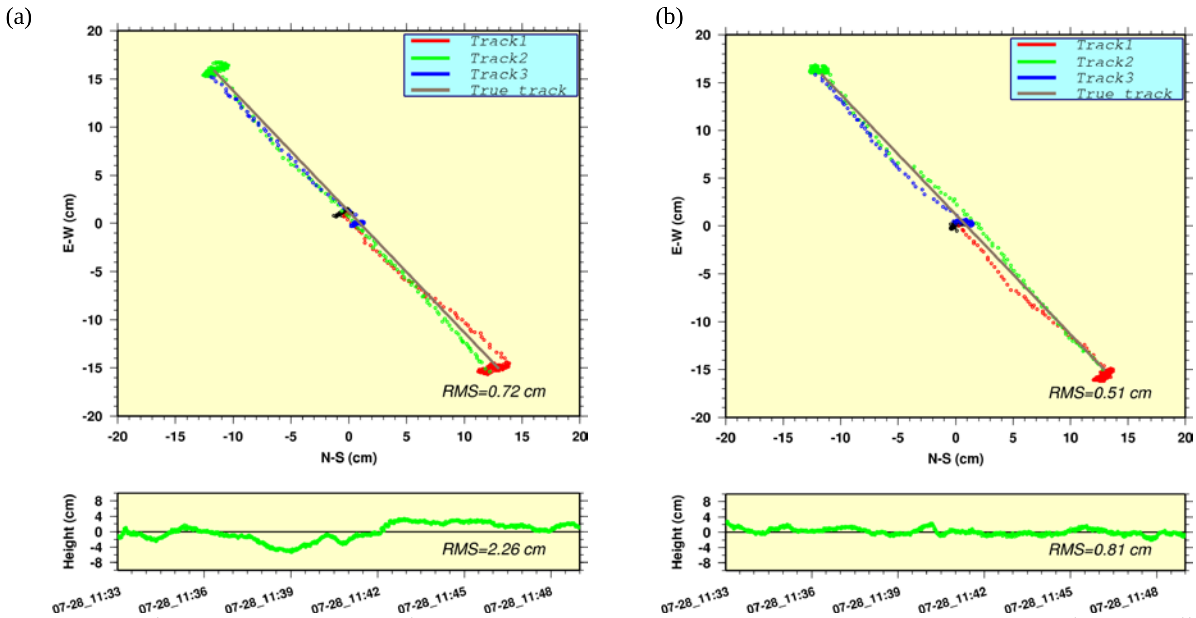

Fig. 4 (a) Results from L3 solution. (b) Results from L1 solution. In both pictures, top plot shows the horizontal trajectories of A17B in difference scenarios, where the purple line represents the real track of the horizontal vibration (true track) and the RMS value refers to the true track. Bottom plot shows height changes of station A17B with respect to the ground truth computed precisely before hand and the RMS value refers to the known height.

3.2 Vertical motion

Vertical motion test was performed using station A17D on 13 May, 2009. During this test, we began to smoothly increase the antenna height at 13:02 (UTC) until the height was increased by 15 cm at 13:03:07 (UTC). After running around 1 hour and 46 minutes, we began to decrease the antenna height by 20 cm. L1 solution was performed with the IGS reference station POTS at GFZ as reference station.

Fig. 5 and Fig. 6 show the kinematic coordinate changes of A17D in real-time relative to its known coordinates. In Fig. 5, a difference of a few mm is observed in two horizontal components and less than 1 cm difference observed in the height component. Both figures show that the manual deformation was precisely recorded.

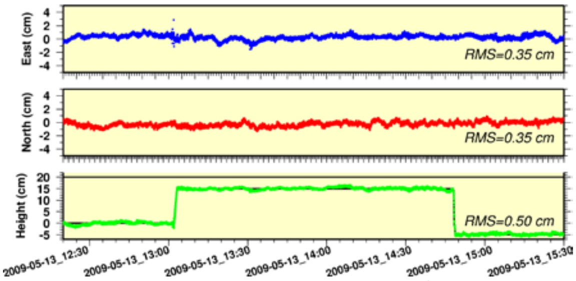

Fig. 5 Colored dots show the coordinate changes of station A17D with respect to the ground truth computed precisely before hand. The black lines represent the real track of the manual height changes and the RMS value refers to the known coordinates

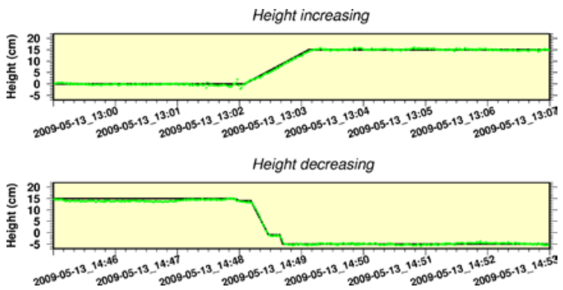

Fig. 6 Coordinate changes of station A17D in details during the height increasing and decreasing period, where the black lines represent the real track of the manual height changes and green dots are the real-time estimated coordinate changes compared to the true

4 Displacement monitoring of a real earthquake event

Eastern Honshu earthquake occurred at 23:43:46 (UTC) on June 13, 2008. The GPS station in Mizusawa (MIZU, receiver type: Septentrio) in Japan, around 50km from the epicenter, recorded the displacement sequence of the event. Using EPOS-RT, the GPS data was analyzed in a real-time-like post-processing mode, where epoch by epoch solutions was obtained. The network showing in Fig. 7 was used where the station PETS (in Russia, receiver type: ASHTECH), SUWN (in South Korea, receiver type: ASHTECH) and SHAO (in China, receiver type: ASHTECH) were fixed and only MIZU was treated as a kinematic station.

Network mode processing was set using the combined L3 observables. GFU orbits and ERPs were fixed in the data processing while the clock biases of both satellites and stations together with the kinematic coordinates of MIZU were estimated at each epoch. Tropospheric parameters were set up and estimated in Piece-Wise-Constant (PWC) mode at interval of 1 hour. The two hour data span staring from 22:00 UT were analyzed. The ambiguity fixing was performed every 20 minutes after the initial 30 minutes.

Due to the long baselines, the ambiguity solutions took longer time to converge (fixing rates are receiver type and distance dependent). In this test, the fixing rate is 54% for baseline MIZU-SUWN, 95% for baseline SHAO-SUWN and 71% for baseline PETS-SUWN. Fig. 8 shows the earthquake caused displacement in all three components at kinematic station MIZU with respect to its known coordinates prior to the quake (from previous daily solution). From Fig. 8, it is clearly shown that the earthquake wave arrived at MIZU around 20 seconds after the main shock. Strong shaking lasted for a few minutes. Later on, an obvious and permanent co-seismic displacement of 10cm in the east-west component was logged.

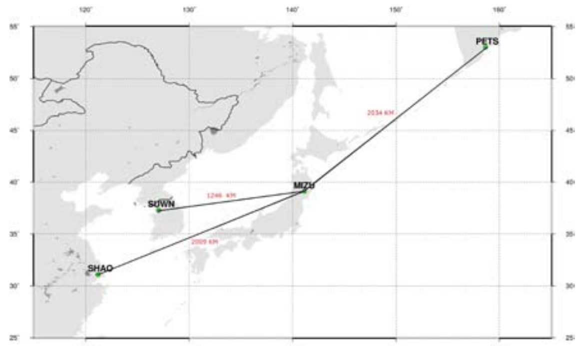

Fig. 7 Illustration of the stations used in the experiment and the lengths of the baselines from the three reference stations to the "rover" (kinematic station), MIZU in Japan

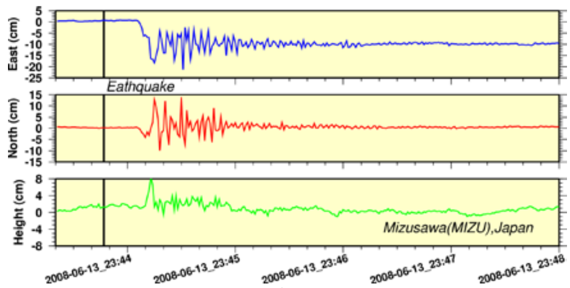

Fig. 8 Displacement sequence of 2008 Eastern Honshu earthquake observed at station MIZU,Japan, on June 13, 2008

5 Summary

A new software system, EPOS-RT, has been developed at GFZ for real-time network deformation monitoring, providing PPP based positioning solutions for real time and post-processing applications. Results from three tests have demonstrated mm horizontal positioning accuracy achievable in real time for a wide range of precision applications.EPOS-RT is designed to have multi-technique and multi-system capability, but currently only GPS is implemented. Currently EPOS-RT does not include orbit integration package (SRIF(ORB) in Fig. 1), therefore its performance depends on the quality of the existing orbits. Continuing efforts will be made to improve the real-time PPP ambiguity fixing capability and faster initial solution convergence.

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