Onboard Real-time Precise Orbit Determination of LEO Satellites Using Space-borne GNSS Measurements

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1. Introduction

With the great progress of the remote sensing based on low Earth orbit (LEO) satellites, onboard real-time precise orbit determination (RTPOD) has been rapidly developed. RTPOD using space-borne GNSS measurements is recognized as the most mainstream technology for LEO satellites, due to its global coverage, abundant observations and low-cost. Onboard RTPOD using space-borne GPS observations is rather mature and could usually achieve orbits of sub-meter or decimeter accuracy (Montenbruck et al., 2008, Wang et al., 2015).

In this contribution, we concentrate on the onboard RTPOD based on space-borne multi-GNSS measurements. The Chinese meteorological satellite Fengyun-3C(FY3C), launched in 2013, was equipped with a GNOS (GNSS Occultation Sounder) instrument onboard which can provide space-borne GPS/BDS pseudo-range and carrier phase measurements. GPS/BDS data from FY3C is employed in experiments for investigating the impact of BDS satellites on RTPOD.

2. RTPOD Strategies

The onboard RTPOD, also known as autonomous orbit determination, has no dependence on ground-based tracking assets. Its processing completes in the embedded system on a space-borne platform, which usually has very limited computing capacity. And the orbit results are required to be delivered within minutes, seconds, or even a fraction of a second after observations are made. So the algorithm of RTPOD must take the autonomy, timing and orbit accuracy into account. The strategies in POD post-processing are not suitable.

Table 1 RTPOD strategies

GPS/BDS data	LC+PC, sampling rate of 30 s
GPS/BDS orbit and clock	Broadcast ephemeris
Earth Gravity Field	EGM 2008, adopt 45×45 degree
Luni-solar gravitation	Low precision model, Moon and Sun's position are computed via analytic method
Earth tides	Low precision model, solid only
Atmosphere Drag	Modified Harris-Priester model (density), fixed effective area, estimates Cd parameter
Solar radiation pressure	Cannonball model, fixed effective area, estimates Cr parameter
Empirical acceleration	Dynamic Model Compensation (DMC) with a first-order Gauss-Markov model
Other perturbations	Neglected
Precession and nutation	IAU1976/IAU 1980 simplified model
Earth rotation parameter	Rapid predicted EOP in IERS Bulletin A
Estimator	Extend Kalman Filter(EKF)

Simulating the onboard real-time operational scenarios, all the settings of RTPOD are listed in Table 1. Its main features are as follows:

- Only broadcast ephemeris can be used to compute orbits and clocks of GPS/BDS satellites due to onboard real-time and autonomy requirements.
- In order to reduce the computational load, the dynamical models are simplified to the maximum extent without notable loss of orbit accuracy.
- The extend Kalman filter(EKF) is employed to process GPS/BDS data in pure real-time mode.

3. RTPOD experiments

Experimental datasets covering from 2015/069 to 2015/075 are processed. Four schemes are designed to examine the impact of BDS satellites on RTPOD.

- Scheme 1: RTPOD only using GPS data ("GPS")
- Scheme 2: RTPOD using GPS and all BDS data ("GPS+BDS with GEOs")
- Scheme 3: RTPOD using GPS and BDS but no GEOs data ("GPS+BDS w/o GEOs")
- Scheme 4: RTPOD only using BDS data ("BDS")

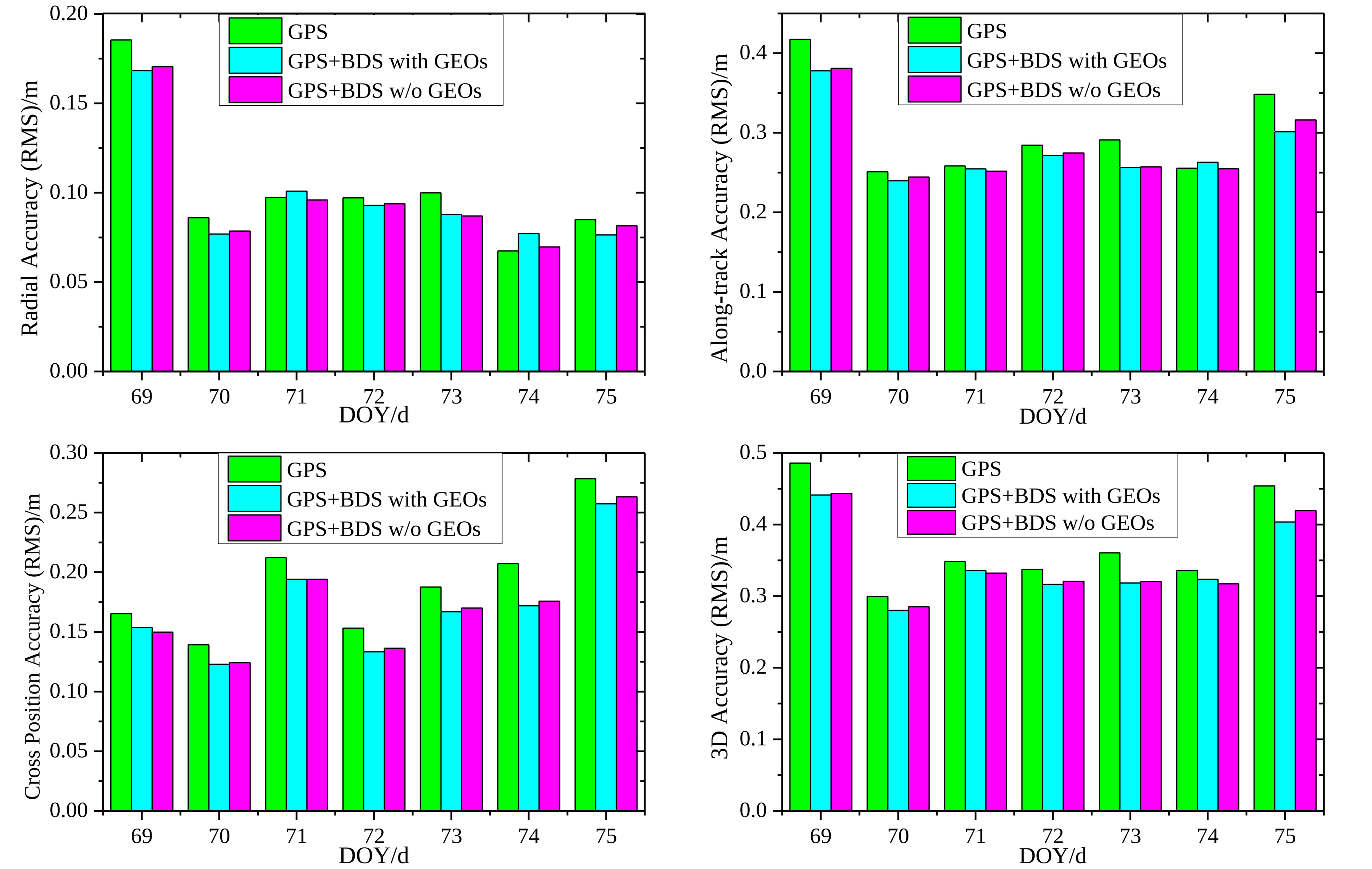

Fig.1 Orbit accuracy comparison of Scheme 1~3

The radial(R), along-track(A),cross(C) and 3-dimensional (3D) position accuracies (RMS) of Scheme 1~3 are presented in Fig.1. 3D position accuracies of Scheme 1~3 are all at 0.3~0.5m, but slightly better results are obtained for Scheme 2 and 3 by combining BDS data . It demonstrates that fusion of GPS/BDS data contributes to improvement of RTPOD accuracy to a certain extent. The difference between Scheme 2 and 3 is very small. It is indicated that there is no obvious orbit accuracy degradation or increase with BDS GEOs involved if reasonable weight factors are adopted for GEOs in EKF filter.

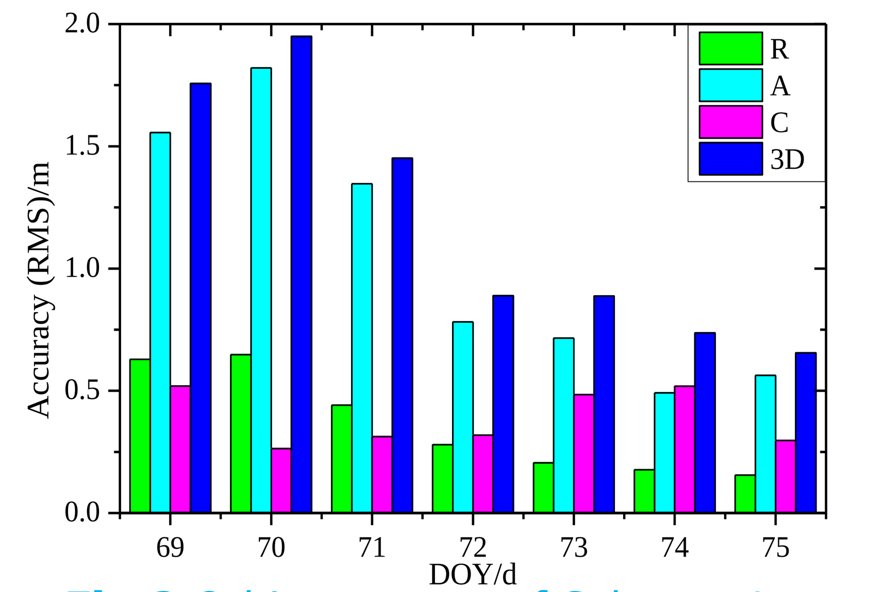

Fig.2 Orbit accuracy of Scheme 4

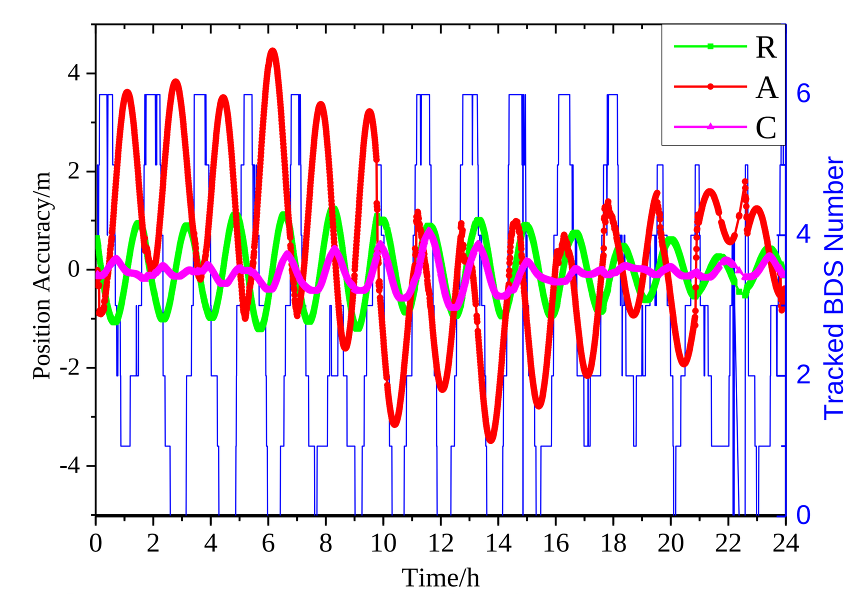

Fig.3 Position error of Scheme 4 in DOY=71

The orbit accuracies of Scheme 4 are shown in Fig.2. The 3D position accuracy are up to 0.6~2.0m. And its position errors even reach to several meters (Fig.3). The reason for this is that only in Asia/Pacific region 4~6 BDS satellites can be tracked and in most arcs with less than 4 BDS satellites EKF filter of RTPOD generates worse predicated orbits by dynamical integration (Fig.3).

Table 2 Overall accuracy statistics

RMS	Position (m)				Velocity (mm/s)			
	GPS	GPS+BDS with GEOs	GPS+BDS w/o GEOs	BDS	GPS	GPS+BDS with GEOs	GPS+BDS w/o GEOs	BDS
R	0.108	0.102	0.102	0.414	0.274	0.256	0.258	0.945
A	0.305	0.283	0.285	1.159	0.152	0.148	0.148	0.437
C	0.195	0.175	0.177	0.399	0.198	0.175	0.178	0.408
3D	0.378	0.348	0.351	1.294	0.371	0.344	0.346	1.118

The overall RMS statistics of orbit accuracy for all schemes are summarized in Table 2. The 3D position and velocity accuracy of Scheme 1 based on GPS data are 0.378m and 0.371mm/s, while those of Scheme 2~3 based on combined GPS/BDS data are improved slightly to about 0.350m and 0.345mm/s, respectively. The orbit accuracy of Scheme 4 only based on BDS data is notably decreased to 1.294m for position and 1.118mm/s for velocity.

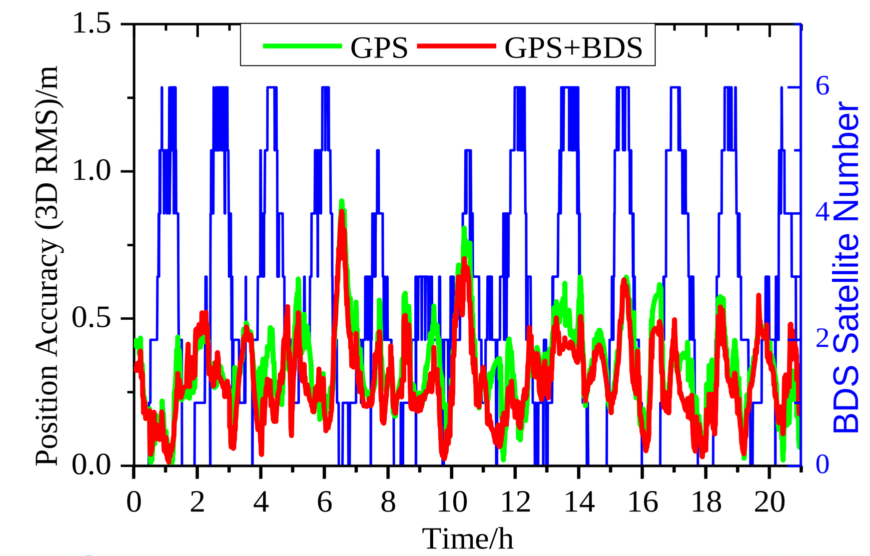

Fig.4 Position error variation in DOY=73

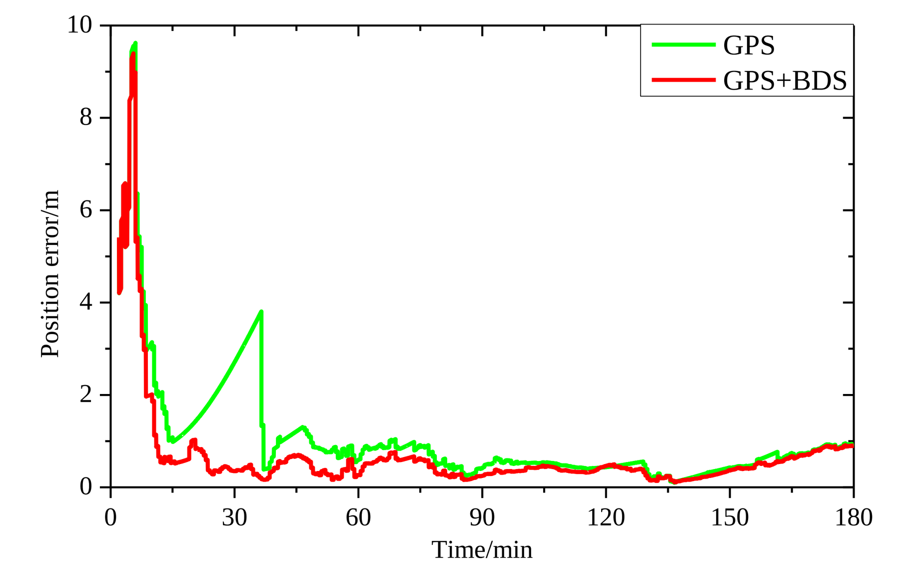

Fig.5 Error variation in convergence stage

Although the participation of BDS is not able to improve the RTPOD accuracy obviously, fusion of GPS/BDS data can reduce the local variation amplitude of orbit errors (Fig.4), especially when more BDS satellites are tracked in Asia/Pacific region. At the same time, the convergence time of EKF filter is shortened notably with BDS involved (Fig.5).

4. Conclusions

Onboard RTPOD using space-borne GPS/BDS measurements can obtain final orbit accuracy of 0.3~0.5m and 0.3~0.5mm/s in terms of 3D RMS for position and velocity, respectively. Although the accuracy is only slightly superior to that using single GPS data, fusion of GPS/BDS data suppresses the local variation of orbit errors and speeds up the convergence of Kalman filter. It should also be noticed that RTPOD orbit accuracy only based on BDS measurements is up to 0.6~2.0m because of only few tracked satellites which is expected to be improved in the near future along with the development of the BDS global navigation system.

5. References

- Montenbruck O, Ramos-Bosch P(2008). Precision real-time navigation of LEO satellites using global positioning system measurements. GPS solutions, 12: 187-198.
- Wang F, Gong X, Sang J, et al (2015). A novel method for precise board real-time orbit determination with a standalone GPS receiver. Sensors, 15, 30403–30418.

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