Orbit/Clock decorrelation approach for precise dynamic orbit determination

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Abstract

A two-step **TWTT** (Two Way Time Transfer) assisted orbit determination approach is proposed. In the first step, the **TWTT** technique, which is un-affected of satellite orbits error, is used to estimate satellite clocks. Afterwards, the precise clocks are fixed as known or tightly constrained in the **POD** (precise orbit determination) processing. This method is used for **BDS** (beidou satellite system) precise orbit determination, in which **TWTT** data is retrieved from the ground tracking antennas and the GNSS observations are from around 50 globally-distributed stations. Results show that the new approach improves the precision of orbit determination and orbit prediction by more than 15% and 70%, respectively.

Parameter correlation problems

Satellite orbit and clock product of IGS are formed as the weighted averages of solutions contributed by the participating **ACs** (analysis centers). Usually satellite orbits and clocks are estimated simultaneously in the precise data analysis of each AC, and the conventional dynamic orbit determination approach is used. However, apparent orbit and clock offsets between different IGS analysis centers can be found.

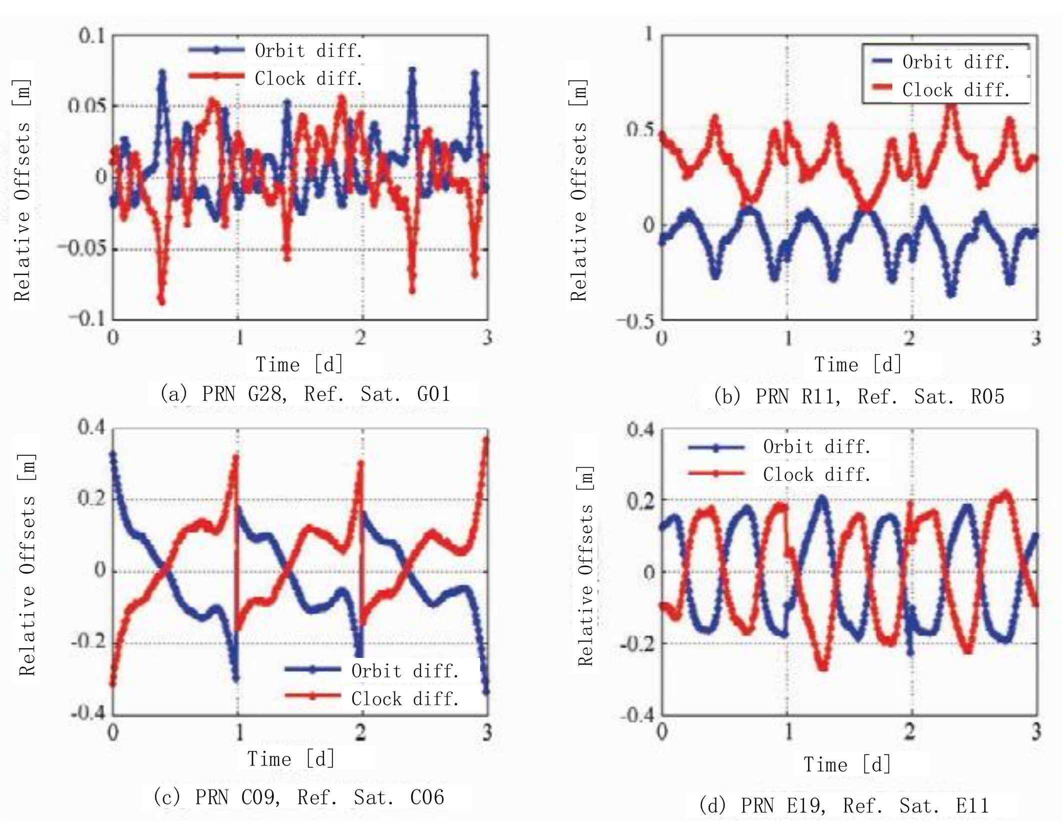

Figure 1: Comparison of satellite radial orbit and clock differences between GFZ and CODE products

Satellite radial orbit and clock differences between GFZ and CODE products are compared. In order to eliminate the effects of systematic offset, for each **GNSS**, one satellite is chosen as the reference satellite. Periodic characteristic of satellite radial orbit differences between GFZ and CODE can be found, and the same is true for satellite clock differences.

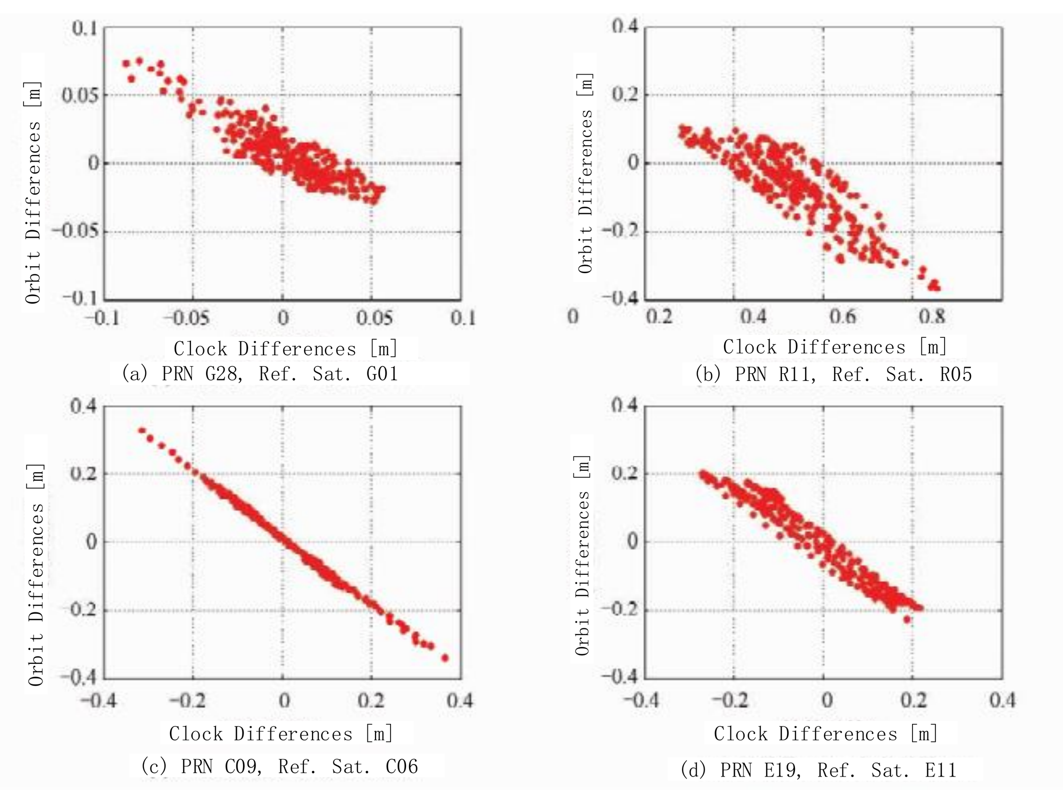

Figure 2: Correlation analysis of satellite radial orbit and clock differences between GFZ and CODE products

Strong correlation between differences of satellite radial orbit and clock for above ACs can be found. The correlation coefficients is -0.7, -0.8, -0.9 and -1, for GPS, GLONASS, Galileo and BeiDou, respectively.

In other words, apparent modelling error still exist in the GNSS precise data processing algorithm. Based on the current data processing algorithm and strategy of IGS, there is strong correlation between satellite radial orbit and clock.

TWTT satellite clock constraint

Compared to the satellite clock estimated by **OD&TS** (orbit determination and time synchronization) algorithm, precision of TWTT satellite clock is higher, especially for **GEO** (geostationary earth orbit) satellites. Because through the differences of up- and down-pseudoranges, most systematic errors, such as orbital error, station position error, tropospheric error, can be eliminated.

In order for real-time **POD**, satellite clock should be predicted, and the quadratic polynomial model is used. The observation equation is as follows:

$$L_i^j = \rho(r_i, r^j) + c \cdot dt_i - c \cdot \left(a_{0,j} + a_{1,j} \cdot \Delta\tau + a_{2,j} \cdot \Delta\tau^2\right) + N_i^j + T_i^j + \epsilon_i^j \quad (1)$$

Advantages of real-time POD based on TWTT satellite clock constraint is:

- Satellite clock is not affected by satellite orbit estimation error
- Better modelling and more stable solutions can be obtained

Experiment

Frequent satellite maneuver reduces the available time of BDS satellites. There will be a GEO/IGSO satellite under orbit control operation every 7âĂŞ10 days. Real-time POD based on TWTT satellite clock constraint is used applied for rapid orbit recovery after the satellite maneuver event to increase the GEO satellite available time. Observations of 7 tracking stations in China mainland are used, and three periods of GEO satellites experienced maneuver operation in October 2017 are selected.

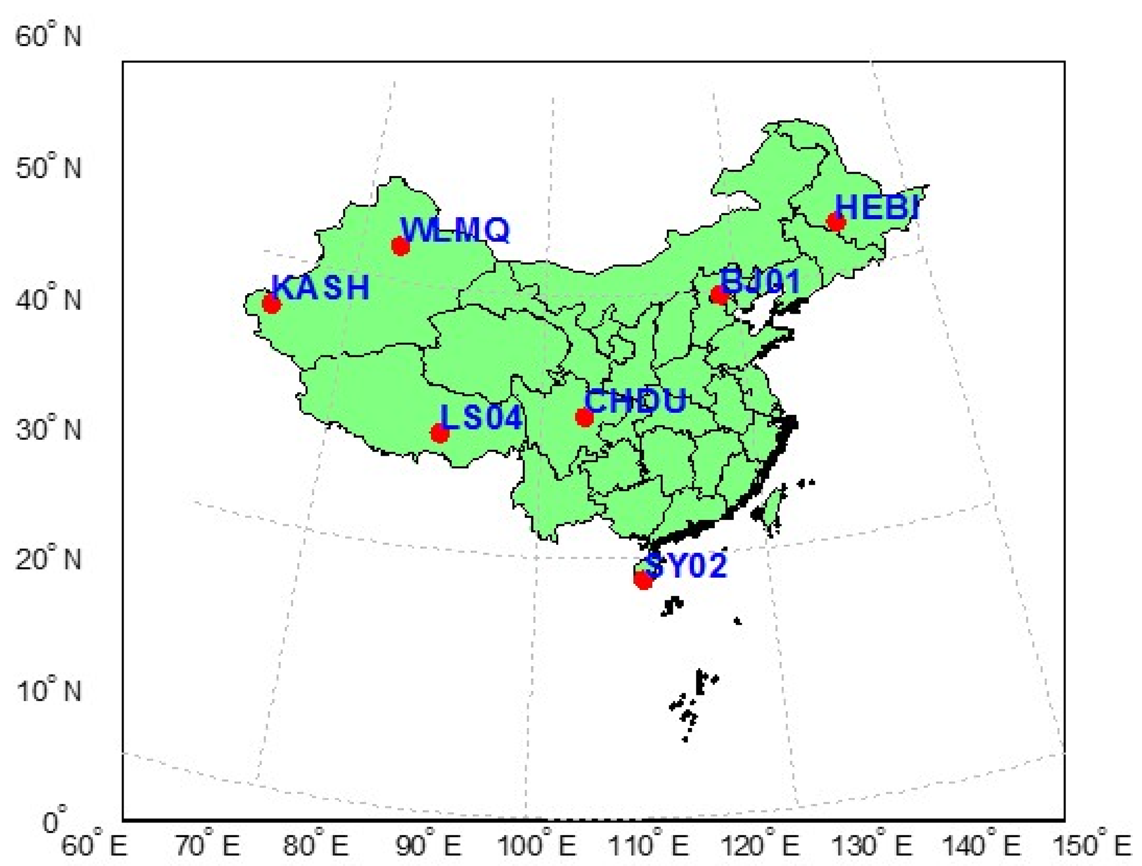

Figure 3: Distribution of tracking stations in China mainland for POD

SatID	Start	End	Available
C01	2017-10-31 8:55	10:15	4 h after maneuver
C02	2017-10-19 8:59	11:15	4 h after maneuver
C03	2017-10-23 8:46	11:15	4 h after maneuver

Table 1: GEO Satellites maneuver information

Results and Discussion

Two types of POD methods are compared: strategy 1, only observed TWTT clocks are used in POD; strategy 2, TWTT observed and predicted satellite clocks are both used in POD. Compared with strategy 1, much more stable and higher orbit estimation accuracy can be obtained.

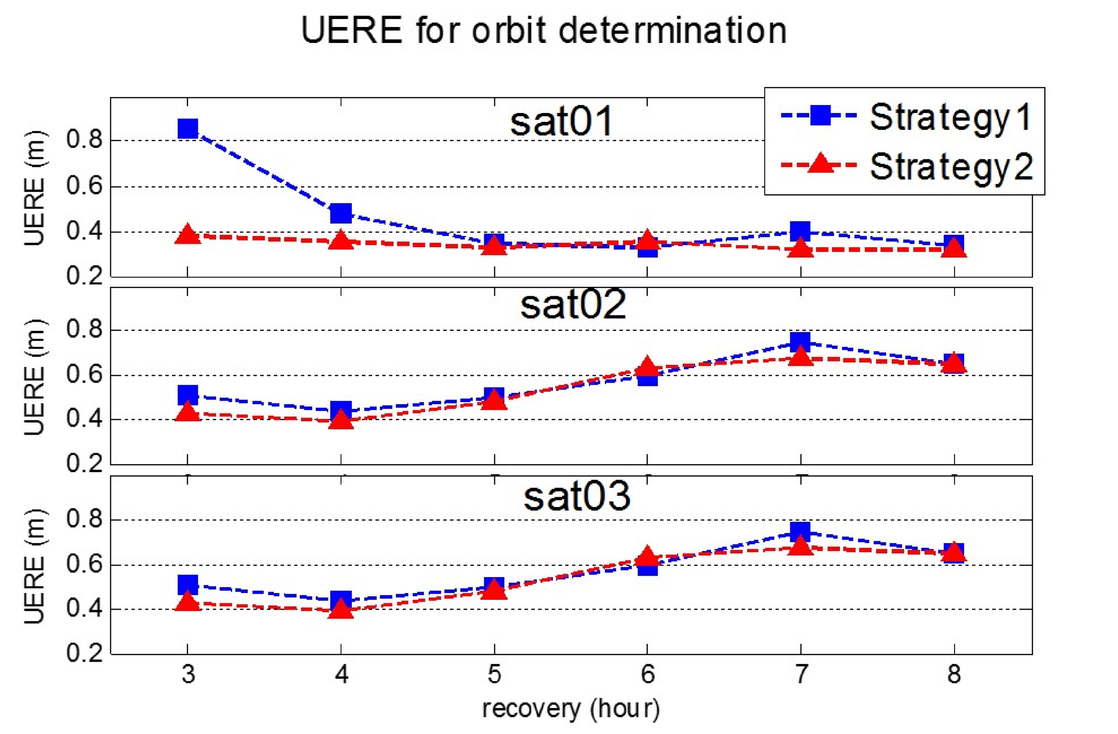

Figure 4: UERE of each satellite during rapid orbit recovery

Satellite **clock modelling** contributes the most for the **first few hours of satellite maneuver**, where very few data are available. It **improves orbit determination accuracy** by more than 15% and over 70% on orbit prediction accuracy.

SatID	DATA SPAN	OBSERV. UERE			1 h Prediction		
		OLD	NEW	Improve (%)	OLD	NEW	Improve (%)
C01	3h	0.856	0.378	55.848	3.982	0.717	81.996
	4h	0.476	0.354	25.672	1.997	0.341	82.919
	5h	0.341	0.326	4.368	0.367	0.435	-18.484
	6h	0.331	0.352	-6.377	0.400	0.486	-21.600
	7h	0.402	0.323	19.497	0.697	0.376	46.114
	8h	0.336	0.320	4.911	0.744	0.819	-10.052
C02	3h	0.505	0.423	16.261	2.308	0.338	85.369
	4h	0.436	0.394	9.529	0.889	0.632	28.941
	5h	0.502	0.483	3.845	1.733	1.130	34.785
	6h	0.600	0.628	-4.600	1.251	1.163	7.049
	7h	0.750	0.679	9.433	1.415	0.564	60.158
	8h	0.647	0.650	-0.526	0.502	0.501	0.179
C03	3h	0.801	0.673	15.980	1.929	0.568	70.561
	4h	0.670	0.680	-1.462	0.503	0.502	0.219
	5h	0.683	0.643	5.801	0.842	0.546	35.139
	6h	0.645	0.672	-4.169	0.506	0.476	5.873
	7h	0.638	0.638	-0.063	0.494	0.513	-3.742
	8h	0.611	0.614	-0.541	0.461	0.463	-0.456
mean		0.568	0.513	8.523	1.168	0.587	26.943

Figure 5: Statistics of orbit determination (unit: m)

Conclusion and future work

1. IGS orbit and clock accuracy is limited by parameter correlations;
2. New strategy with satellite clock modelling is proposed and validated for the precise orbit determination process, especially for satellite in maneuver period;
3. With the new approach, orbit determination accuracy improved by more than 15% and orbit prediction accuracy improved by over 70%.

Further Reading

[1] Chen Qian, Chen Junping, and Zhang Yize. Analysis of bds satellite clock prediction contribution to rapid orbit recovery. In *Preoceedings of China Satellite Navigation Conference (CSNC) 2018*, pages 399–407, 2018.

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[3] Chen Junping, Zhang Yize, and Wang Jungang. A simplified and unified model of multi-gnss precise point positioning. *Advances in Space Research*, 55(1):125–134, 2015.