Statistical Orbit Determination for Geostationary and Geosynchronous Satellite Orbits in BeiDou Constellation: A Simulation Study

Radhika A. Chipade* (1, 2) and T. V. Ramanathan(2)
(1) Space Applications Centre (ISRO), Ahmedabad – 380015; e-mail: radhikachipade@gmail.com
(2) Department of Statistics, S. P. Pune University, Pune – 411005; e-mail: madhavramanathan@gmail.com

Statistical Orbit Determination techniques are used to find satellite positions for various navigation applications. The present paper reports the simulation study of the statistical orbit determination algorithm developed for geostationary and geosynchronous orbits for BeiDou constellation. BeiDou Navigation Satellite System (BDS) space constellation is composed of geostationary earth orbit (GEO), medium earth orbit (MEO) and inclined geosynchronous satellite orbit (IGSO). However, predicting the orbital parameters for geostationary earth orbits with zero inclination and for geosynchronous satellite orbits (GSO) with small inclination angle and small eccentricity is a challenging task [1]. Thus this paper is focused on mainly satellite orbit determination techniques for GEO and GSO orbits in the BDS.

Statistical Orbit Determination algorithm involves two parts: (a) orbit prediction and (b) orbit determination. The orbit prediction algorithm utilizes a set of force models that determines acceleration of the satellite due to various effects as given in equation (1) and a numerical integration technique to predict the state of the satellite at time t_k if the state of the satellite at some initial epoch time t_0 is known. In the present study, the orbit prediction algorithm was developed using 4^{th} order Runge-Kutta numerical integration method. The orbit determination algorithm modifies the state of the satellite at the start of the orbit prediction. The orbit determination algorithm can be used to help the orbit prediction algorithm to improve the accuracy of the predicted state of the satellite. Extended Kalman Filter (EKF) was used as orbit determination algorithm for GEO and GSO orbits in the current study.

$$\vec{a} = \frac{\mu \vec{r}}{r^3} + \vec{a}_{har} + \vec{a}_{sun} + \vec{a}_{moon} + \vec{a}_{srp} \tag{1}$$

Elementary orbital parameters that determine the satellite orbit showed variation with respect to earth's oblateness and other zonal harmonics, solar radiation pressure, solar attraction and lunar attraction forces. Thus, comparative analysis for Keplerian orbit and full force model as given in equation (1) was carried out for BDS orbits. The right ascension of ascending node (RAAN) was varied for different values as it is the parameter to determine the orientation of satellite orbit in the space. The satellite positions were predicted using EKF in earth-centred earth-fixed (ECEF) reference frame for a period of next 1 day at time step of 1 sec. Table 1 shows the root mean square (RMS) errors in the prediction of BDS orbits using EKF algorithm for different values of RAAN. Kolmogorov-Smirnov (KS) test was performed to test the goodness of fit of the predicted orbit with the simulated orbit. Orbit determination results through perturbation force model were compared with that through Kepler's Orbit. Wilcoxon Rank Sum test was performed to compare the residuals for EKF algorithm through Kepler's Orbit and perturbation force model.

Table 1: RMS Errors in satellite position (in cm)

Force Model	RAAN (in deg.)	RMS Errors in	ECEF X (in cm)	ECEF Y (in cm)	ECEF Z (in cm)
Full Force Model	0	GSO	8.50	5.24	7.24
		GEO	10.96	7.43	0.16
	120	GSO	3.30	9.44	7.69
		GEO	3.48	13.44	0.17
	240	GSO	8.20	5.67	7.09
		GEO	11.98	6.39	0.10

Centi-meter level accuracy was achieved to predict BDS orbits using EKF algorithm. Kolmogorov-Smirnov test for EKF algorithm reported p-value > 0.05 indicating goodness of fit of predicted BDS orbits. The EKF predictions through Perturbation force model were better than or as good as Keplerian force model. The developed algorithm thus gives encouraging results that can be used in future technologies for GNSS receiver developments such as Self-Assisted Ephemeris technology.

1.X. Xiaoganag and L. Mingquan, "Broadcast Ephemeris Model of the BeiDou Navigation Satellite System", *JESTR*, **10**, 4, 2017, pp. 65-71.