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Precise Orbit Determination for NavIC Satellites

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Abstract

Precise Orbit Determination (POD) is an important process for navigation applications like Precise Point Positioning (PPP) and Real Time Kinematics (RTK). Earlier researchers have carried out extensive research for GNSS constellations placed in Medium Earth Orbits (MEO) having dynamic behaviour different from Geo-Synchronous Orbits (GSO) satellites. In this paper an attempt is made to study the challenges that have to be addressed for implementing POD along with the corresponding ground segment.

The Navigation with Indian Constellation (NavIC) is a satellite-based navigation system offering an independent positioning and timing service over India and neighbouring regions using constellation of 3 near Geosynchronous and 4 Inclined Geosynchronous (IGSO) Satellites[1]. Presently orbit estimation of these satellites is being carried-out based on statistical orbit determination techniques using measurements from a network of 16 IRNSS Range and Integrity Monitoring Stations (IRIMS) and 4 IRNSS CDMA Ranging Stations (IRCDR) at regular intervals. Satellite laser ranging data provided by a few stations of the International Laser Ranging Service (ILRS) is also being utilized to assess the quality of Signal in-Space Range Error (SISRE).

Currently the NavIC system is able to provide a user position and velocity accuracy of around 10 meter and 1 cm/sec (3σ) using least square batch processing orbit determination methods. In order to meet the Real Time Kinematics (RTK)[3] and Precise Point Position Products (PPP)[4] wherein the user has to determine his position within sub-meter accuracy, it is necessary to incorporate Precise Orbit Determination (POD)[2] in the process which uses Extended Kalman Filter with smoother function. Along with this, by locating optimal number of International GNSS Service stations within the coverage area would further aid in improving the POD accuracy. The precise ephemeris for the NavIC constellation can be generated using measurements from a wide baseline of IGS stations. These measurements need to be processed by a precise orbit determination engine in order that very accurate estimates of the orbit and clock are generated in near real time. This paper addresses the implementation of such an engine for deriving the precise ephemeris of the NavIC constellation and thus support PPP and RTK services through NavIC.

1 Introduction

NavIC is a regional navigation satellite constellation realized by the Indian Space Research Organization consisting of 7 satellites placed in geostationary and geosynchronous orbits such that they provide navigation services over the Indian landmass and in the region extending to 1500 kilometres beyond the Indian geopolitical boundary. Three of the NavIC satellites are in geostationary orbit (32.5 E, 83E and 125.5E) while four of the satellites are in two geosynchronous orbits having an inclination of 29 degrees. While one of the geosynchronous orbit planes crosses the equator at 55 degrees east longitude, the other geosynchronous orbit crosses the equator at 111.75 degrees east longitude. The NavIC constellation along with the other segments such as the ground segment and the user segment is depicted in Figure-1. The NavIC satellites provide the navigation signals in two frequency bands namely the L5 (1176.45 MHz) and S band (2492.028 MHz) and in tow services namely the Standard Positioning Service (SPS) and the Restricted Service (RS). Figure-1 shows the concept of NavIC satellite navigation system.

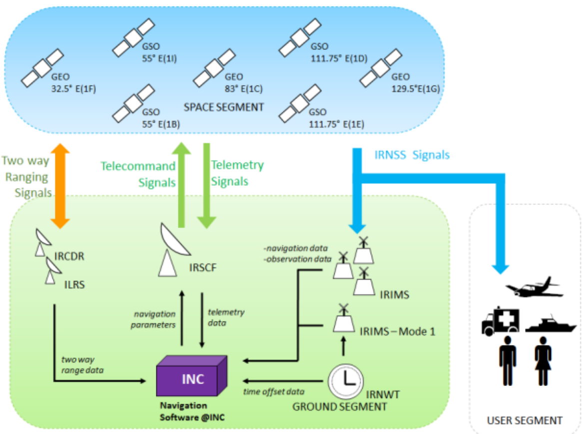


Figure 1: Concept of NavIC Satellite Navigation System

The NavIC ground segment consists of a network of IRNSS Range and Integrity Monitoring Stations (IRIMS), a network of IRNSS CDMA Ranging stations (IRCDR). While the IRIMS perform one way ranging to the NavIC constellation, the IRCDR stations perform two way CDMA ranging to the NavIC constellation. Laser ranging of the NavIC constellation is carried out on a best effort basis by the International Laser Ranging Service (ILRS).At the heart of the NavIC ground segment is the ISRO Navigation Center (INC) which also houses the IRNSS Network Timing facility (IRNWT) and performs the ODTS of the NavIC constellation.

2 System Requirements

The three fundamental system requirements for incorporating POD to assist PPP and RTK services through NavIC are the following:

1. Ingestion of high quality measurements from a long baseline network such as the IGS
2. Development of an engine for estimating the precise orbit and precise clock parameters for NavIC
3. Realization of a satellite system for broadcasting the precise parameters in real time for supporting RTK

One of the important requirements for enabling PPP and RTK services is to ensure that the existing IGS network becomes NavIC enabled. This means that apart from tracking the MEO constellations such as GPS, GLONASS, Galileo an Beidou, the IGS network needs to track the NavIC constellation and provide dual frequency measurements in L5and S bands to the IGS data centres. Figure-2 shows the distribution of the IGS stations around the world.

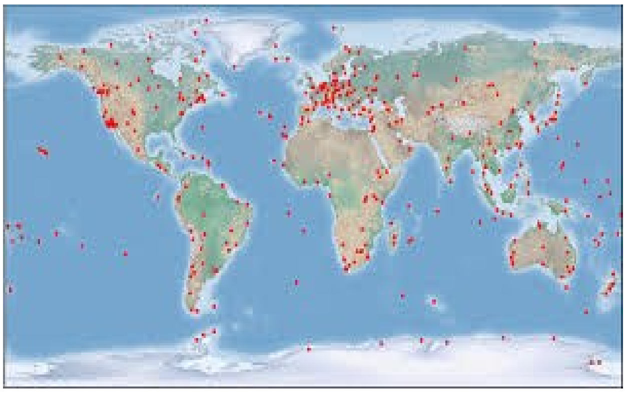


Figure 2: IGS Station distribution (courtesy: www.igs.org)

A study was undertaken to identify a network of such IGS stations that are in the footprint of the NavIC constellation. An effort is underway to develop a IGS class receiver that is also capable of tracking the NavIC signals in both the bands namely L5 and S. The other important requirement in the implementation of the PPP and RTK techniques for NavIC would be the realization of a high precision orbit and clock estimation for the NavIC constellation. There is also a concerted effort to improve the density of IGS stations within India .Once a sufficient number of IGS stations provide precise dual frequency measurements of the NavIC system in a sustained manner than precise product generation of the NavIC constellation would be possible. Figure-3 shows the IGS stations that are under the foot print of the NavIC constellation. If these IGS stations become NavIC enabled and support dual frequency measurements then the orbit determination of the NavIC constellation could improve significantly.

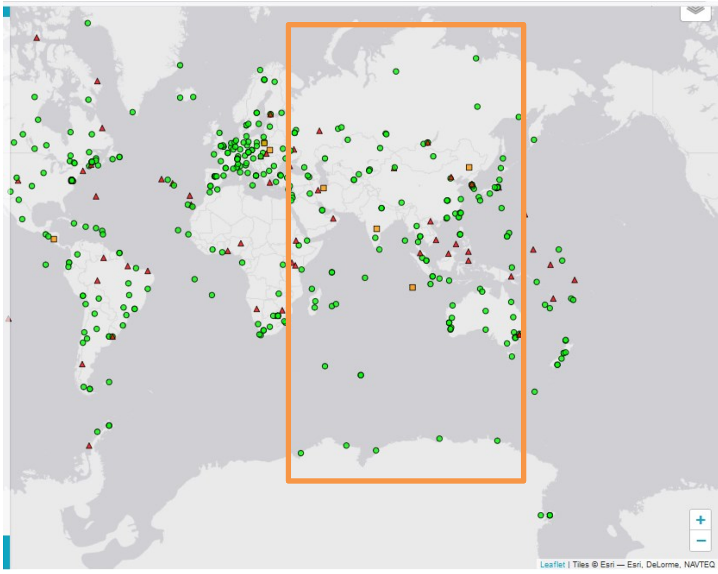


Figure 3: IGS Stations under the NavIC foot print.

The Precise Orbit determination (POD) of the NavIC satellites is being carried out in near real time using the data from one way ranging and two way ranging stations by means of Least Square batch processing and ephemeris is generated for future time. One of the major sources of error in satellite navigation is the inaccuracy of the broadcast ephemeris which in turn is highly dependent on the orbit prediction models employed by the ground segment. In order to improve Orbit determination (OD) accuracy, it is proposed to use an OD model with sequential EKF and smoother along with statistical orbit determination techniques. The dynamical forces considered are with full force model of EGM-2008 of 70x70, factoring conical SRP model along with lunisolar, tidal and relativistic effects. The POD used to calculate State estimate by sequential processing accounting modelling error and measurements information. The Kalman's state estimate error model is defined by the "formal" linear stochastic differential equation-1

$$\frac{d}{dt}\delta X(t) = A(t)\delta X(t) + B(t)\delta w(t) \qquad (1)$$

Where $\delta X(t)$ is an n x 1 matrix, $\delta w(t)$ is p x1 Gaussian white noise matrix, A(t) is n x n time dependent matrix and B(t) is n x p time dependent matrix. Here $\delta w(t)$ denote the resultant of gravity modelling errors and solar pressure modelling errors.

3 POD Performance

Using the one way and two way ranging data, currently NavIC is able to achieve 10 meters and 0.1 cm/sec in position and velocity (3σ) accuracy. The orbit accuracy of the NavIC satellites using such a scheme is depicted in Figure-4.

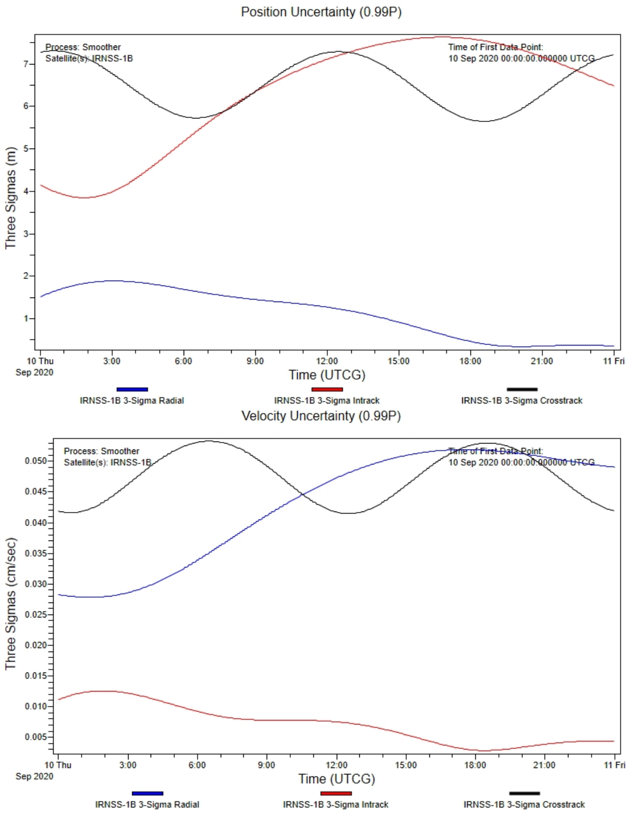
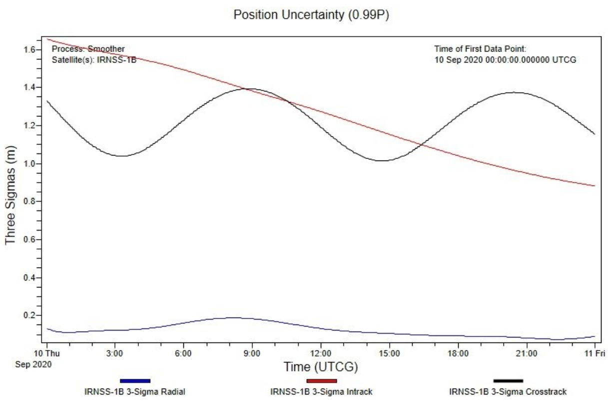


Figure 4: Position and Velocity uncertainties of the NavIC satellites with existing IRIMS & IRCDR N/w

However, with Improved OD estimation using Extended Kalman Filter and smoother we are able to achieve better than 2 meters and 0.2 mm/sec accuracies for position and velocity respectively. We have also considered a network of IGS stations over NavIC service area along with existing IRIMS and the IRCDR network to achieve this accuracy. The orbit accuracy of the NavIC satellites using such a scheme is depicted in Figure-5.



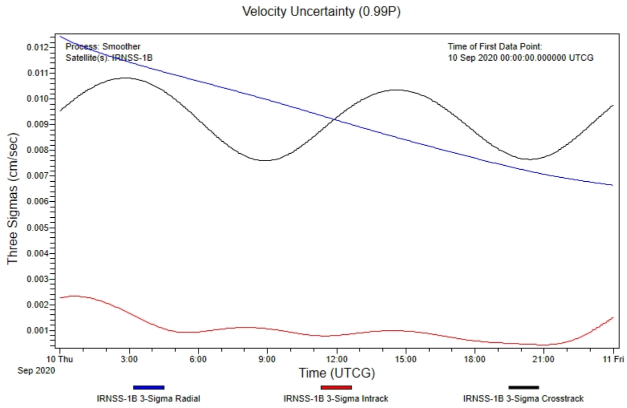


Figure 5: Position and Velocity uncertainties of the NavIC satellites considering a network of IGS stations and improved OD model with EKF and smoother

4 Conclusions

The system requirement for incorporating POD technique for NavIC satellite navigation system is being studied. An effort is made to identify an optimal IGS sub network that if it is NavIC enabled could provide the much needed measurements for supporting the generation of precise products for NavIC. An attempt has been made to develop a high precision orbit determination engine for generating the precise ephemeris and clock parameters of the NavIC constellation in order to enable the PPP and RTK services.

5 Acknowledgements

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