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Accuracy Improvement of Primary Navigation Parameter for Navic Satellites

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Abstract

The aim of this paper is to describe a strategy to provide improved accuracy of primary navigation parameters to the Indian regional Navigational satellites. The broadcast parameters of the Navic satellites can be classified under two category, one is the validity period of 7200s called long period normal sets and second one is the validity period of 900s called short period contingency sets of primary navigation parameters. The Navic satellite constellation works with minimum number of synchronous satellites to provide the best user solution within India and boundaries. Thus the outage of any one or more satellites will increase the Dilution of Precision (DOP) and degrades the user solution for any sudden anomalous behaviour of the measurements. This anomalous behaviour (called events) arises due to on-board frequency variations, frequent planned Station Keeping (SK) operations because of synchronous orbits, IRNSS system time scale switch-over or the combination of events. In loop back the broadcast parameters accuracy was continuously monitored through Line of Sight (LOS) range error from the observed IRNSS ground reference stations range measurements. In begin conditions the Least square (Lsq) based solutions were accurate and the observed LOS error were as expected. But post the occurrence of any event, the accumulation of batch data starts freshly for least square solution. The obtained Lsq based solution was inaccurate due to lack of data under many circumstances. During the events occurrence to minimize the outage duration of the satellite contingency sets were generated using continuously running Kalman Filter based near real time estimation using one-way measurements. But the filter estimated state may not be optimum at the particular epoch. Hence a strategy of forward and backward approach (FBF) was adopted just before parameter uplink through sequential (KF) for adaptation of real behaviours of the measurements to providing an improved optimal solution.

Keywords: Navic, Lsq, LOS, KF, DOP

1. Introduction

Indian regional Navigation Satellite system (IRNSS) is an independent, indigenous navigation satellite system fully controlled by India, planned by ISRO. A system was designed of regional navigation satellite constellation named Navic (Navigation with Indian constellation), for providing space based navigation support to various land, sea and air navigation users over the Indian region. The IRNSS constellation consists of 7 satellites (3 inclined with 5 deg inclination and 4 with 29 deg inclination). The continuous visibility of GEO and GSO satellites for near-equator regions provides a promising alternative for regional navigation. The IRNSS constellation, ISRO has already launched four GSO satellites (IRNSS-1A, 1B, 1D and 1E) with inclination 29 degree and three GEO satellites (IRNSS-1C, 1F and 1G) with inclination of 5 degree. These satellites transmits signal in two frequencies in L5 and S Band which is unique combination never exists before any were in the world. The navigation parameter is generating in ISRO Navigation Centre (INC) and uplink to the IRNSS satellites for IRNSS user position computations. The primary parameters are the quasi-Keplerian elements of fifteen orbital elements with satellite clock bias drift and drift rate. The IRNSS user position computation has been provided through the IRNSS-SIS (Signal In-Space) ICD (Interface Control Document).

The navigation parameter has been generated through navigation software using 15 IRNSS Integrated Monitoring Stations (IRIMS) and reference clock of IRNSS Network Time (IRNWT). Out of which 8 IRIMS stations have caesium standards and remaining 7 stations have rubidium standards frequency clock for generating the one-way range measurements. For orbit estimation the 8 reference stations equipped with caesium frequency standard clocks are used for Orbit and clock coefficients determination and all IRIMS station used for Iono-delay computation. The IRNWT facility consists of an ensemble of atomic clocks, namely three Active Hydrogen Maser (AHM) and four Cesium Atomic clock with appropriate Time and Frequency (T&F) measurement equipment and algorithms. It is the reference time for the IRNSS system.

In navigation software two types of estimation techniques are used for determination of orbit and clock coefficients viz batch least square (named OCEB) technique and near real time sequential Kalman Filter technique (named OCEK) (Babu R, et al [3]). The batch least square technique uses three days of measurement data to obtain the end epoch solution. In normal case where a measurements variation does not happen, the parameter has been generated from OCEB. In other case the parameter has been generated from OCEK with short term validity period. Out of all IRIMS, the Bangalore station is considered as the reference station because the reference station is driven with IRNWT times (IRNSS system time), hence there is no receiver clock offset error for this reference station. The main aim of the navigation software is to generate the navigation parameter with the accuracy of less than 20 meter for the IRNSS user position. For the monitoring of the IRNSS user position UERE (User Range Equivalent Error) of Bangalore station should be within 2.5m.

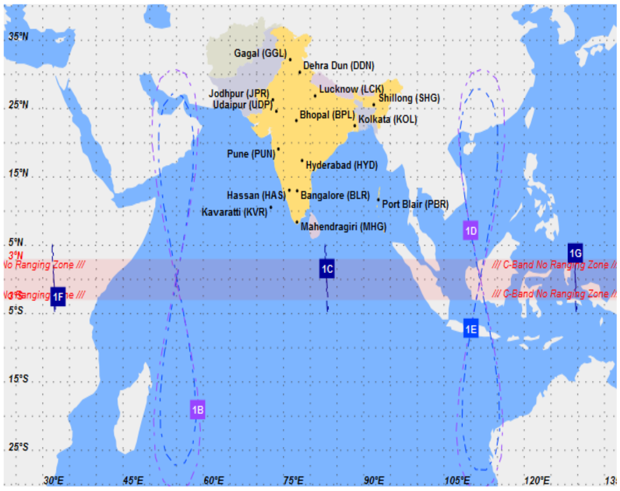

Figure 1: IRNSS Satellite Ground Trace and IRIMS Reference Location

2. Principles of Orbit Improvement

The procedure by which the final state vector and dynamical parameters of a satellite are estimated using the range observations (Gelb A [1]). These estimation techniques are based on minimization of residue by iterative update of state parameters for OCEB and by sequential modification of state in OCEK. In orbit determination method the range residue is difference between observed range measurement (measured from IRIMS stations) and computed range measurements.

The range modelling error includes station displacement, sagnac effect, relativity effect, Ionospheric delay, troposphere delay, receiver and satellite clock error, satellite and receiver hardware delay, phase centre offsets. Firstly the smoothed ionospheric free measurements are obtained from observed range using code carrier smoothening technique with dual frequency (L5 and S) code and carrier measurement combination and ambiguity resolution. The accuracy of the estimation technique depends upon the accuracy of measurement error model and quality of the measurements. In sequential estimation used the uncertainty of the smooth value in measurements noise and process noise is the uncertainty of the propagation model (Kavitha S, et al [4]).

3. Dynamical System Modelling

The satellite is usually assumed to be influenced by a variety of external forces, including gravity, solar radiation pressure, third-body perturbations, Earth tidal effects, and general relativity in addition to satellite propulsive manoeuvres (T. Takasu, et all [5]). The complex description of these forces results in a highly nonlinear set of dynamical equations of motion. The IRNSS orbits are propagated by numerically integrating, gravitational accelerations due to the Earth, Moon, Sun and other solar planets, together with the accelerations due to solar pressure. The gravity model used is of the order of 20X 20 EGM-2008 models. The predicted positions of the Earth, Moon, Sun and other planets such as Venus and Jupiter are from the JPL DE405 ephemeris.

4. Parameter Estimation and Accuracy Improvement

A. Batch Least Square Process (OCEB)

The orbit and clock parameters were estimated with batch least square techniques using multi-days typically 3 days of data, every 4hours. The parameter estimation happens in data sliding mode. The fresh new incoming processed smoothed range measurements were used every time it executes discarding the initial 4 hours range measurements every time for parameter estimation. The estimation parameters include receiver clock coefficients (B0-Receiver bias, B1- Receiver drift, B2- Receiver drift rate) of all participating stations.

The other parameters are satellite position and velocity (6) for each of the satellite, onboard clock coefficient (A0, A1 and A2) namely the satellite clock bias, drift and drift rate. Apart from these parameters the batch least square process also includes solar radiation pressure coefficients along 3-mutual directions with Sine and cosine components to absorb other dynamical model and measurements model uncertainties.

B. Sequential Kalman Filter Process (OCEK)

The other estimation is the real time KF based process, uses every instant smoothed range measurements but with limited parameter estimation (Kalman R E [5]). Since the IRNSS satellites are synchronous satellites, the dynamics of the system is relatively very small which limits the OCEK process with few parameters. The parameter estimated in this process includes only the satellite position and velocity determination with only satellite clock offset at every instant. Hence the accuracy of the OCEK estimation is also depends upon the accuracy of fixed parameters.

C. Primary Parameter Generation Dynamical System

The uplink parameters were generated once in every 2-Hour (normal sets) from batch least square solution to maintain the UERE as minimal as possible which uses fresh estimated solution available at any point of time. This strategy was adopted to maintain the user Line of sight error small, thus IRNSS can able to provide better solution than targeted and able to achieve better than 10m 95 percent of the time within Indian landmass. The greatest advantage in Navic constellation is that all the IRNSS satellites were visible 24 x 7. The below plot shows typical position Error observed along several IRIMS reference stations. The following plots show the position error of Bangalore stations with Doppler

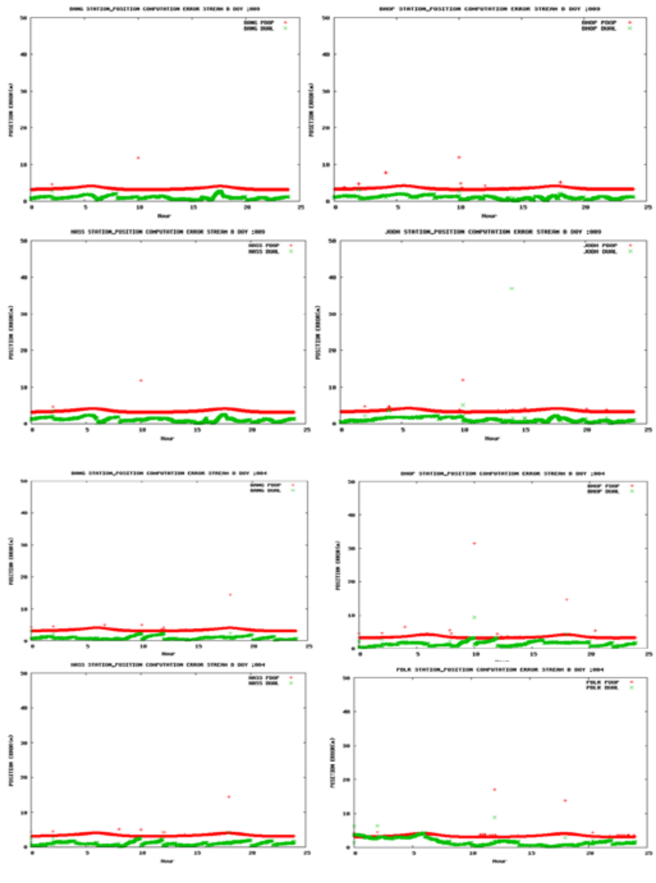

Figure 2: RSS Station Position Error (computed- surveyed) and DOP

Firstly the position solution is computed using the broadcast parameters and the ranges obtained in each reference stations (IRIMS). The computed station position is then compared against precise surveyed locations. The above plot shows the position error and Position Dilution of precision Variation (PDOP) in a day.

It has to be noted that the IRIMS are equipped with dual frequency receivers to remove ionospheric error. Thus under normal conditions the parameters were updated once in 2 hours called normal mode of parameter generation in IRNSS system. These parameters were generated from multi days batch least square based solution. The typical IODE ranges between 1-12 during this type of broadcast parameters.

During non-nominal conditions, i.e., the primary parameters were generated using KF based solution, in which the impact of event is mitigated in real time, and the updated parameter were estimated within shorter duration in the fully automated navigation ground software. Thus during the occurrence of sudden clock variations, post the event of SK schedule, or time scale anomaly, are combination of events, the parameters were generated using KF estimator. Because of the geometry of the reference stations (spread of the stations) and synchronous orbits of satellites, the generated primary parameters were valid only for shorter duration of about 900 seconds. This mode of operation is called as contingency mode of operation, and the IODE ranges 100-200. Hence this mode of operation, the service outage is minimised in case of anomalous circumstances.

5. Smoothening and its improvements

In the following figure shows the typical estimation schedule and parameter generation Schedule

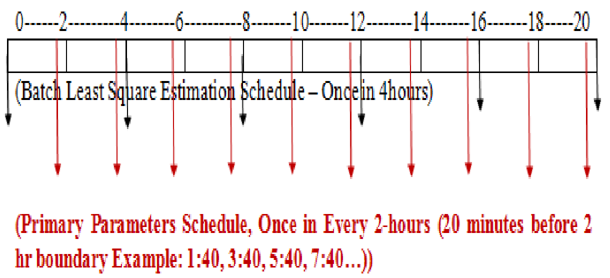

Figure 3: Estimation Strategy

From the above figure it can be observed that between successive estimation and parameter generation about 2-4 hours prediction of orbit and clock parameters is expected. Under nominal conditions, when the past measurements behaviour is the same as that of the future, the prediction error of the primary parameters will be minimal and is well below the targeted UERE< 3. But in reality due to non-nominal behavior clock and other disturbances causes the measurements differ abruptly. Thus at sometimes the prediction error is found to be above the desired threshold, thus the role of smoothening and its improvement becomes effective. The smoothening algorithm and strategy part of primary parameter generation module, firstly checks the residual threshold on the new measurements with predicted primary parameters. These residual checks where applied on reference station residual. If the reference station residual satisfies the predicted parameters were uplinked with the previous estimated parameters. Suppose if the threshold check fails, then KF based estimation employing backward and forward processing (FBKF) of measurements gets initiated to tune the clock offset parameters to minimize the bias offset. During this initiation of smoothening about 30-2Hours (depend on mode) minutes of latest measurements data just before the parameter generations were used through which tuning the final primary parameters were generated. The following flow diagram shows the typical process involved in smoothening process.

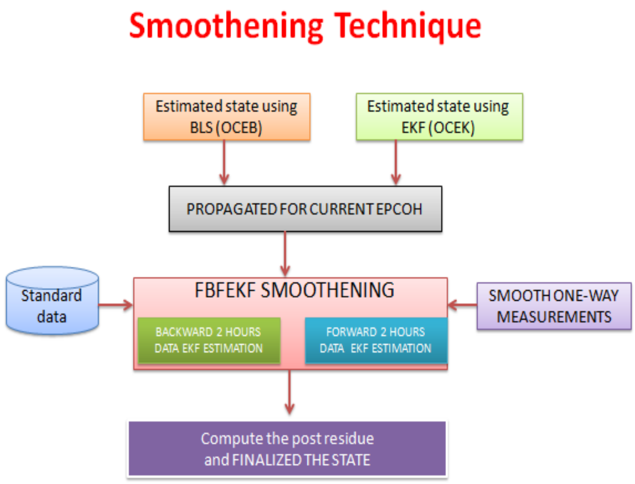

Figure 4: Flow diagram of smoothening technique

The FBKF follows the following sequence to finalize the estimated state using last two hours data.

$$\text{Residue}: \Delta Z = \rho_{\text{smooth range}} - \rho_{\text{computed range}}$$

$$\text{Kalman Gain}: K = \frac{P \times H^T}{H \times P \times H^T + R}$$

$$\text{Correction of State}: \Delta X = K \times \Delta Z$$

$$\text{State Uncertanity}: P = (I - K \times H) \times P$$

Where H is the partial derivative (parameter distribution matrix) and R is the measurement uncertainty. Final estimated state is again propagated in the future and past measurement to find the statistical finalized the state for primary parameter generation. The following plot shows the pre-residue before smoothening, the residual error in the forward process were minimised when it passes through backward and final state improves the final residual error.

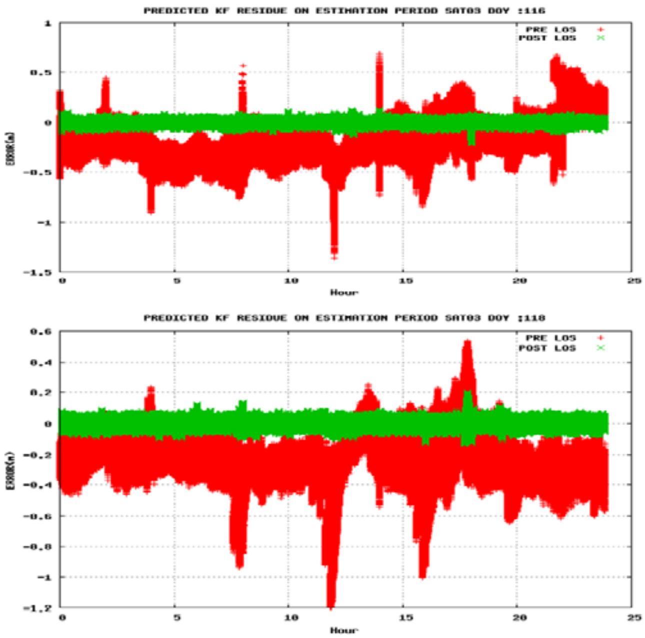

Figure 5: Residual error of Bangalore station before and after smoothening

6. User Equivalent Range Error (UERE)

The estimation accuracy is validated in the future measurements. The final smoothed state has been uplink to the satellite with future period validity. The range residue of Bangalore station where there is no receiver clock, tails about the accuracy of the smoothening parameters. The following plots show the UERE of Bangalore stations.

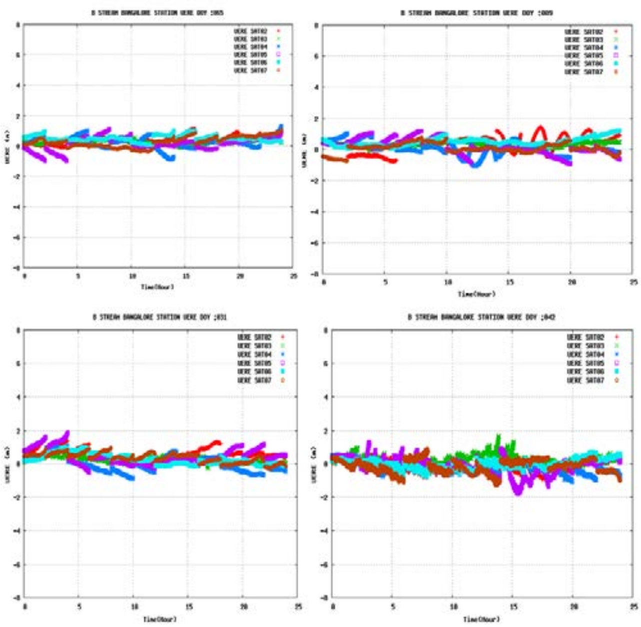

Figure 6: Line of sight Error of Bangalore stations of all IRNSS satellites

7. Summary

Smoothening technique is the residual minimisation process adopted in generation of primary parameters generation of IRNSS. The processes thus check for the necessity of the primary parameters to be updated are to be retained without alteration depend on the residual threshold set. If the residual bound above the desired threshold backward and forward smoothening process is initiated which thus minimises the future UERE, helping in maintaining the subsequent broadcast parameters within certain allowable error and thus the user position error were well below the target and thus the position error were found to be well below 10m 95 percent of the within the Indian landmass.

8. Acknowledgements

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