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REVIEW ON DIFFERENT CLOCK ERROR ESTIMATION METHODS FOR IRNSS RECEIVER

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Abstract - The review on Indian Regional Navigation Satellite System (IRNSS), also known as NAVIC (Navigation with Indian Constellation) provides real time positioning and timing services. IRNSS-GPS-SBAS (IGS) receiver designed and developed by ISRO is used to receive signals from both L5 and S band for IRNSS. Every receiver has a crystal oscillator which provides time that should be synchronized with the onboard satellite precise and stable atomic clocks. Clock is an important parameter in providing position accuracy. In this paper, the satellite and receiver clock error is observed and clock error estimation methods for IRNSS satellites are discussed.

Key Words: IRNSS, IGS receiver, Clock error estimation

I. INTRODUCTION

The Indian Regional Navigation Satellite System (IRNSS) with an operational name NAVIC is an autonomous regional satellite navigation system that is being set up by India that will be used to provide accurate real-time positioning and timing services over India and the region extending to 1,500 kilometres (930 mi) around India. The present constellation of NAVIC comprises of seven satellites, 3 GEO (Geostationary Earth orbit) satellites and 4 GSO (Geosynchronous orbit) satellites are shown in fig1. IRNSS will provide two types of services, namely, Standard Positioning Service (SPS) which is provided to all the users and Restricted Service (RS), which is an encrypted service provided only to the authorized users. The IRNSS satellite signals are in L band and S band.

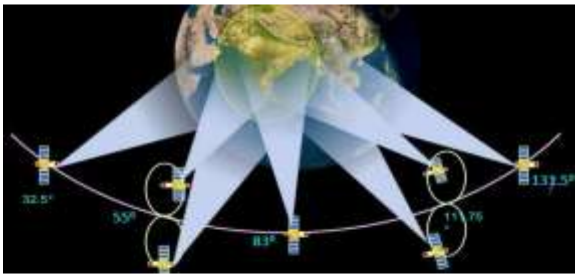

Fig 1: IRNSS constellation

NAVIC will provide two levels of service, the standard positioning service will be open for civilian use, and a restricted service (an encrypted one) for authorized users (including the military). Navigation signals transmitted on each carrier frequency are imperfectly synchronized due to different hardware paths corresponding to each signal. Each satellite's navigation message contains parameters describing the timing bias. A user receiver uses these parameters to compute the clock correction for each observation.

IMPORTANCE OF CLOCK ESTIMATION

ISRO have included atomic clock, which are used in navigation satellites to measure precise position. Clock is the important parameter in finding an accurate position of any object or position. The receiver's built-in clock is not as accurate as the atomic clocks on-board the satellites, and it is not exactly synchronized with satellite onboard clock, hence a variable clock offset is observed between receiver and satellite clocks. The correction parameters bias, drift and drift rate are available in navigation data. Which are estimated by ISRO and sending it for increasing receiver accuracy which in turn increases position accuracy. The clock estimation is necessary to reduce the clock errors.

II. RELATED WORK

Estimation is a process of finding an approximation, which is a value that is usable for some purpose even if input data may be incomplete, uncertain or unstable. Estimation involves using the value derived from a sample to estimate the value of corresponding parameter. The clock estimation for the satellite is an important parameter for precise position. ISRO has included atomic clocks which are installed in navigation satellites to measure precise location data. The receiver clock is not exactly synchronized with satellite onboard clock, hence a variable clock offset is observed between receiver and satellite clocks. So the clock error estimation of the satellite is necessary to reduce the clock errors [1].

In GNSS (Global navigation satellite system) several methods are used to determine precise position, orbit determination and clock estimation for GPS satellite.

Nonlinear Least Squares (LS) method is used for position computation from pseudo ranges, Linearization is done to convert non linear into linear system. The accuracy of the positioning results is compared for various numbers of required iterations using real GPS data so as to increase the accuracy in reference [2].

Reference [3] uses least squares (LS) is a method used for the position smoothing in GPS by means of pseudo-range and carrier phase measurements. The carrier phase data will be used to estimate the difference between the receiver and satellite clock. Authors explain the importance of carrier phase, pseudo-range data together relative to pseudo-range data in isolation. The results are analyzed by using the combination, and have compared to earlier work come up with the conclusion that position accuracy is increased by more than 45%.

GPS system is based on pseudo-range measurement, and there is four unknown parameter, but the navigation observation equation is nonlinear. In least squares algorithm, there is a hidden premise condition, that is all the measurement accuracy should be equal this is the deficiency of least squares algorithm, paper [4] gives the weighted least squares iterative algorithm and result is analyzed with GPS data.

A globally distributed network including 70 stations tracking mostly satellites of GPS, GLONASS, BDS, and Galileo is employed for experimental validation. The sequential least squares adjustment with an adapted online quality control is applied to Multi-GNSS real-time clock estimation. The estimated clocks are evaluated by comparing final clock product whose orbits are fixed in there clock estimation [5].

The two main estimation techniques, the batch least squares approach and the Kalman filter for precise orbit determination is used in paper [6] by David Hobbs and Preben Bohn. The batch least squares solution is typically employed in post-processing while the Kalman filter finds its main use in real-time applications. The implementation of the Kalman filter is generally faster and more efficient in terms of storage capacity.

Kalman-filter algorithm is used for clock offset estimation of GPS satellite is presented. The filter process in forward/backward filter to improve the accuracy of clock error because it works in two steps the result obtained from forward filter is applied to the backward filter. The filter state includes the satellite clock error and the clock drift for the complete constellation. Accuracy of the orbit and clock product is assessed with a precise orbit determination of the MetOp satellite [7].

In paper [8] “Use of Kalman Update Algorithm for vivid enhancements of GPS and navigation”, explains about Kalman-filter algorithm that uses a series measurements observed over time, that contains errors and other inaccuracies. The algorithm works in a two-step process, prediction step and update step.

A robust Kalman filter improved with IGG (Institute of Geodesy and Geophysics) scheme is proposed in reference [9] and used to resist the harmful effect of gross error from GPS observation in PPP/INS (precise point positioning/inertial navigation system) A new robust filter factor is constructed as a three-section function to increase the computational efficiency based on the IGG principle. The results of simulation analysis show that the robust Kalman filter with IGG scheme is able to reduce the filter iteration number and increase efficiency.

Inertial Navigation systems combined with other navigational aids like GPS, has picked up significance due to the upgraded navigation execution. There are extensive numbers of errors that are acquainted from time to time due to which there are inadmissible floats in the yields. Henceforth GPS is utilized to help INS utilizing the Kalman channel which helps in redesigning the position precision and the errors are evaluated. The result obtained demonstrates the minimized errors in the parameters when both INS and GPS are integrated using Kalman Filter [10].

Paper [11] gives an idea of extended kalman filter that overcomes the disadvantage of kalman filter, Kalman filter (KF) is applied only for linear estimation. Extended kalman filter (EKF) algorithm provides nonlinear estimation through the linearization of the nonlinear system, after linearization the KF is applied at each step. The EKF estimation is used for GAGAN application, for minimizing the errors.

In paper “The performance comparison and algorithm analysis of first order EKF, Second Order EKF and smoother for GPS/DR navigation” [12], several algorithms based on the global positioning system (GPS) and the dead reckoning (DR) are proposed. The performance of the GPS/DR integrated navigation system is analyzed with first extended Kalman filter (FEKF), second extended Kalman filter (SEKF) and the Rauch Tung Striebel-smoother (RTS). The GPS/DR integrated navigation system based on the three algorithms is simulated, and the algorithm performance is compared by the simulation results.

This paper uses both batch least square (BLS) and Extended Kalman Filter (EKF) are considered for satellite parameter estimation in paper [13] which forms the primary navigation parameters. Batch least square techniques are unfavorable during the occurrence and sudden inclusion of clock jump events. On the other hand EKF techniques under considered circumstances yields good solution but cannot be used for longer duration as the propagation error increases. Both the algorithms have some disadvantage so in this paper the author presented the combination of both estimation and results are analyzed.

Comparison of different Methods

Table 1: Comparison Table

YEAR	AUTHOR	METHOD	PURPOSE
2011	Y. He and A. Bilgic	Nonlinear least square with pseudo range measurement	Position estimation
2012	David Hobbs and Preben Bohn	Batch Least square and kalman filter	Orbit determination
2017	M. R. Mosavi, S. Azarshahi	Least square with pseudorange and carrier phase measurement	Position estimation
2018	Wenju Fu1,Guanwen Huang	Least square	Clock error estimation
2008	Andre Hauschild, Oliver Montenbruck	Kalman filter	Clock offset estimation
2014	Tejas N. Mamidwar, Neha P. Bandal	Kalman filter	Position
2014	M.A. Khadar Baba, Dr. V. Malleswara Rao	Extended kalman filter	GAGAN application
2015	By Babu R, Prasanta Mula	Batch least square and extended kalman filter	Satellite parameter estimation

III.Clock error estimation methods

Methods used for clock error estimation of GNSS Satellite are

- Iterative Least Squares
- Batch least square
- Kalman filter / Extended Kalman filter

Least square

Iterative Least square (ILS) is computed for each time instant and output is obtained for that instant. The ILS estimates the clock error by considering the observed pseudo range and measured pseudo range. The pseudo range is calculated using satellite position, receiver position and clock bias.

Batch least squares (BLS) approach where all the data for a fixed period is collected and processed together. The BLS estimates the clock error by considering the observed pseudo range and measured pseudo range. The pseudo range is calculated using satellite position, receiver position and clock bias.

Algorithm steps for least square:

- Iterative least square is computed only for fixed interval
- Batch least square is computed for multi days of data

- Inputs are taken from the IGS receiver
- Jacobian matrix(G) is calculated using satellite and receiver position
- Delta-Rho ($\delta\rho$) is computed which is the difference between observed pseudo range (from Rx) and theoretically calculated pseudo range (which includes clock bias)
- $\delta X = (G^T.G)^{-1}.G^T.\ \delta\rho$ is calculated
- Receiver Clock bias and position is estimated

Kalman filter

Kalman filter operates recursively on streams of noisy input data to produce a statistically optimal estimate of the underlying system state. The algorithm works in a two-step process, the time prediction step and the measurement update step. In the prediction step, the Kalman filter produces estimates of the current state variables, along with their uncertainties. In the measurement update step, the prediction is corrected using a weighted average of the noisy sensory input. The main assumption of the Kalman filter is that the underlying system is a linear system and that all error terms and measurements have a Gaussian distribution. Extensions and generalizations to the method have been developed, such as the extended Kalman filter which work on nonlinear systems.

Algorithms step for Kalman filter/EKF:

Kalman filter is used for linear data. As our receiver gives the non-linear data we are using the Extended Kalman filter. The step for estimating Kalman filter and EKF is same only difference is in EKF the jocobian matrix is considered to convert non-linear data to linear data.

- Inputs are taken from IGS receiver.
- Initial values of X and priori estimated state covariance P
- f= State vectors and velocity vectors are calculated using the input X and time interval T.
- g=Pseudo range and jacobian matrix is calculated using satellite position, receiver position and clock bias.
- Process noise covariance Q= calculated using power spectral density
- Measurement noise covariance R= computed using Identity matrix and pseudo range
- Z=Pseudo range that is taken from the receiver
- [Xo, Po]= Extended KF (f, g, Q, R, Z, X, p), position and clock error is estimated

IV. CONCLUSION

The research motivation of this paper is the importance of clock estimation for precise position. The importance of clock estimation, and the methods used for clock estimation that is iterative least square, Kalman filter/Extended Kalman filter, Batch Least square are discussed in this paper. The main advantage of kalman filter is its ability to provide the quality of the estimate (i.e, variance) and its relatively low complexity. Limitation of Kalman filter is it provides accurate result for linear model. The limitation of kalman filter is over come by extended kalman filter. Iterative least square technique is used only for some fixed period of time but batch least square is used to estimate for multiple days of data.

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