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Estimation and Analysis of Instrumental Biases for GPS and NavIC Satellites and Receivers

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ABSTRACT

The positional accuracy of Global Positioning System (GPS) and Navigation with Indian Constellation (NavIC) are affected by errors, one of the predominant errors is instrumental delay. This delay distorts the satellite signal and effect the position accuracy. To counter this problem, efficient models shall be used. In this paper, satellites' and receivers' instrumental bias is estimated using a modified Fitted Receiver Bias (FRB) method, Singular Value Decomposition (SVD) technique and Self-Calibration of Pseudo Range Error (SCORE) model. The FRB method is based on the minimization of standard deviation of vertical Total Electron Content (TEC) computed from different satellites. The SVD based Least Mean Square (LMS) algorithm uses the values of one-day period corresponding to four GPS and NavIC stations. It uses data from dual frequency GPS receivers. To derive the instrumental bias errors the SCORE technique uses a self-consistency constraint on the receiver's measurements of ionospheric delay.

Key words: FRB, Instrumental Delay, SVD, SCORE

1. INTRODUCTION

GPS is a satellite based navigation system developed by the Department Of Defense (DOD) of United State Government. The GPS consists of six orbital planes with four satellites each. Hence, GPS constellation contains a minimum of 24 satellites [1]. NavIC has a 7-satellite constellation which covers India and a range of 1,500 km beyond its borders [2]. NavIC can provide position accuracy of within 10m over the Indian landmass and less than 20m over the oceans. NavIC system operates at two frequencies L5 and S that provide two types of services i.e. Standard Positioning Service (SPS) for civilians and Restricted Service (RS) for specific users. The accuracy of user position depends on ranging errors. For better position estimation these errors should be analyzed and mitigated. The GPS receiver makes corrections for clock errors and other effects but there are still residual errors which are not corrected. The signal that is modulated by the carrier is delayed by the instrumental bias [3]. The amount of delay in the signal is directly proportional to the TEC in the signal path and inversely proportional to the square of the operating frequency.

2. SINGULAR VALUE DECOMPOSITION ALGORITHM

To reduce multipath errors noise and Singular Value Decomposition (SVD) algorithm is used. The SVD based LMS algorithm is used to estimate the instrumental biases [4].

Step 1: The GPS position is estimated using Bancroft method and Kalman filter.

Step 2: The earth-centered angle is estimated using elevation angle (E) of the satellites with respect to the ground station GPS and also IRNSS receiver.

[E, S, A] = elevation (receiver(x,y,z),satellite(X,Y,Z)) (1)

Where, x,y,z are the receiver's and X,Y,Z are the satellite's coordinates respectively.

Step 3: TEC is estimated using GPS dual frequency and pseudo ranges by using the following formula,

TEC= (P2-P1)/40.30*($f1^2 * f2^2$)/($f1^2 - f2^2$) (2)

Where, f1 and f2 are the GPS frequencies, P1 and P2 are the pseudo ranges

Step 4: Slant TEC is computed using the vertical TEC and Slant factor,

STEC= Slant factor*TEC–(fitted biases) (3)

Where, Slant factor is estimated from,

1+ (16*((0.53-elev).^3)) (4)

Step 5: SVD matrix A is formed with diagonal Slant factor values and identity matrix

Step 6: [U S V]= svd(A,'econ') (5)

Where, S is the array of diagonal values

Step 7: Least squared values obtained from U.'*A*V-diagonal ((STEC)) (6)

Thus, instrumental bias is the diagonal values of Least Squaring Values (LSV) and also mean bias can be obtained by sum of Instrumental bias by number of epochs.

3. SELF CALIBRATION OF PSEUDO RANGE ERROR (SCORE) ALGORITHM

The Self-Calibration of Pseudo Range Error (SCORE) technique used to improve the accuracy of TEC measurement from the GPS observations [5].

Step 1: $T_{\delta k} = (S_{\delta k} - B_{\delta})* \cos(\arcsin(\mu \cos(\varepsilon_{\delta k})))$ (7)

Where, $S_{\delta k}$= slant TEC

B_{δ}= satellite plus receiver bias for PRNδ, in TECU

$\varepsilon_{\delta k}$ = elevation angle, at observing site

μ= altitude factor for conversion to IPP zenith angle

Step 2: $\mu = \frac{R_e}{R_e + H_{IPP}}$ (8)

Where R_e = 6378 km

H_{IPP} =350 km

Step 3: Gaussian function

$$W_{ij} = \left(-\frac{1}{2}\frac{(\theta_i - \theta_j)^2}{\theta_0} - \frac{1}{2}\frac{(\lambda_i - \lambda_j)^2}{\lambda_0}\right) \quad (9)$$

For θ_k= Latitude

Step 4: λ_k= MJD+LT/24 (10)

Where, MJD is Modified Julian Day and LT is local time.

θ_0= reference latitude difference (degrees)

λ_0= reference local time difference (days).

Step 5: Equivalent vertical TEC difference for multiple observations,

$$E = \frac{1}{2}\sum_{i=1}^{i_\propto}\sum_{j=1}^{j_\beta} W_{\alpha_{i,\beta_j}} * (T_{\alpha i} - T_{\beta j})^2 \quad (11)$$

Where, $\propto$ is the satellite PRN number and 'i' is sample number.

$W_{\alpha_{i,\beta_j}}$ = weighting factor b/w samples αi and βj

$T_{\delta k}$ = calculated vertical TEC for sample δk

4. FITTED RECEIVER BIAS (FRB) ALGORITHM

The following are the steps of FRB algorithm

Step 1: The GPS user position is estimated using Bancroft method and Kalman filter.

Step 2: The earth-centered angle is calculated using elevation angle (E) of the satellites with respect to the ground station GPS and also IRNSS receiver [6].

[E, S, A] = elevation (receiver(x,y,z),satellite(X,Y,Z))
(12)

Where, x,y,z are the receiver's coordinates and X,Y,Z are the satellite's coordinates

Step 3: TEC can be estimated using GPS dual frequency and pseudoranges by using the following formula,

TEC=(P2-P1)/40.30*($f1^2 * f2^2$)/($f1^2 - f2^2$) (13)

Where, f1 and f2 are GPS frequencies and P1 and P2 are the pseudo ranges.

Step 4: TEC=TEC*2.853/(10^16) (14)

Average Tec=TEC/(no. of rows*column) (15)

Difference of TEC = (TEC-Average Tec).^2 (16)

Step 5: Sum of difference of TEC is obtained to add the rows and column values such that standard deviation can be easily calculated and TEC can be estimated.

Step 6: Mean FRB Instrumental bias can be obtained from sum of instrumental bias by the number of epochs.

5. RESULTS

The GPS TEC using SVD algorithm with respect to UTC time is shown in Figure 1 and it compares TEC values of all epochs for the day 26th September 2016 of Hyderabad station. It is inferred that TEC differs with respect to UTC time. The maximum value of TEC is 126.42TECU at 13:55 UTC i.e. 07:30 PM IST and minimum value is -99.194TECU at 17:00 UTC i.e. 10:30 PM IST.

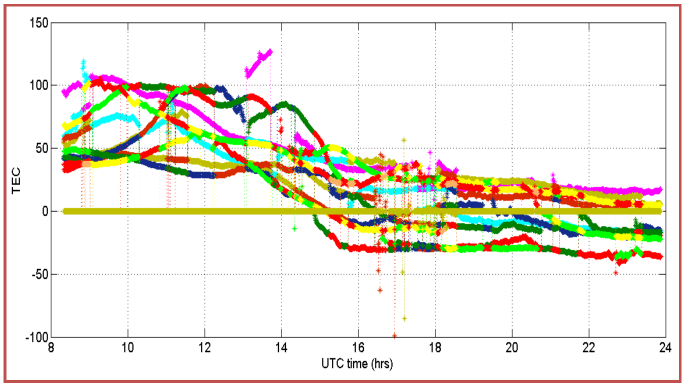

Figure 1: GPS TEC using SVD with respect to UTC time

The GPS Slant TEC (STEC) using SVD algorithm with respect to UTC time is shown in Figure 2. STEC values of all epochs for the day 26th September 2016 of Hyderabad station are compared. It is observed for a complete day i.e. 26th September 2016 the STEC differ with respect to UTC time. The maximum value of STEC is 427.559TECU at 13:55 UTC i.e. 07:30 PM IST and minimum value is -335.479TECU at 17:00 UTC i.e. 10:30 PM IST.

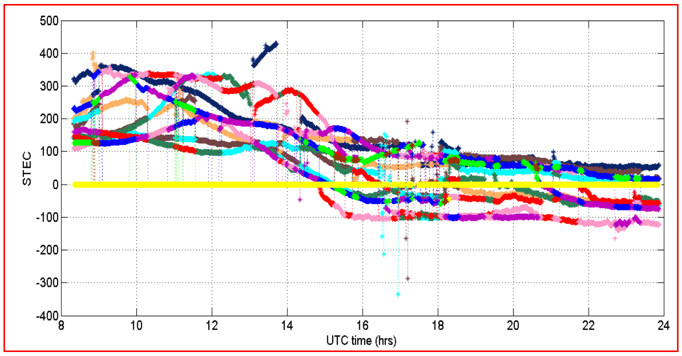

Figure 2: GPS Slant TEC using SVD w.r.t UTC time

The GPS satellite bias using SVD algorithm with respect to UTC time shown in Figure 3 and it compares Satellite Bias values of all epochs for the day 26th September 2016 of Hyderabad station.

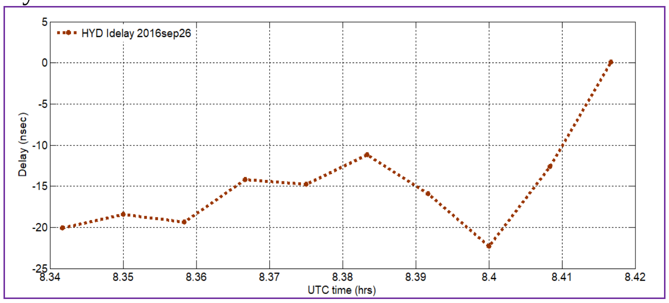

Figure 3: GPS Satellite bias using SVD with respect to UTC time

It is observed that satellite bias differs with respect to UTC time. The maximum value is 0.1ns at 08:42 UTC i.e. 02:12 PM IST and minimum value is -22.3ns at 08:40 UTC i.e. 02:10 PM IST.

The GPS receiver bias using SCORE algorithm w.r.t UTC time shown in Figure 4. It compares receiver bias values of all epochs for the day 26th September 2016 of Hyderabad station. It is observed that receiver bias differs with respect to UTC time. The maximum value is -4.45ns and minimum value is -44.0ns.

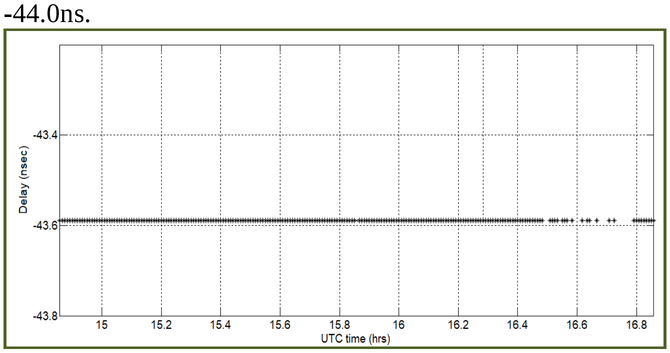

Figure 4: GPS receiver bias using SCORE with respect to UTC

The GPS receiver bias using FRB algorithm with respect to standard deviation of TEC is shown in Figure 5. It compares receiver bias values of all epochs for the day 26th September 2016 of Hyderabad station. It is observed that receiver bias differs with respect to standard deviation of TEC. The maximum value is -12ns and minimum value is -20ns.

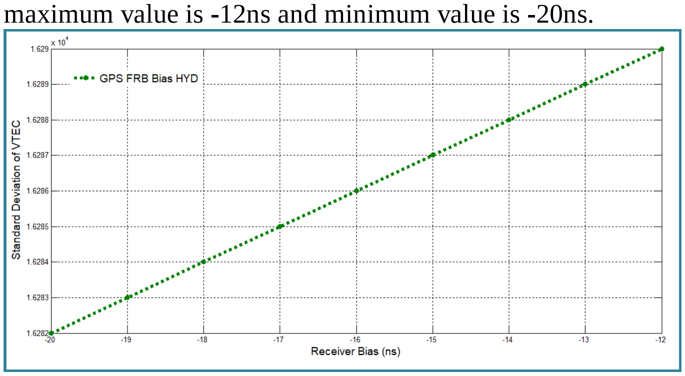

Figure 5: GPS receiver bias w r t standard deviation of TEC using FRB.

The NavIC (TEC) using SVD algorithm with respect to UTC time shown in Figure 6. It compares TEC values of all epochs for the day 20th September 2016 of Hyderabad station. It is also observed that TEC differs with respect to UTC time. The maximum TEC value is 18.936TECU and minimum TEC value is 4.5694TECU.

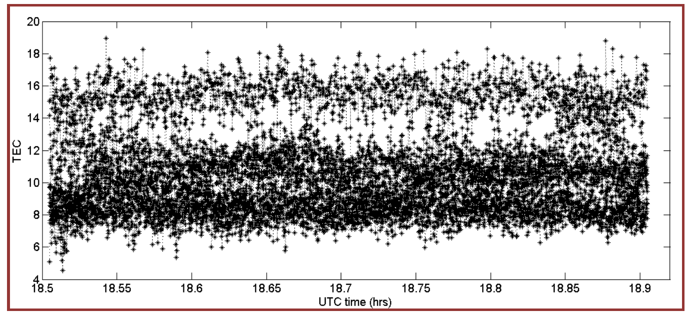

Figure 6: NavIC TEC using SVD with respect to UTC time

The Figure 7 describes NavIC STEC with respect to UTC time. It compares STEC values of all epochs for the day 20th September 2016 of Hyderabad station. It is observed that for one day i.e. 20th September 2016 the STEC differ with respect to UTC time. The maximum STEC value is 32.9766TECU and minimum STEC value is 7.9575TECU.

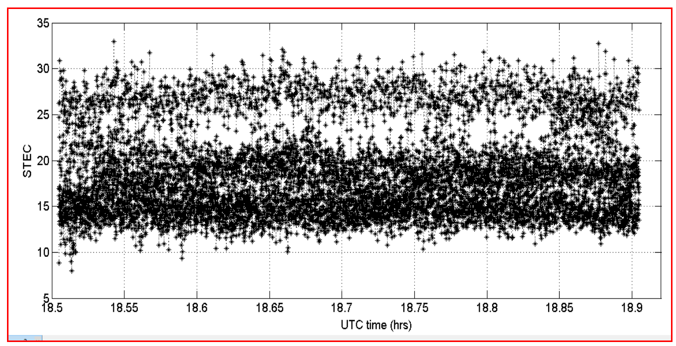

Figure 7: NavIC STEC using SVD with respect to UTC time

The NavIC satellite bias using SVD algorithm with respect to UTC time is shown in Figure 8. It compares satellite bias values of all epochs for the day 20th September 2016 of Hyderabad station. It is observed that differ with respect to UTC time. The maximum value is 17.299ns at 18:50 UTC and minimum value is -26.80ns at 18:58 UTC.

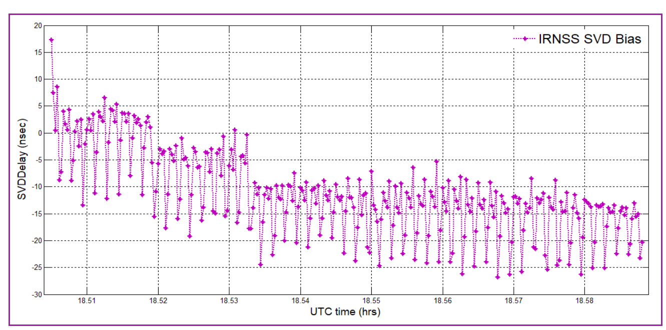

Figure 8: NavIC satellite bias using SVD with respect to UTC

The NavIC receiver bias using SCORE algorithm with respect to UTC time is shown in Figure 9.It compares receiver bias values of all epochs for the day 20th September 2016 of Hyderabad station. It is observed that receiver bias differs with respect to UTC time. The maximum value is 0.4935ns and minimum value is -4.7952ns.

Maximum and minimum biases of GPS and NavIC using SVD, FRB and SCORE models are summarized in Table 1 and 2 respectively.

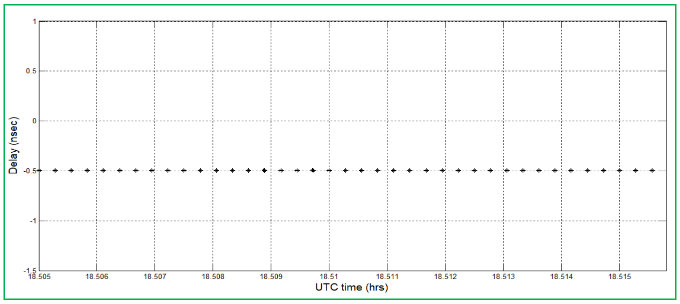

Figure 9: NavIC receiver bias using SCORE with respect to UTC

The NavIC receiver bias using FRB algorithm with respect to UTC time is shown in Figure 10. It compares receiver bias values of all epochs for the day 20th September 2016 of Hyderabad station. It is observed that receiver bias differs with respect to UTC time. The maximum value is 29.8ns and minimum value is -30ns.

Maximum and Minimum TEC, STEC values of GPS and NavIC satellites is summarized in Table 2 and 3 respectively.

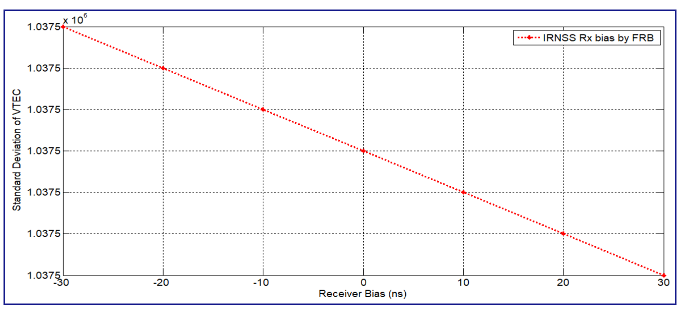

Figure 10: NavIC receiver bias using FRB w.r.t standard deviation of VTEC.

Table 1: Maximum and minimum biases of GPS using SVD, FRB and SCORE models

	GPS Satellites	
	Max(ns)	**Min(ns)**
SVD Algorithm	0.1	-22.3
FRB Algorithm	-12	-20
SCORE Model	-4.45	-44.0

Table 2: Maximum and Minimum biases of NavIC using SVD, FRB and SCORE models

	NavIC Satellites	
	Max(ns)	**Min(ns)**
SVD Algorithm	17.29	-26.80
FRB Algorithm	29.8	-30
SCORE Model	0.493	-4.795

Table 3: Maximum and minimum TEC, STEC values and visibility of GPS satellites

	GPS Satellites	
	Max(TECU)	**Min(TECU)**
SVD Algorithm	126.42	-99.194
FRB Algorithm	427.559	-335.47
SCORE Model	12	7

Table 4: Maximum and minimum TEC, STEC values and visibility of NavIC satellites

	NavIC Satellites	
	Max(m)	**Min(m)**
SVD Algorithm	18.93	4.569
FRB Algorithm	32.94	7.95
SCORE Model	18	-

6. CONCLUSION

In this paper, three models namely SVD, FRB and SCORE techniques are implemented for GPS and NavIC signals using RINEX data. It is observed that the model obeys the SVD, SCORE and FRB principles. For GPS, the receiver bias minimum value is (-0.4935ns) for SCORE model. For NavIC also the receiver bias value is minimum (-4.7952ns) for SCORE model.

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