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Estimation of Doppler Positioning for NavIC System in Static and Dynamic Conditions

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Abstract: *The primary objective of any navigation system is to provide accurate user position. Navigation with Indian Constellation (NavIC) is an emerging regional satellite navigation system being developed by ISRO, India. The positional accuracy of the NavIC depends upon various parameters based on the application. Doppler shift is one among those parameters which plays an important role in finding the user position in dynamic conditions. The effect of the Doppler shift is more in high dynamic applications like missiles launching, air navigation due to high relative velocity between receiver and satellite. In this Paper, an efficient algorithm is developed to estimate the Doppler positioning using least squares method in static and various dynamic conditions. For this, the experimental data acquired from Indian Regional Navigation Satellite System (IRNSS)-GPS receiver located at low latitude station (Hyderabad: 17.39˚N, 78.31˚E) is used. A trajectory path has been simulated to estimate the user position and its accuracy measures in low and high dynamic conditions. It is noticed that, Doppler shift vary ±1KHz for geosynchronous satellites in static conditions, whereas it is ±40KHz in high dynamics. It is observed the position error is high in high dynamics as compared with low dynamics because of the higher Doppler shifts.*

Keywords: *Doppler positioning, NavIC, IRNSS, Positional accuracies, dynamic conditions*

I. INTRODUCTION

NavIC is regional satellite system that provides Standard Position Service (SPS) for civilian users and Restricted Service (RS) for authorized users. It operates with a carrier signal frequency of L5-1176.45MHz and S1-2492.028MHz [6]. Under an MoU between SAC Ahmedabad and Chaitanya Bharathi Institute of Technology (CBIT), an IRNSS User Receiver (IRNSS-UR) is installed in the Navigation and Communication Research Centre (NCRC), Dept. of ECE, CBIT Hyderabad, India. IRNSS-UR receives, down converts and demodulates the transmitted satellite signals. There are various applications that can be developed by using IRNSS receiver. Some applications may require sub meter position accuracy like aircraft navigation, marine navigation and automotive applications [2],[5].

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The performance of IRNSS receiver varies based on the application particularly for dynamic conditions. Therefore, it is necessary to evaluate the performance of IRNSS receiver in static and different dynamic conditions. Various applications including land, marine, aeronautic and space navigation can be classified based on relative velocity, acceleration and jerk [3], [4].

The civilian applications like land vehicles and pedestrian navigation with low velocity and acceleration comes under low dynamic applications. Whereas the space applications like aircrafts navigation and missile navigation which exhibits severe maneuvers have accelerations of about 40g (where g=9.80665 m/s^2) comes under high dynamic applications [8]. IRNSS receiver performs the measurement of Doppler shift by comparing the received signal with reference signal generated by local oscillator of the receiver. Due to relative velocity between satellite and receiver, receiver experiences Doppler shift [7], [9].

To minimize the code tracking errors due to Doppler shift variations in GEO satellites, a narrow band correlator is used. In low dynamics conditions, the receiver position may not effected significantly due to Doppler shift. Whereas in high dynamics, the rate of change in Doppler shift is very high due to which the receiver position is inaccurate. By modifying the performance parameters of the receiver, accurate receiver position is possible under high dynamic conditions. The typical Doppler range for conventional GPS receiver in low dynamics is ±7 KHz and the Doppler rate is 1Hz/s, whereas in high dynamics, the Doppler frequency is expected to vary in the range ±100KHz with Doppler rates of about 100Hz/s [10]. The estimation of Doppler positioning for NavIC system in static and dynamic conditions will be helpful for precise point positioning applications [11]. The typical values of various parameters such as velocity, acceleration and jerk for low and high dynamic conditions are presented in Table-I [7]. The applications related to low dynamics are foot walk, land vehicles and for high dynamics spacecraft vehicles and missiles [14].

Table-I: Comparison of various parameters in dynamic conditions

Dynamics	Velocity(m/s)	Acceleration (m/s^2)	Jerk(m/s^3)
Low	<25	<1g	<10g/s
High	>1000	>40g	>50g/s
Where g is earth gravitational force = 9.80665 m/s^2			

II. IRNSS USER RECEIVER

IRNSS user receiver performs various functions such as signal acquisition, tracking, data decoding and PVT estimation. It is designed with Right Hand Circular Polarized (RHCP) antenna of 15m RF cable connected to receiver front end. To enhance the strength of the IRNSS signal, approximately to 20dB, a Low Noise Amplifier is used. Also, a high frequency filter is used to minimize the signal interference.

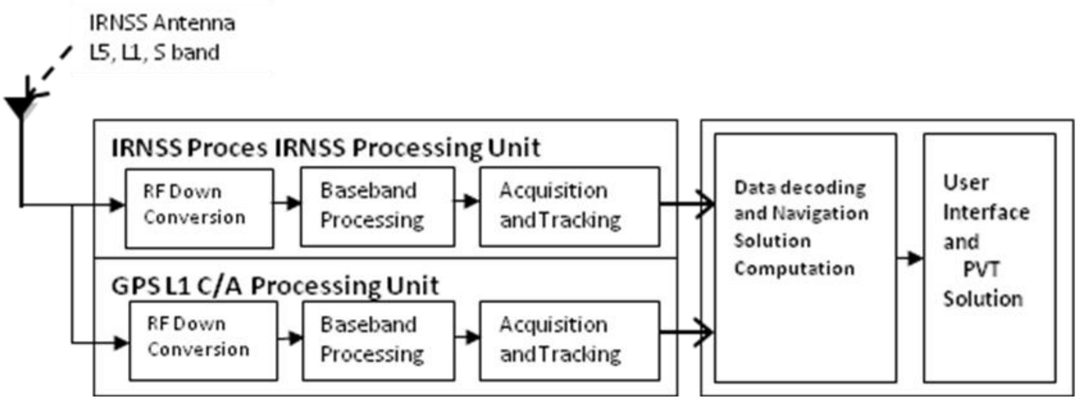

Fig.1 Typical block diagram of IRNSS User Receiver

Further, the received IRNSS signal is down converted Intermediate Frequency (IF) signal by mixing it with the local oscillator signal. Following is the base band signal processing unit which performs acquisition and tracking functions. The unit which performs data decoding and PVT estimation is Navigational unit. The importance of each receiver function described with the help of Fig. 1

Receiver functions

A. Acquisition: It is the process to identify the visible satellites in the incoming data. Then to find coarse values of the Doppler frequency and phase of C/A code [12]. This is done by and correlating the incoming signal with receiver locally generated signal. There are several methods of acquisition such as serial search in time domain or parallel search (FFT method) in frequency domain [16].

B. Tracking: After accomplishment of acquisition, next process is the tracking. To track the code phase and frequency, A delayed lock loop (DLL) and a phased locked loop (PLL) or a frequency locked loop (FLL) are used, respectively [15], [17]. Tracking is one of the important function of receiver in dynamic conditions. Under dynamic environments, due to the various operating conditions, induced inferences are Line-of-Sight (LOS) effect and multipath fading. Due to this, the strength of the IRNSS signal may degrade even below the normal tracking thresholds [13]. The performance of the IRNSS receiver depends on tracking.

C. Data decoding: When both DLL and PLL tracking loops are in lock, it is then to decode navigation data, this data IS divided into frames, with each frame transmitted within one second and determine the receiver position.

D. Position solution: The navigation unit consists of the navigation processor and other I/O peripherals in order to calculate the receiver position, velocity and time

III. METHODOLOGY

The following are the important steps to estimate Doppler positioning in static and dynamic conditions.

Step 1: IRNSS data extraction from IRNSS user receiver by using IRNSS data utility software

Step 2: Estimation of the IRNSS satellite position from RINEX data

Step 3: Calculation of user position by using least square method (Bancroft Method) [1]

Step 4: Computation of the Doppler shift by using following equation

$$f_r = \left(1 + \frac{\Delta v}{c}\right) f_T$$

where, $$\Delta v = \vec{v}_s \cdot \frac{\vec{p}_s - \vec{p}_u}{\left\|\vec{p}_s - \vec{p}_u\right\|} - \vec{v}_u \cdot \frac{\vec{p}_s - \vec{p}_u}{\left\|\vec{p}_s - \vec{p}_u\right\|}$$

$\|\ \|$ is the magnitude of a vector.

where c indicates the velocity of light V_u, V_s are velocities of the receiver and satellite, P_u and P_s are position of the receiver and satellite. f_T represents the transmitted frequency of the IRNSS satellite.

Step 5: Applying various dynamics by changing user velocity in low and high dynamics to compute the Doppler shift using step 4

Step 6: Simulation of the trajectory path in dynamics conditions

Step 7: Estimation position accuracy measures in static and dynamic conditions

IV. RESULT AND DISCUSSIONS

In this work, the navigational data is acquired from IRNSS receiver located at Navigation and Communication Research Centre, CBIT, Hyderabad station (17.39˚N, 78.31˚E). IRNSS satellite position is computed from RINEX data and Doppler shift values are calculated in static and dynamic conditions for IRNSS GSO and GEO satellites on 08 October 2017.

A. Estimation of Doppler shift

I. Static conditions:

The Doppler shift values are calculated for IRNSS GSO (1A, 1B and 1D) and GEO (1C) satellites on 08 October 2017 from RINEX data. These values are compared with the observed Doppler shift values obtained from IRNSS Receiver. The mean error of Doppler shift is calculated as shown in Fig. 2.

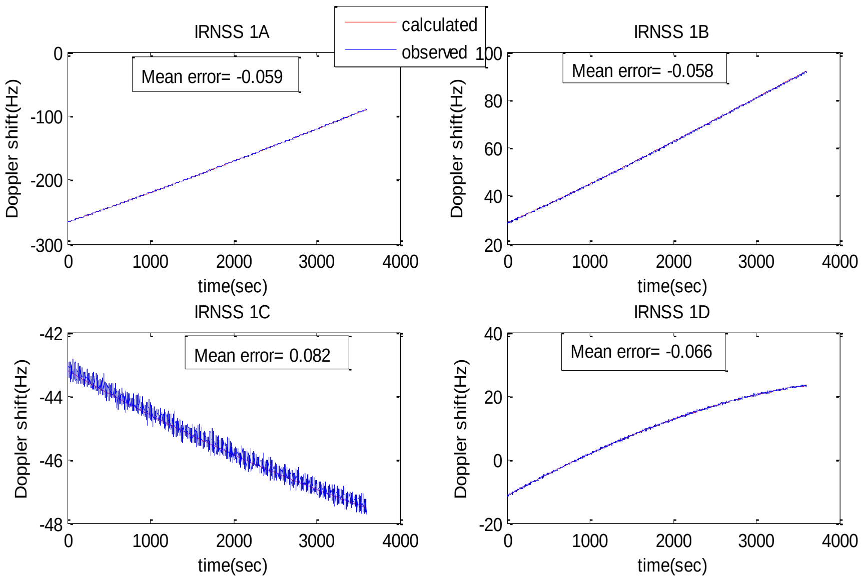

Fig. 2 Doppler shift for IRNSS GSO and GEO satellites in static conditions

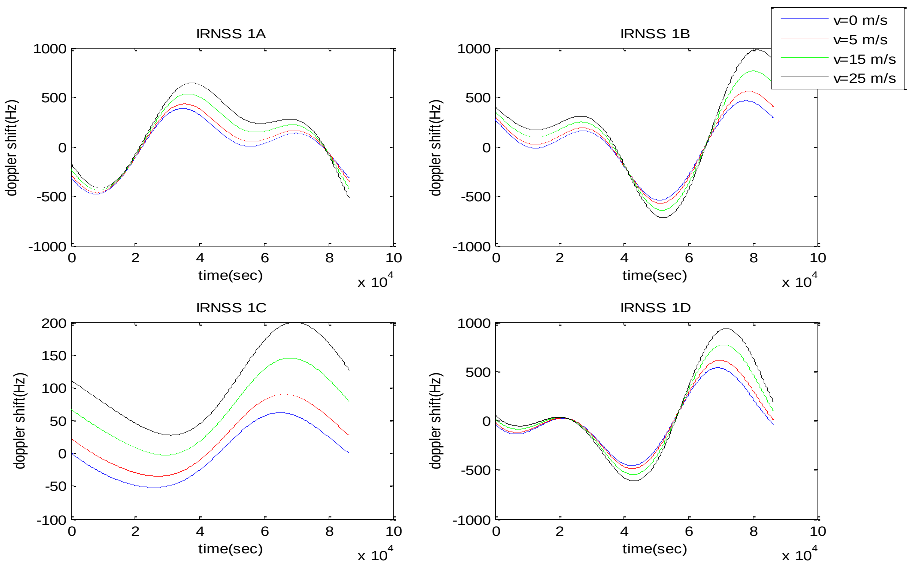

Fig.3 Doppler shift values in low dynamic conditions

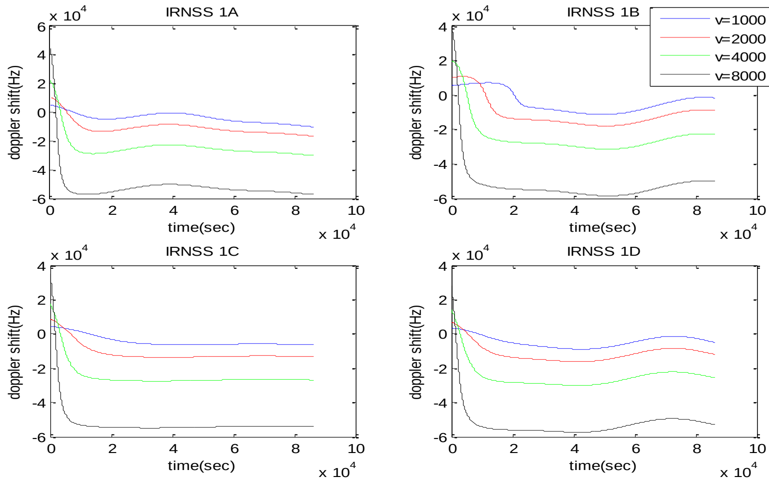

Fig.4. Doppler shift values in high dynamic conditions

The results shows that, the Doppler shift range values for IRNSS GSO satellites in static condition varies ±270Hz for Geosynchronous satellites and ±50Hz for Geostationary satellite.

II. Dynamic conditions

In low dynamic conditions with user velocity 0 to 25m/sec, the calculated Doppler shift values due to IRNSS satellites for 24 hours on 08 October 2017 are plotted as shown in Fig. 3. It is observed that Doppler shift values vary ±1KHz for geosynchronous satellites and ±200Hz for geostationary satellite which is less due to least relative motion between user and satellite.

In high dynamic conditions with user velocity 1000m/s to 8000m/s, the Doppler shift values are calculated as shown in Fig. 4. For a given user velocity of 8000m/sec, the Doppler shift due to geosynchronous satellites is greater than that due to geostationary satellite by 16kHz.

B. Position Performance Analysis of NavIC

The user position is calculated using the least squares method based Bancroft algorithm. The calculated user position is compared with the values observed from IRNSS user receiver as shown in the Table II.

Table-II: Comparison of calculated user position with IRNSS-UR

S.No	Average user position(m)	
	Calculated	***Observed***
1.	X-1232833.607	X-1232834.089
2.	Y-5962758.757	Y-5962759.151
3.	Z-1894315.345	Z-1894316.434

Various position accuracy measures such as DRMS, 2DRMS and CEP are computed. The mean value of observed position error is 0.2479 and that of estimated position error is 0.2786. The mean observed and estimated values of 2DRMS are 0.858 and 0.9649 respectively. The mean observed and estimated values of CEP are 0.2988 and 0.3086 respectively as shown in Fig. 5. Due to clock bias, clock offset and instrumental bias, there is a deviation in the calculated and observed user position accuracy measures.

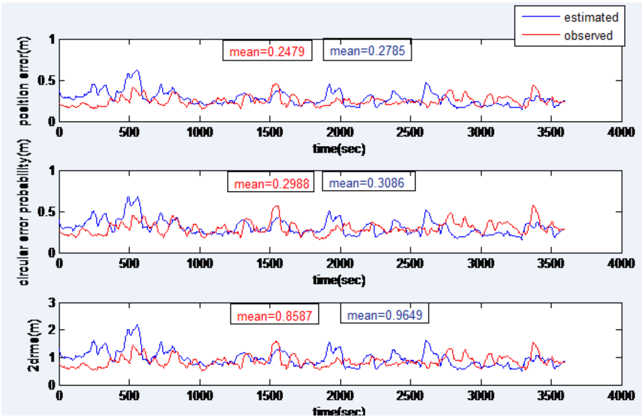

Fig.5.Comparison position accuracy measures with IRNSS receiver

In order to analyze the position performance of NavIC in dynamic conditions, a trajectory path is simulated with different accelerations and velocities. It is assumed that the trajectory of moving vehicle is linear as shown in Fig. 6.

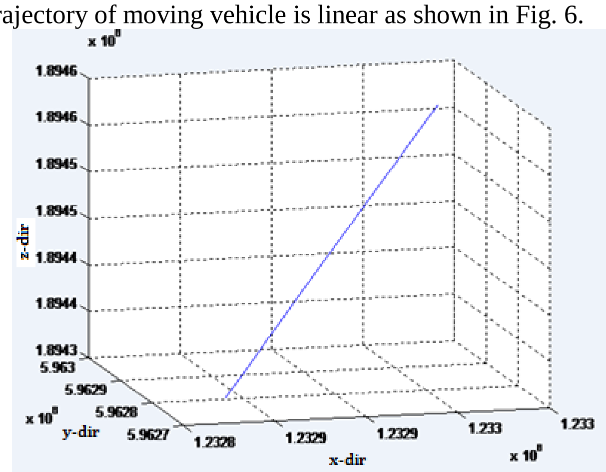

Fig. 6 IRNSS receiver trajectory path in dynamic conditions

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During trajectory path simulation, Initial 4 sec of time, IRNSS receiver is in low dynamics with different acceleration 0m/s^2 to 10m/s^2. The receiver enters into high dynamics after 4 sec of time with acceleration 20m/s^2 to 110m/s^2 as shown in Fig. 7

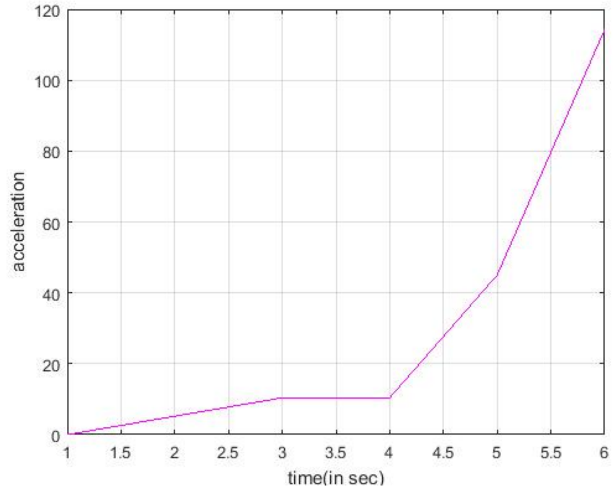

Fig.7 Trajectory path in dynamic conditions

Using the simulated trajectory, the position performance of IRNSS is evaluated for low and high dynamics. The mean value calculated for positional error for low dynamics in x, y and z-coordinates are 39.69m, 40.75m and 28.58m respectively as shown in Fig. 8. The mean value calculated for positional error for high dynamics in x, y and z-directions are 397m, 408m and 285m respectively as shown in Fig. 9. It is observed the position error is high in high dynamics as compared with low dynamics because of the higher Doppler shifts.

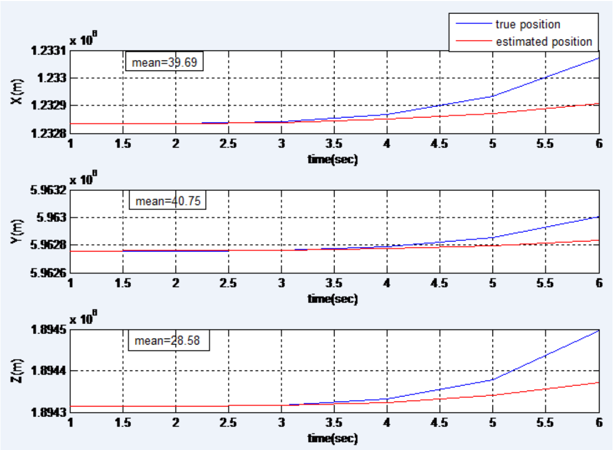

Fig.8 Position accuracy for trajectory path in low dynamics

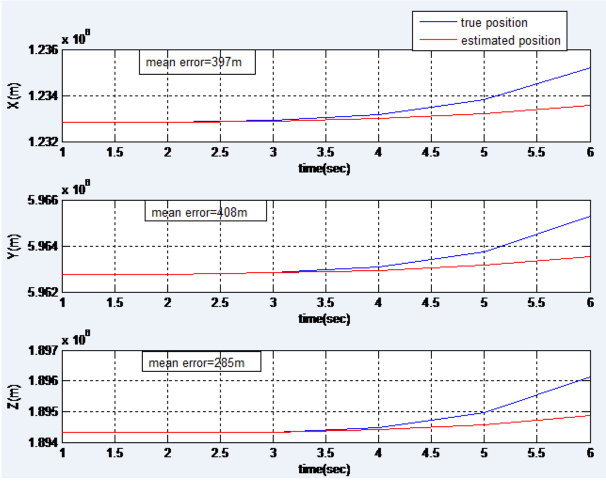

Fig.9 Position accuracy for trajectory path in high dynamics

V. CONCLUSION

The performance of Doppler positioning for NavIC system in both static and dynamic conditions is analyzed. The Doppler shift values are calculated from RINEX data for IRNSS satellites and compared with observed values obtained from IRNSS user receiver. It is noticed that, calculated Doppler shift values are very much closer to observed results. Doppler shift mean errors are found to be -0.059Hz, -0.058Hz, 0.082Hz and -0.066Hz for IRNSS 1A, 1B, 1C and 1D respectively. For static conditions, it is observed that Doppler shift values vary ±1KHz for geosynchronous satellites. For Geostationary satellites, this variation is ±200Hz which is less due to low relative motion between user and satellite. By using least squares method the calculated user position is compared with the values observed from IRNSS receiver. The mean value of observed position error is 0.2479 and calculated is 0.278. The mean observed and estimated values of 2DRMS are 0.858 and 0.9649 respectively. Similarly, the mean value observed and estimated values of CEP are 0.2988 and 0.3086 respectively. To estimate the Doppler positioning in dynamic conditions, a trajectory path is simulated with different accelerations and velocities. The calculated mean positional error for low dynamics in x, y and z-directions are 39.69m, 40.75m and 28.58m respectively. The calculated mean positional error for high dynamics in x, y and z-directions are 397m, 408m and 285m respectively. It is noticed that the calculated position errors are more in high dynamics as compared to that of low dynamics due to higher Doppler shifts. Further analysis need to be carried by applying the kalman filtering for various dynamic conditions to improve the positional accuracy.

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