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GPS/NavIC Based Relative Position Estimation and Analysis using Real Time Measurements of Zero-Baseline Experiment

Abstract: - This paper focuses on estimation and evaluating relative positioning accuracy using carrier phase measurements of GPS-alone, NavIC-alone, and GPS/NavIC. To make this happen, a zero-baseline method is used with single constellation as well as the combined processing of GPS and NavIC. Double difference method considerably reduces tropospheric and ionospheric delays yet, multipath signals remain a major source of error for different generic Global Navigation Satellite System (GNSS) baseline applications. In zero base-line method, a splitter is used to link two GPS/NavIC receivers to a single antenna. With the help of this technique, all errors or delays are eliminated, leaving alone the haphazard measurement noises resulting from the double difference processing. Baseline error time series show that the GPS and NavIC can both reach centimeter precision, further GPS outperforms NavIC. Comparing the combined GPS and NavIC processing results to the GPS-alone and NavIC-alone results, it is clear that integrating the two can greatly increase precision.

Keywords: GPS; NavIC; Zero base line; Relative positioning; Double difference.

I. INTRODUCTION

India is developing its own positioning system called NavIC (Navigation with Indian Constellation). Currently, NavIC has 7 satellites distributed in two different orbit types. The four satellites are arranged in two Geosynchronous orbits (GSO) and three satellites are arranged in Geostationary orbit (GEO) at longitude of 83^0E, 32.5^0E and 129.5^0E (Fig.1). On July 1, 2013, the first satellite, IRNSS-1A (I01), was launched. Following that, India launched seven more navigation satellites in the following four years. The fundamental details of NavIC's navigation satellites are displayed in Table 1. Additionally, the NavIC offers restricted service (RS) with binary offset carrier, or BoC (5, 2) on S-band (2492.028 MHz), with a bandwidth of 24 MHz and 16.5 MHz, respectively, and Standard Positioning Service (SPS) through BPSK (1) modulated signals on L5 band (1176.45 MHz) [1-2]. Thus, in addition to existing GNSS systems, navigation users throughout India and its environs could access data from the NavIC constellation.

Table 1: The Basic details of NavIC constellation

S.No	PRN	Type	Launch Date	Longitude	Orbital Inclination	Remarks
1	IRNSS-1B(I02)	GSO	04/04/2014	55^0E	31.0^0	Operational
2	IRNSS-1C(I03)	GEO	16/10/2014	83^0E	0^0	Operational
3	IRNSS-1D(I04)	GSO	28/03/2015	111.75^0 E	30.5^0	Operational
4	IRNSS-1E(I05)	GSO	20/01/2016	111.75^0 E	28.1^0	Operational
5	IRNSS-1F(I06)	GEO	10/03/2016	32.5^0E	0^0	Operational
6	IRNSS-1G(I07)	GEO	28/04/2016	129.5^0E	0^0	Operational
7	IRNSS-1I(I09)	GSO	12/04/2018	55^0E	29^0	Operational

This article evaluates the relative position accuracy of NavIC and GPS carrier phase measurements. In comparison to GPS-alone and NavIC-alone results, the study's findings show that it is possible to increase accuracy by integrating both GPS and NavIC. The structure of this paper is as follows. A brief description of the zero-baseline experiment is given in section 2. The availability of NavIC satellites is described in detail in section 3. Also, presented the findings for GPS alone, NavIC solely, and combined GPS and NavIC in section 3.

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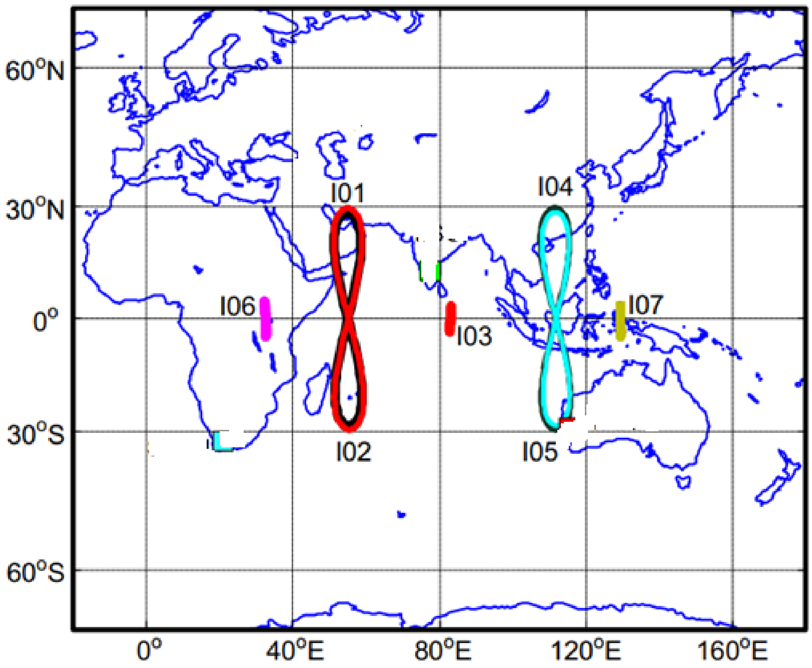


Figure 1. NavIC GEO and GSO satellites track during one complete orbital period.

II. ZERO BASELINE EXPERIMENT

A signal splitter was utilized to link two GPS/ NavIC Accord receivers to a solitary antenna mounted on the roof of the building. The two NavIC signals on L5 (1176.45 MHz) and S-band (2492.028 MHz) frequencies and GPS L1(1575.42 MHz) and L2(1227.6 MHz) were received as a baseline with a distance of "zero" units as they were tracking the satellite signals at the same antenna phase center. On a pillar on the roof of the ECE building at Osmania University, Hyderabad (Fig. 2). In this experiment, the splitter was connected to the two receivers via two 3 m long antenna cables, and the antenna was connected to the splitter via a 15 m long wire. For both receivers, the cut-off angle was set to 20° and the sampling rate to 1 Hz.

Zero baseline errors

Considering that the two receivers are referred to as '*i*' and 'j', and the two monitored satellites are labeled '*p*' and '*q*'. By taking into account the tropospheric delay, ionospheric delay, multipath error, satellite and receiver clock errors, as well as the random reception noise errors, these two receiver observation equations to satellite '*p*' can be represented as follows[3-4]:

$$\varphi_i^p = \rho_i^p + c(\delta t^p - \delta t_i) + N_i^p + T_i^p + I_i^p + M_i^p + \xi_i^p \quad (1)$$

$$\varphi_j^p = \rho_j^p + c(\delta t^p - \delta t_j) + N_j^p + T_j^p + I_j^p + M_j^p + \xi_j^p \quad (2)$$

where ρ is the geometrical distance between satellite p and receivers *i* and *j*, φ is the carrier phase measurement, and c is the speed of light in a vacuum. The integer ambiguities of receivers *i* and *j* from satellite p carrier phase measurements are denoted by N_i^p and N_j^p respectively. δt^p represents the clock error of the satellite p; δt_i and δt_j denote the clock errors of the receiver i and receiver j, respectively. M_i^p and M_j^p are the multipath noise of receivers i and j from satellite p; I_i^p and I_j^p are the ionospheric delays from satellite *p* to receivers *i* and *j*, respectively. The tropospheric delays of satellite *p*'s receivers *i* and *j* are denoted as T_i^p and T_j^p. Receivers *i* and *j* experience the same tropospheric and ionospheric delays when tracking the same satellite over a zero baseline. Choke ring antennas are capable of resisting most multipath. Receivers *i* and *j* are equally impacted by the residual multipath in the zero-baseline scenario. The single difference equation between the two receivers takes the following form:

$$\varphi_{i,j}^q = \rho_{i,j}^p - c\delta t_{i,j} + N_{i,j}^p + \xi_{i,j}^p \quad (3)$$

A second single difference equation can be expressed as follows when taking into account a second satellite *q*:

$$\varphi_{i,j}^q = \rho_{i,j}^q - c\delta t_{i,j} + N_{i,j}^q + \xi_{i,j}^q \quad (4)$$

where $g_{i,j} = g_j - g_i$ is the general connection. Differentiating between the carrier phase data of the receivers would completely eliminate the tropospheric, ionospheric, and multipath errors. The single difference receivers' clock inaccuracy, single difference integer ambiguity, and random errors that represent the signal quality are still there. The double difference observation can be obtained by computing the difference between eq. 4 and eq. 3.

$$\varphi_{i,j}^{p,q} = \rho_{i,j}^{p,q} + N_{i,j}^{p,q} + \xi_{i,j}^{p,q} \tag{5}$$

where $g_{i,j}^{p,q} . g_{i,j}^{p,q}$ is the general relationship for each individual component, and $g_{i,j}^{p,q} = g_j^q - g_j^p - g_i^q + g_i^p$ is the double difference operator.

The satellite position is also a basis for baseline resolution. Errors are present in the satellite positions determined by the ephemeris, which may lower the baseline resolution's accuracy. The following is the correlation between satellite orbital precision and baseline precision[5]:

$$\delta b = \frac{\delta s}{\rho} . b \tag{6}$$

where ρ is the distance from the tracked satellite to the receiver, b is the baseline's length, and δb is the baseline's error. δs represents the satellite orbital error. Differentiating (Eq. 6) can be used to remove the satellite orbit error in the zero-baseline case.

Rewriting eq.5 and linearizing $\rho_{i,j}^{p,q}$ outcomes are:

$$\varphi_{i,j}^{p,q} = [l_{i,j}^{p,q}\ m_{i,j}^{p,q}\ n_{i,j}^{p,q}].[\delta x\ \ \delta y\ \ \delta z]^T + N_{i,j}^{p,q} + \xi_{i,j}^{p,q} \tag{7}$$

The double difference distance between the satellites and the receivers is represented by the formula $[l_{i,j}^{p,q}\ \ m_{i,j}^{p,q}\ \ n_{i,j}^{p,q}]$, which may be computed using the approximate coordinates of the receivers and the tracked satellites. The 3D distance of the baseline is corrected by $[\delta x\ \ \delta y\ \ \delta z]$, where $N_{i,j}^{p,q}$ represents the double difference integer ambiguity and $\xi_{i,j}^{p,q}$ represents the double difference random noise. The precision of the baseline correction is influenced by both the observation noise and the coefficient $[l_{i,j}^{p,q}\ \ m_{i,j}^{p,q}\ \ n_{i,j}^{p,q}]$, following the geometrical impact of the double difference integer ambiguity $N_{i,j}^{p,q}$ is correctly fixed[6-7].

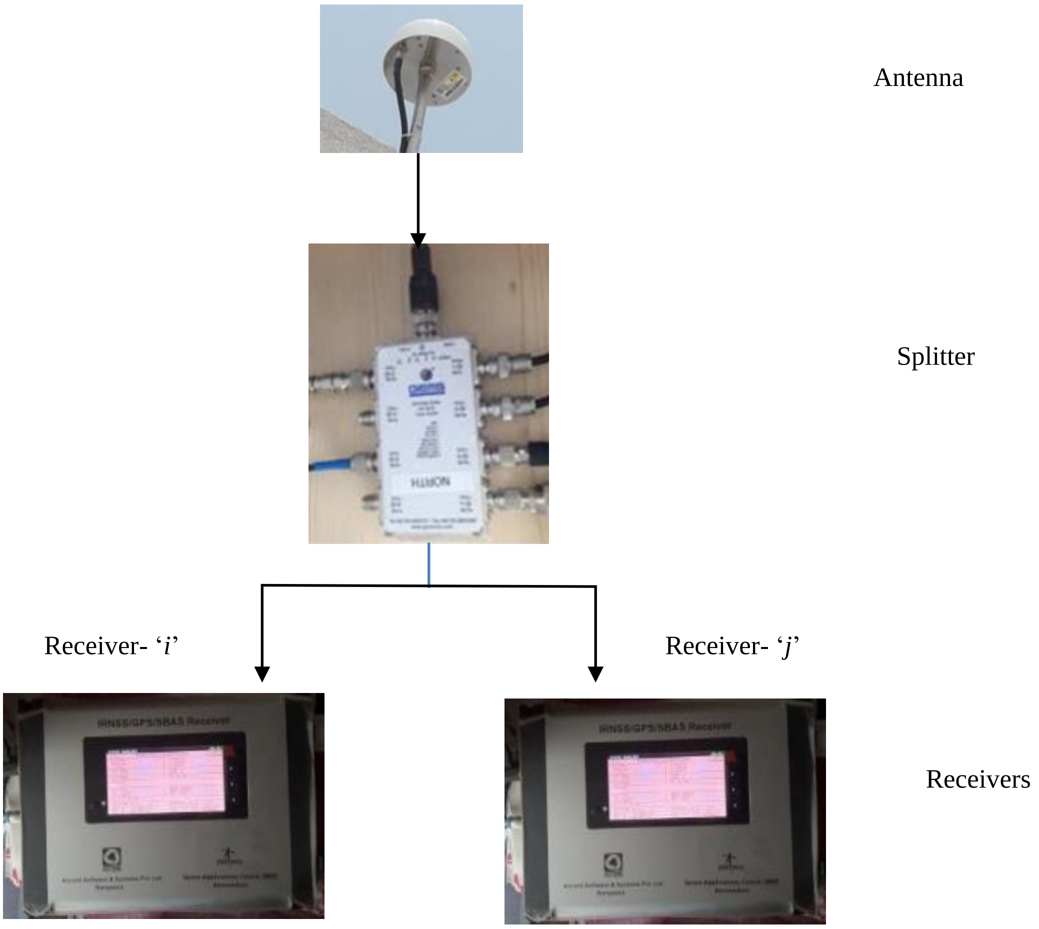


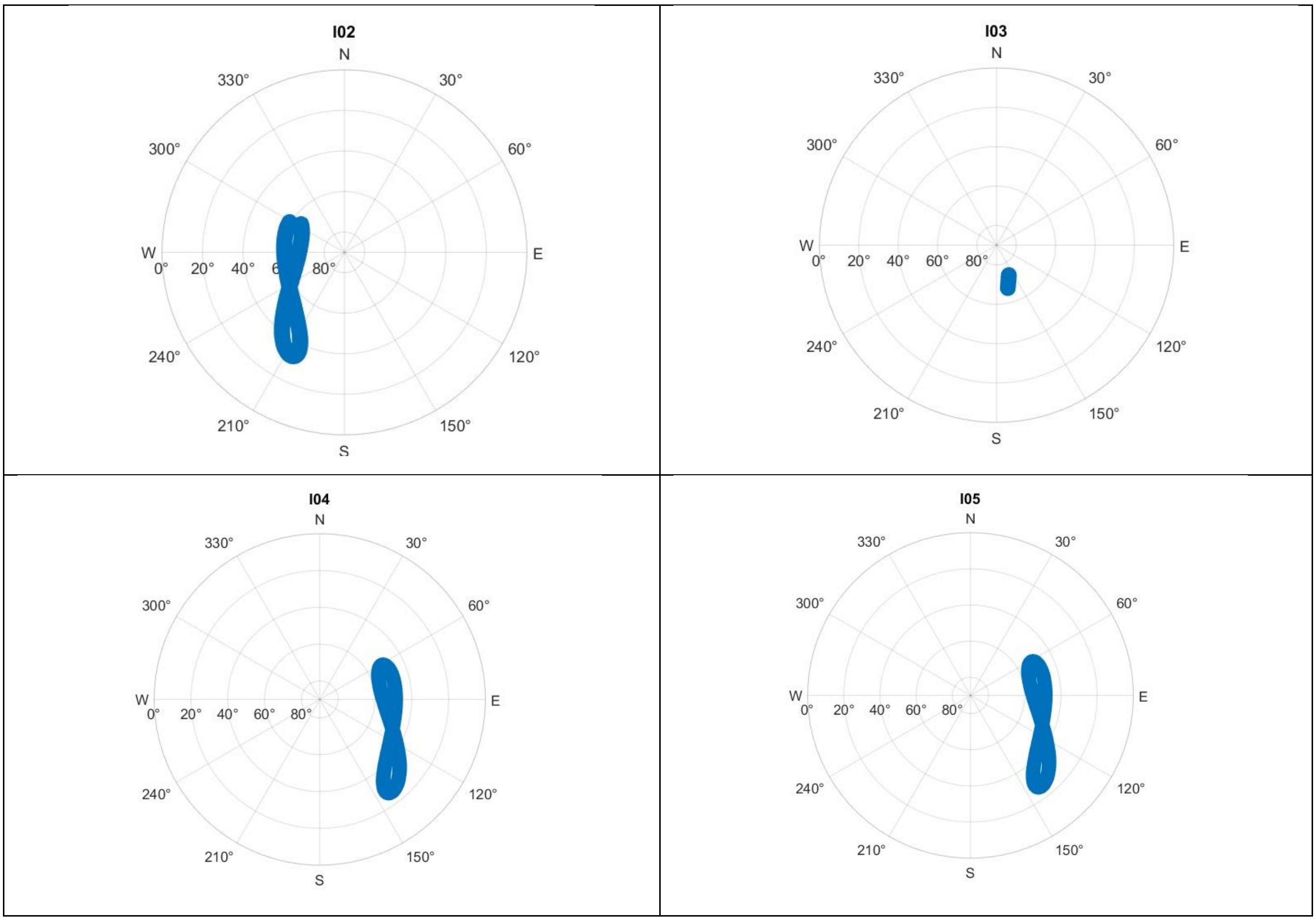
Figure 2. Zero baseline experimental set up using two receivers ‘i’ and ‘j’.

The coefficients in this research, which employs variance of unit weight during the least squares adjustment, show the effectiveness of various satellite geometries. Distinguishing between these sources of errors is a work in progress. The main topic of this research is the comparison of GPS-alone and NavIC-alone location precision and the improvement achieved by integrating GPS and NavIC data. The geometrical influence of the satellites and random noise from the observations combine to produce the ultimate positional error.

III. RESULTS AND DISCUSSION

NavIC Satellite’s Visibility

This section presents NavIC constellation visibility using ephemeris data of during entire orbital period. The NavIC GEO and GSO satellites sky plots are shown in Figure 3. Every GEO satellite is looks stationary for the user located on the earth. But, similar to Medium Earth Orbit (MEO) satellites, GSO satellites may disappear from view because of their orbit. The satellites never appear in a particular region of the sky. The number of GPS and NavIC satellites visible over a 20∘ elevation mask shows that during some epochs, there are 12 GPS satellites visible, but NavIC has all 6 satellites that are trackable over a 24-hour period. There are situations where more NavIC satellites are being tracked than GPS. When GPS and NavIC are used together for locating, at least 14 navigation satellites are being tracked[8]. When a user finds himself in an area that is not GNSS-friendly, the integration of GPS and NavIC might be quite helpful.



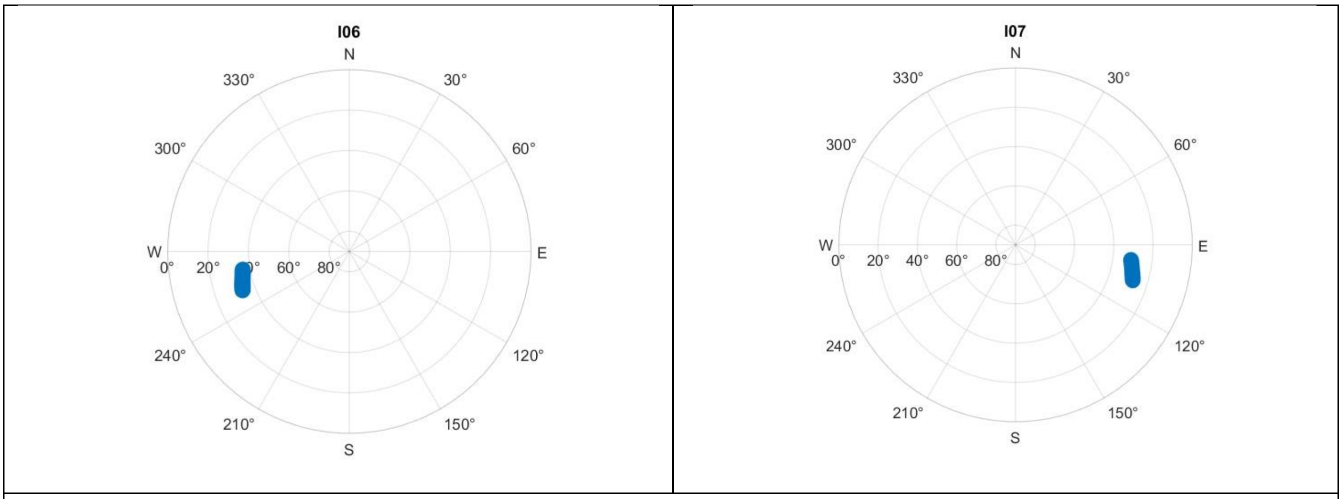


Figure 3. Skyplot of NavIC GEO and GSO satellites

GPS-alone, NavIC-alone and GPS+NavIC position error

The two receivers connected to the single antenna through the splitter collect the exact carrier phase data. A 15m low loss coaxial cable, with the splitter at the GNSS reception end, is used to link the antenna to the receivers. Tropospheric and ionospheric delays, as well as the multipath effect, are eliminated on both receivers by the double differencing. The pre-processing of the data also employed a cycle-slip detection technique (Liu 2010). Epoches by epoch, the GPS and NavIC data collected on April 4, 2022, were processed. The positioning errors time series for GPS, NavIC, and a combined GPS + NavIC solution in east, north, and height components are shown in Figures 5, 6, and 7. In both the East and North components, the GPS location inaccuracy for most of the times is typically less than ± 2.5mm. The maximum error in NavIC position within the east component is ±3.6 mm. In terms of height and north accuracy, NavIC is not as reliable as GPS. In the north component of the NavIC positional error time series, errors are seen to be larger than at other periods between 07:00 and 09:00, and some epoches around 21:30. This phenomenon is also seen in the height component. As can be shown by comparing the resolutions obtained using GPS alone and NavIC alone in Figures 5, 6, and 7, GPS positional precision now outperforms NavIC in all three components. In Figure 6, position noise from NavIC is significantly less noticeable than that from GPS from 12:00 to 14:00. Over a two-hour period, the orbital paths of the GPS satellites are longer than those of the NavIC GEO and GSO satellites. During this period, the coverage of GPS satellites is also more dispersed than that of NavIC. Overall, the results show that GPS has a better geometrical spread and also for the NavIC constellation. The integrated GPS/NavIC system, however, has the finest satellite distribution. The North and East position errors are far smaller than the height component, which is a trait shared by both GPS and NavIC.

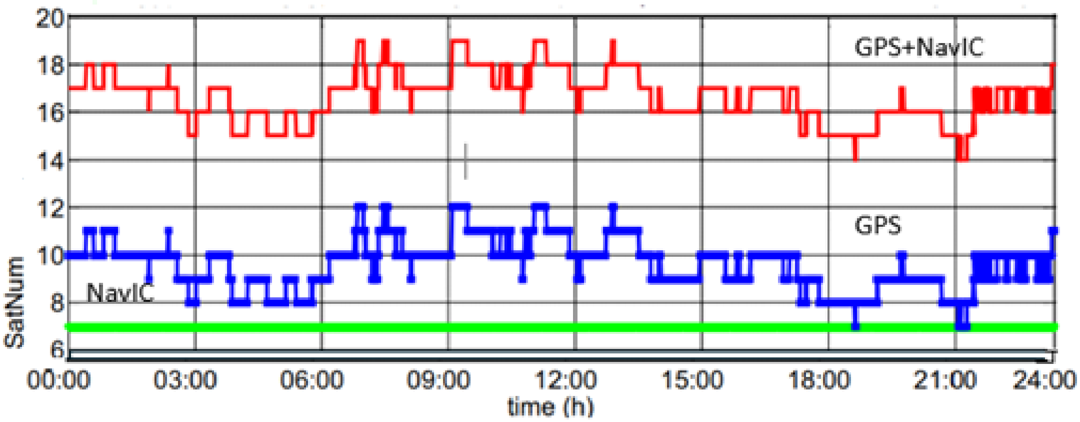


Figure 4. The number of visible satellites in 24 hours period

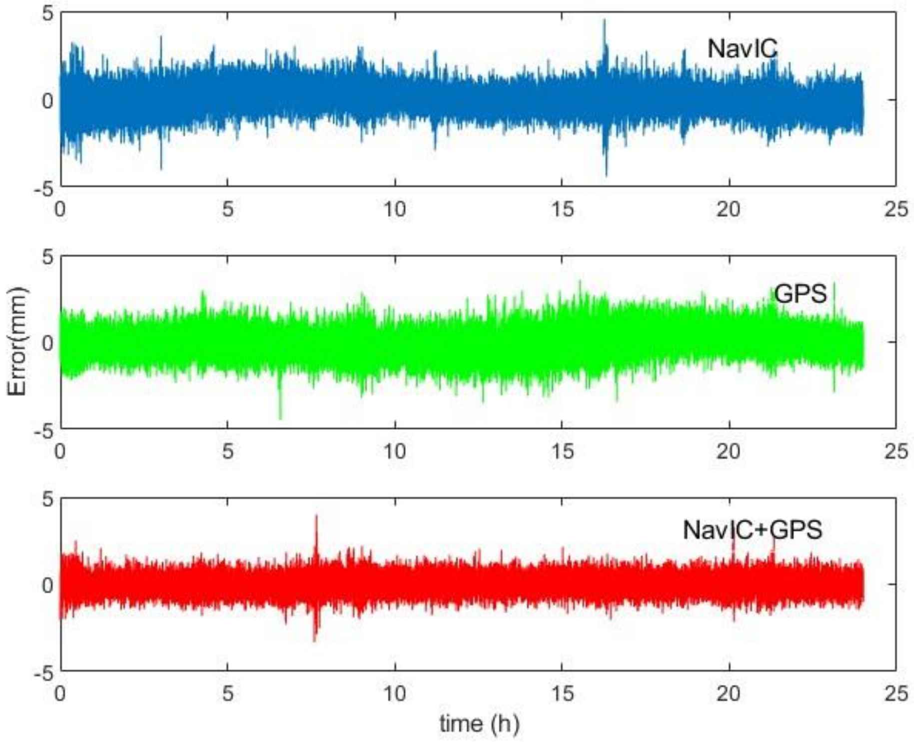


Figure 5. Relative position error variation in the east component for NavIC alone, GPS alone and NavIC+GPS

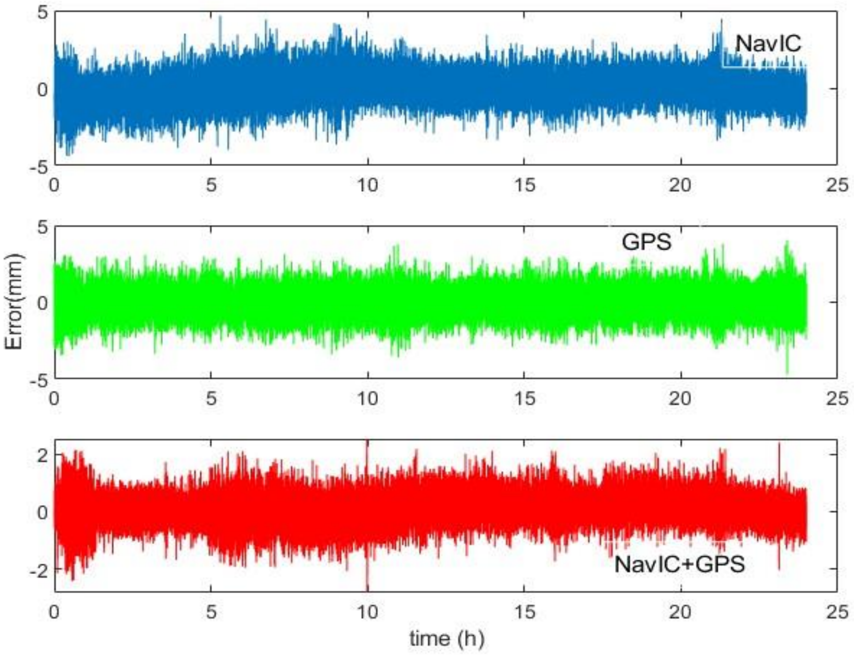


Figure 6. Relative position error variation in the north component for NavIC alone, GPS alone and NavIC+GPS

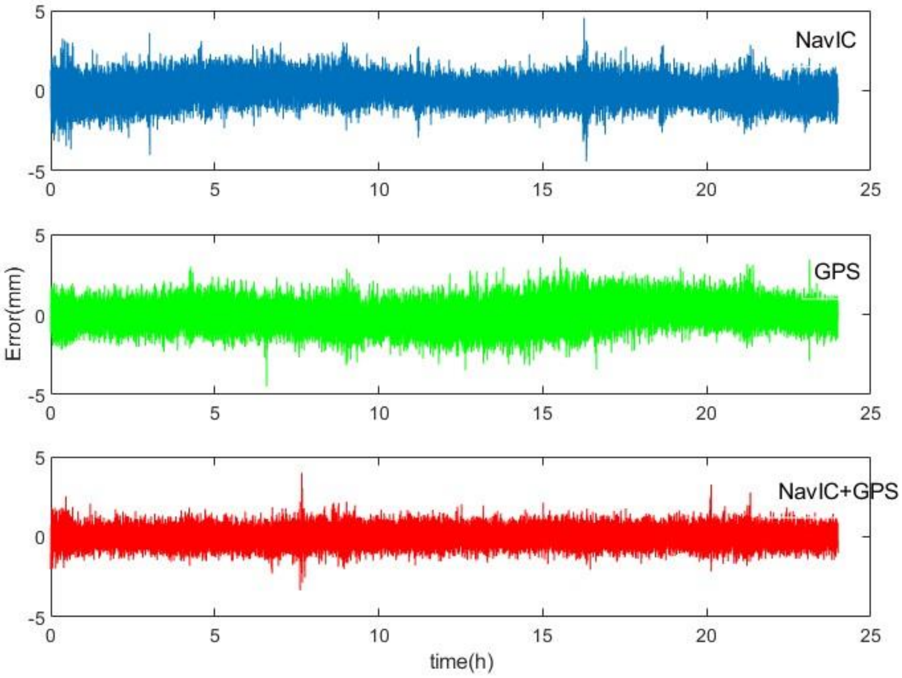


Figure 7. Relative position error variation in the height component for NavIC alone, GPS alone and NavIC+GPS

Positioning with both GPS and NavIC together offers many benefits over utilizing them separately. When GPS and NavIC are used together, it may be possible to increase satellite availability in challenging scenarios when using either technology alone may not be feasible. It is crucial to examine the accuracy of using both GPS and NavIC together for exact positioning, since the relative positioning precision of each technology can differ significantly. The RMS of the double difference relative locations for the whole-time series' three components-GPS-alone, NavIC-alone, and integrated GPS and NavIC position errors is displayed in Table 2. When GPS and NavIC position are combined, the accuracy is higher than when GPS and NavIC position are used separately. Both GPS-alone and NavIC-alone have more inaccuracies in some cases. The distribution of the positioning error time series for GPS-alone, NavIC-alone, and GPS + NavIC integration is analyzed. This is the discrepancy between the actual outcomes in the time series and the truth, which is zero baseline and consequently zero distance.

Table 2: RMS value in the various position components for GPS-alone, NavIC-alone, and GPS+NavIC double difference position errors

S.No.	System	North (mm)	East(mm)	Height(mm)
1	NavIC-alone	1.25	1.01	3.62
2	GPS-alone	0.82	0.64	1.90
3	GPS+NavIC	0.67	0.59	1.67

The findings of zero baseline positioning show that position precision using alone GPS is now superior to NavIC-alone. More redundant observations made during the least square adjustment should yield more precise and dependable positions since more available satellites are being observed at each epoch. It is demonstrated that the precision of the two independent results can be increased by combining GPS and NavIC.

IV. CONCLUSION

In order to evaluate the accuracy of GPS-alone, NavIC-alone, and the combination of GPS and NavIC relative positioning, zero baseline observations were collected. The receivers installed at Osmania University, India are able to track minimum of eight GPS and six NavIC satellites during orbital period of a NavIC, for the elevation cut-off angle of 20^0. Using the same elevation mask of 20^0, the studies monitored a minimum of six NavIC satellites. The findings show that although NavIC relative positioning accuracy can reach centimeter level, it is still inferior to GPS. GPS and NavIC integration have the potential to increase position accuracy using NavIC alone as well as GPS alone.

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