Performance Observation of IRNSS in Terms of Receiver Geometry and Position Accuracy Over Hyderabad Region

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Abstract

The Indian Regional Navigation Satellite System (IRNSS) is a satellite navigation system developed by the Indian Space Research Organization (ISRO), using the frequencies of the L5 and S1 bands. The IRNSS system is independent of GPS. It is used for position, velocity and timing (PVT) services over the Indian region and surrounding coverage area of 1500 km. The positional accuracy of IRNSS system suffers from many sources of errors. To achieve better accuracy, combination of different navigation systems is required. This paper presents the detailed analysis of IRNSS satellite visibility, dilution of precision (DOP) and signal strength under open sky. The effect of satellite geometry on position accuracy and performance of IRNSS is presented. From the results, it is observed that the combined IRNSS/GPS hybrid mode of operation of dual frequency receiver measurements gives better accuracy compare to hybrid mode of operation using single frequency measurements.

Keywords: *DOP, GLONASS, GPS, IRNSS*

1. Introduction

A navigation system developed by ISRO is IRNSS. India will be able to track the NavIC/IRNSS satellites with a precision of 10 meters as it combines three geostationary satellites (GEO) and four geosynchronous satellites (GSO). IRNSS satellites broadcast the signals in carrier frequencies of 1176.45 MHz (F1) and 2492.08 MHz (F2), respectively, in the L5 band (1164.45–1188.45 MHz) and S band (2483.5–2500 MHz) [2]. A system such as the IRNSS has been proposed by the Indian government to provide positioning services for disaster management, navigation services for aircraft landing in CAT-1 cases, and precision surveying over the subcontinent and 1500 km in the surrounding area [1]. In the upcoming years, Internet of Things (IoT) will be an exciting technology that will connect devices together through internet. IRNSS will be fundamental for Indian navigation in the future, which can be integrated with IoT for access anywhere, anytime, and allow data back-ups and mobile assistance to be provided via IRNSS. There are a number of factors that can influence the positioning accuracy of such a system, including the geometry used, receiving the signal takes longer than expected due to the ionosphere and troposphere, multipath, Doppler Effect, clock drift, and receiver noise. Positional inaccuracies/miscalculations may arise as a result of these effects. The majority of these errors are caused by atmospheric refraction, multipath, and refraction due to atmospheric layers can be modelled, and the resulting error, namely “User Equivalent Range Error” (UERE), can be estimated based on algorithms described in the literature.

Due to the interdependence of UERE and satellite reception, positioning accuracy is determined by GNSS satellite-receiver geometry needs to be investigated as a factor in positioning accuracy. Geometric dilution of precision (GDOP) refers to how the satellites are viewed from the perspective of a GNSS receiver with regard to the satellite's spatial location. If the receiver is not able to see all satellites, the optimum-4 satellites can be used to compute the GDOP. To select the most suitable satellites from all the visible satellites at an instant, Jao et al. proposed the use of optimum interpolative networks based on neural networks. Neural

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network-based approaches allow for efficient evaluation of all satellite sets without matrix inversion, thus reducing computational complexity. Without complexity matrix inversion, Mosavi proposed a "genetic algorithm" (GA) to compute GPS GDOP. The study presented by Wu et al. used SVR to approximate GPS GDOP. This method was compared with Artificial Neural Networks and genetic programming as regression methods. In a two-dimensional environment, Sharp et al. analyzed GDOP in order to determine accuracy for target tracking, which is very relevant to sports applications both indoors and outdoors [1]. In an effort to predict GDOP at a point in time, Lohani and Kumar used LiDAR data to forecast the GDOP in the presence of trees. GDOP was examined for different configurations by Srilatha Indira Dutt et al., the entire view is used instead of the optimal four satellites, which simplifies the selection process. In this paper we analyze data due to the IRNSS and GPS constellations. With the help of the IRNSS and GPS constellations, the satellite–receiver geometry is explored here to obtain a more accurate GDOP, with which the accuracy of positioning can be improved. It has been found that the GPS and IRNSS constellations with their combined satellite-receiver geometry give the best GDOP. For a typical day of 22nd January 2022, the data is obtained from IGS dual frequency receiver and Navlan IG3 single frequency receiver which are placed at AGRL, Department of ECE, UCE, OU station, Hyderabad, (Latitude/Longitude:17.4078^0 N/78.5178^{0}E) was used for the proposed study.

2. Geometric Dilution of Precision (GDOP)

Any navigation system's ability to estimate position accurately is measured by its accuracy of position estimation. As the signal propagates from satellite to receiver, many factors, including refraction in the atmosphere, multipath errors, satellite clock errors, and satellite geometry, influence the accuracy of the positioning solution. By measuring geometric dilution of precision (GDOP), we can determine the impact of satellite-receiver geometry on measurement error and positioning error. GDOP is a GPS Precision quality that measures the multiplicative effect of satellite-receiver geometry on positioning error and measurement error. The GDOP can be computed by considering pseudorange equations of all the satellites in view or the best and/or most reliable satellites of all the satellites visible. A pseudorange measurement of all visible satellites is used to compute the GDOP instead of selecting the four best satellites, which is very complicated and time consuming. Linearize with receiver position the pseudorange equations for n >= 4 satellites. The pseudorange equations for n number of satellites is shown in Equation 1 [1].

$$\begin{bmatrix}\Delta_{prn1}\\ \Delta_{prn2}\\ \Delta_{prn3}\\ \cdot\\ \cdot\\ \cdot\\ \Delta_{prnn}\end{bmatrix}=\begin{bmatrix}g_{11} & g_{12} & g_{13} & 1\\ g_{21} & g_{22} & g_{23} & 1\\ g_{31} & g_{32} & g_{33} & 1\\ & \cdot & & \\ & \cdot & & \\ & \cdot & & \\ g_{n1} & g_{n2} & g_{n3} & 1\end{bmatrix}\begin{bmatrix}\Delta_{UX}\\ \Delta_{UY}\\ \Delta_{UZ}\\ C\Delta_b\end{bmatrix}+\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \cdot\\ \cdot\\ \cdot\\ \varepsilon_n\end{bmatrix} \quad \text{.....(1)}$$

The general form of equation 1 is $P_r = G * U + \varepsilon$, where G is the n x 4 geometry matrix, an indicator of the satellite's direction cosine, U is the user position, in addition to measurement noise, ε accounts for unmodeled effects, such as selection and multipath. Equation 1 can be written in linear least squares approximation as shown in equation 2 [1].

$$\Delta U = (G^T G)^{-1} G^T \Delta P_r \quad \text{.....(2)}$$

GDOP is calculated using equation 3[1].

$$\text{GDOP} = \sqrt{Trace(G^T G)^{-1}} \quad \text{.....(3)}$$

GPS positioning accuracy is often measured by GDOP, which is a multiplication of the measurement error of the system. The accuracy is given by

Accuracy of position = UERE * GDOP …..(4)

The UERE provides the root sum square of a variety of errors and biases. The accepted range of DOP values is shown in table 1.

Table 1: Range of DOP [1]

Range of DOP Value	Rating
1	Ideal
2-4	Excellent
4-6	Good
6-8	Moderate
8-20	Fair
20-50	Poor

2.1 IRNSS VISIBILITY OVER THE SERVICE REGION

Any GNSS system is considered to be available as long as the signal can be received in a specific region, and the number of satellites visible from any point therein can be measured. Simulation of the NavIC satellite visibility patterns is used to generate the service region's visibility patterns for 5^0 elevation masks over a day using the method discussed earlier. There are always at least 5 NavIC satellites visible over the whole landmass of India, except for a small area in the extreme north. Satellites broadcast signals continuously. There is no difference in the strength of satellite broadcast signals. Due to path loss from free-space and interference in the transmission path, the user receives discontinuous and varying-quality signals from satellites. A GNSS satellite transmitting to a receiver will encounter a different environment depending on the user's location. The distance and the interference along this path will vary as well. Due to autocorrelation function errors in the code tracking loop, ranging error increases when received signal power is significantly below specified levels. Integer ambiguity is a problem with carrier-phase measurements, and pseudorange measurements are more precise. Centimetre-level positioning can be attained by resolving the integer ambiguity [1]. Sometimes, however, GNSS receivers are not able to generate carrier-phase measurements because a GPS signal has been temporarily blocked from latching onto the carrier. The satellite signal can be interfered with by radio interference, Ionospheric disturbances, or obstructions such as buildings and trees. Signal lock loss has been associated with high receiver dynamics. Receiver lock on satellite signals must be periodically recalculated if the receiver loses its connection to the satellite [2]. The carrier-phase measurement will be discontinuous or jumpy if the integer ambiguity changes for a satellite. Loss of satellite signals is indicated by a cycle slip in GNSS receivers. In order to calculate the new ambiguity value, receivers should allocate extra time. This results in decreased availability. In order to provide precise positioning, it can be helpful to analyse the satellite signal continuity for a given user. This study investigates the sensitivity to IRNSS and GPS signals. The following table compares IRNSS and GPS signal strength and continuity. Signal strength and quality are determined by the carrier-to-noise ratio (C/N_0). In the front-end of a receiver, the C/N_0 output indicates satellite tracking status and quality, as well as whether there is any noise.

3. METHODOLOGY

Analyzing real-time L5 and S-Band data allows us to study the quality of NavIC solutions. GNSS/NavIC users would find the latter to be of interest due to its capability to provide

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positional information. In the central NavIC service area, the quality of NavIC position solutions is evaluated in single and dual frequency operation in L5+S and GPS L1bands. An L5+S of IRNSS and GPSL1 band antenna of IGS dual frequency receiver is mounted on the roof top AGRL, Department of ECE, University College of Engineering, Osmania University. L5 of IRNSS, L1 of GPS and L1 of GLONASS, Navlan IG3 single frequency receiver, antenna is also placed on the same roof top. The 24 hours data is recorded from both the receivers. Based on the geodetic coordinate system position solutions are transformed into an East-North-Up (ENU) coordinate system. Next, the precision parameters for the solutions, namely 2DRMS, CEP, SEP, and MRSE are computed with the formulae given below using the RMS of East error (σ_x), RMS of North error (σ_y), and the RMS of Up error (σ_z) [3].

$$2DRMS = 2\sqrt{\sigma_x^2 + \sigma_y^2} \quad \text{.....(5)}$$

$$CEP = 0.62\sigma_x + 0.56\,\sigma_y;\ \text{for}\ \frac{\sigma_x}{\sigma_y} > 0.3 \quad \text{.....(6)}$$

$$SEP = 0.51(\sigma_x + \sigma_y + \sigma_z) \quad \text{.....(7)}$$

$$MRSE = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2} \quad \text{.....(8)}$$

4. RESULTS AND DISCUSSION

DOP values are estimated using two different types of receivers (single and dual frequency) using all available satellites of GPS, GLONASS and IRNSS (single frequency receiver) and GPS+IRNSS (dual frequency receiver). Figure (1-2) show the computed DOP values due to single frequency receiver and dual frequency receiver for a typical day of 22nd January, 2022.

The PDOP of obtained data from single and dual frequency receivers are shown in table 2 and table 3, it is observed that the maximum PDOP value of single frequency multi-constellation (GPS+GLONASS+IRNSS) receiver is 1.60 and the minimum PDOP is 1. Whereas for IGS dual frequency (GPS+IRNSS) receiver it is 2.623 and 1.184 respectively. The variation in PDOP value of both the receivers due to number of satellites in view are more for single frequency receiver. The maximum GDOP due to dual frequency receiver data is 3.346 and minimum value is 1.3.

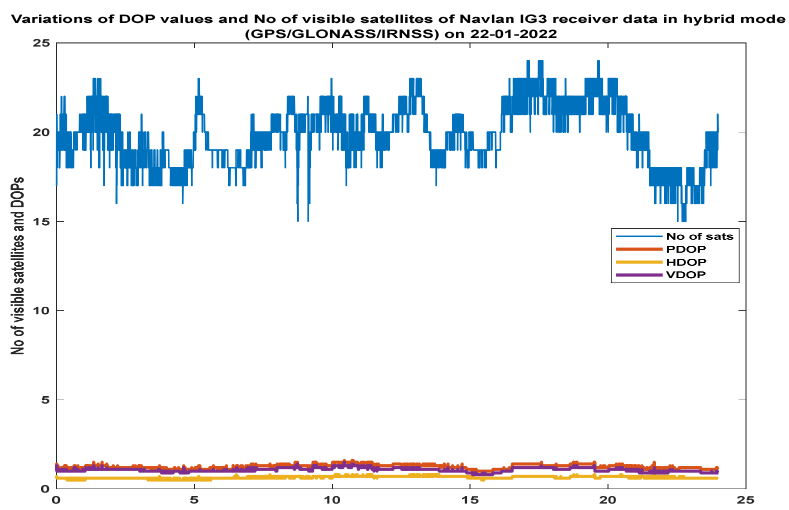

Figure 1: Number of visible satellites and DOP values of Navlan IG3 single frequency multi-constellation (GPS+GLONASS+IRNSS) receiver on 22-01-2022

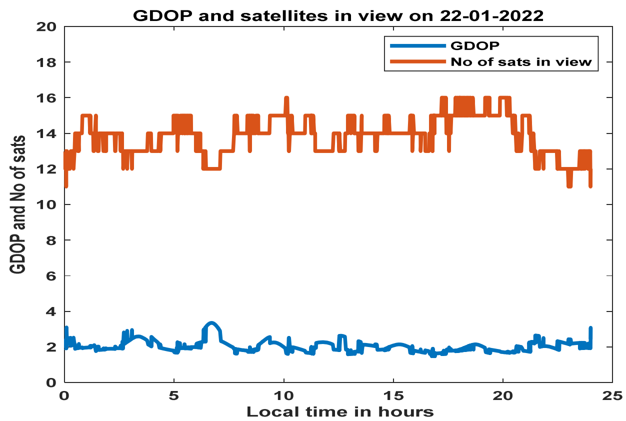

Figure 2: GDOP computed using GPS+IRNSS hybrid mode using dual frequency receiver

Figure 3 shows the C/N_0 variations of IRNSS L5 signal on 22-01-2022. The IRNSS signal strength is more than 45 dB-Hz for all the PRNs. The maximum and minimum values of signal strength is shown in table 4.

Table 2: Precision parameters of single frequency receiver in hybrid mode (GPS+GLONASS+IRNSS) on 22-01-2022

S. No	Minimum PDOP	Maximum PDOP	Mean PDOP
1	1.00	1.60	1.2328

Table 3: Precision parameters of dual frequency receiver in hybrid mode (GPS+IRNSS) on 22-01-2022

S. No	Minimum		Maximum		Mean	
	GDOP	PDOP	GDOP	PDOP	GDOP	PDOP
1	1.3	1.1848	3.346	2.6239	2.0297	1.6315

Table 4: C/N_0 variations of IRNSS using single frequency receiver data on 22-01-2022

	Max. C/N_0 in dB-Hz					Min. C/N_0 in dB-Hz				
PRN No.	97	98	99	101	105	97	98	99	101	105
C/N_0	47	52	51	45	48	32	34	41	29	33

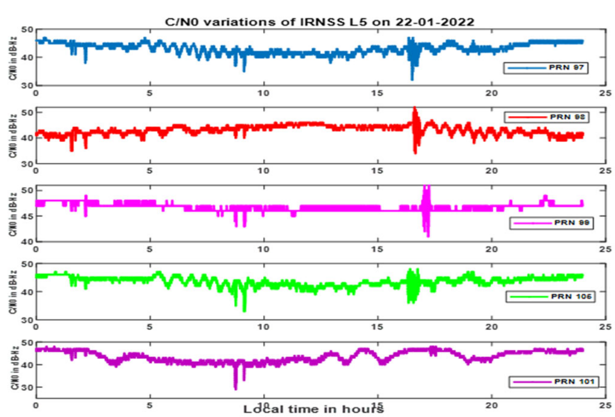

Figure 3: C/N0 variations of all IRNSS PRNs using single frequency receiver data on 22-01-2022

The maximum and minimum C/N_0 values for GLONASS system is noted in table 5 using single frequency receiver. The maximum and minimum C/N_0 values of IRNSS and GPS systems using dual frequency receiver are shown in table 6 and 7 respectively.

Table 5: Variations in C/N_0 of GLONASS using single frequency receiver data on 22-01-2022

	GLONASS PRN Number											
	65	**66**	**67**	**68**	**68**	**70**	**71**	**72**	**75**	**76**	**77**	**78**
Max. C/N0 (dB-Hz)	48	48	46	43	47	50	50	50	46	44	47	44
Min. C/N0 (dB-Hz)	40	28	29	22	37	31	33	35	38	9	40	28

Table 6: Variations in C/N_0 of IRNSS L5 and S BAND using dual frequency receiver on 22-01-2022

	IRNSS L5 band									
	Max. C/N_0					**Min. C/N_0**				
PRN No.	**2**	**3**	**4**	**6**	**9**	**2**	**3**	**4**	**6**	**9**
C/N0 in dB-Hz	53	53	50	50	52	32	43	40	33	40
	IRNSS L5 band									
	Max. C/N_0					**Min. C/N_0**				
PRN No.	**2**	**3**	**4**	**6**	**9**	**2**	**3**	**4**	**6**	**9**
C/N0 in dB-Hz	46	46	43	43	47	36	37	36	36	36

Table 7: Variations in C/N0 of GPS L1 band using dual frequency receiver on 22-01-2022

	GPS C/N_0 (dB-Hz)							
PRN No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**10**
Max.	49	50	51	49	48	51	48	48
Min.	22	21	20	21	20	19	20	23

From table 8, the position accuracy of IRNSS is measured in terms of 2DRMS, CEP, SEP and MRSE. In case of single frequency (SF) receiver placed at AGRL, Department of ECE, UCE, OU station, the position accuracy is 5.3423 m (2DRMS), 2.0459 m (CEP), 2.4371 m (SEP) and 2.9464 m (MRSE). Where for the dual frequency receiver the accuracy is 2.666 m (2DRMS), 1.0483 m (CEP), 1.3096 m (SEP) and 1.5362 m (MRSE) are noted. Therefore, the positioning accuracy of SF receiver on 22nd January, 2022 deviated by 50% in 2DRMS, 49% in CEP, 46% in SEP and 48% in MRSE. In this study it is observed that the DF receiver measurements in hybrid mode gives better accuracy compared to SF receiver in hybrid mode. Inspite of inclusion of one more Global constellation in the SF receiver, the performance of DF receiver is much better in the order of above said percentage, when compared to SF receiver, in terms of GDOP and position accuracy

Table 8: Positional accuracy of SF and DF measurements on 22-01-2022

S. No.	Receiver type	CEP (m)	SEP (m)	2DRMS (m)	MRSE (m)
1	**SF receiver**	2.0459	2.4371	5.3423	2.9464
2	**DF receiver**	1.0483	1.3096	2.666	1.5362

5. CONCLUSION

In this paper, performance of IRNSS system is studied in terms of signal strength, DOP, east, north and up errors and positional accuracy using SF receiver and DF receiver over the low latitude Hyderabad station. Initially, the precision parameters of SF receiver is measured and compared with precision parameters of DF receiver. It is observed that the GDOP is better for DF receiver in hybrid mode. Secondly, the position accuracy is measured in terms of 2DRMS, CEP and SEP. 2DRMS is improved by 50%, CEP is improved by 49% and SEP is improved by 46% due to the DF receiver hybrid mode. In terms of root mean square error (MRSE), the error is improved by 48% compare to SF receiver in hybrid mode. So that, by the results, this paper concludes that the DF receiver in hybrid mode gives the better accuracy. Inspite of inclusion of one more Global constellation in the SF receiver, the performance of DF receiver is much better in the order of above said percentage, when compared to SF receiver, in terms of GDOP and position accuracy.

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