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Evaluation of Best Satellite-Receiver Geometry for Improved IRNSS/GPS Position Accuracy

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Abstract— A GPS-IRNSS combined navigation system is emerging in India. It is possible to increase the accuracy of the receiver or user's position at any time and under any weather conditions with a combined system. It is possible to use these navigation systems for finding the precise location of receivers in civil aviation, precision applications such as surveying, disaster management, and other applications. Usually, satellite navigation systems are based on a geometric relationship between satellite and receiver, with errors caused by atmospheric conditions, multipath, and other factors affecting accuracy. Geometry of satellite receivers is measured by the Dilution of Precision (DOP), a unit less quantity. This paper investigates the possibility possible to obtain better accuracy by combining GPS and IRNSS constellations. This improved accuracy is typically useful for precision applications such as surveying and disaster management.

Keywords- GPS, IRNSS, GNSS, DOP, UERE.

I. INTRODUCTION

A navigation system developed by ISRO is Indian Regional Navigation Satellite System (IRNSS). India will be able to track the IRNSS satellites with a precision of 10 meters as it combines three geostationary satellites (GEO) and four geosynchronous satellites (GSO). NavIC/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]. To provide positioning services for disaster management, navigation services for aircraft landing in CAT-1 cases, the Indian government proposal calls for precision surveying of 1500 km of landmass and the surrounding region [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. Positioning accuracy of such a system is influenced by a number of factors. Several factors contribute to the delay in signal reception, including the ionosphere and troposphere, geometries used, multipath effects, 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, algorithms described in the literature can be used to estimate User Equivalent Range Error (UERE). 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. 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 a set of all visible satellites at a given instant, Jao et al. proposed an optimal interpolative network based on neural networks. Neural 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 [1]. This method was compared with ANNs and Genetic Algorithm (GA) as regression methods. In a two-dimensional environment, Sharp et al. [1] analysed GDOP in order to estimate the accuracy of position for target tracking, which is very relevant to sports applications both indoors and outdoors. Using LiDAR data, Lohani and Kumar forecasted GDOP where trees were present. Srilatha Indira Dutt et al. analysed GDOP for different configurations, using the entire view rather than the optimal four satellites. In this paper we analysed data due to the IRNSS and GPS constellations. With the help of the IRNSS and GPS combined constellations, the satellite–receiver geometry is explored here to obtain a more accurate GDOP, which improves positioning accuracy. For a typical day of 19th September 2021, the test data is obtained

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from IGS dual frequency receiver which is installed in Advanced GNSS Research Laboratory (AGRL), Department of ECE, UCE, OU, Hyderabad (Latitude/Longitude:17.4078^0 N/78.5178^{0}E) used for the proposed study.

II. METHODOLOGY

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. Measurement error and positioning error can both be calculated by measuring GDOP. An accurate measurement of GDOP measures the multiplicative effect of receiver geometry on measurement and positioning errors. If the pseudorange equations of all satellites visible are considered, the GDOP can be calculated based on the most reliable satellites in view. Instead of selecting the four most suitable satellites, GDOP is computed based on pseudorange measurements of all visible satellites. which is very complicated and time consuming. Linearizing the pseudorange equations with the receiver position for n >= 4, the pseudorange equation for 'n' number of satellites is shown in (1) [1].

$$\begin{bmatrix} \Delta_{prn1} \\ \Delta_{prn2} \\ \Delta_{prn3} \\ \vdots \\ \Delta_{prnn} \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} & G_{13} & 1 \\ G_{21} & G_{22} & G_{23} & 1 \\ G_{31} & G_{32} & G_{33} & 1 \\ & \cdot & & \\ & \cdot & & \\ G_{n1} & G_{n2} & G_{n3} & 1 \end{bmatrix} \begin{bmatrix} \Delta_{u_x} \\ \Delta_{u_y} \\ \Delta_{u_z} \\ c\Delta_b \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \cdot \\ \cdot \\ \varepsilon_n \end{bmatrix} \quad (1)$$

The general form of equation 1 is $P_r = G*U+\varepsilon$, where G is the nx4 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 (2) [1].

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

GDOP is given by:

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

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

$$Accuracy\ of\ position = UERE \times GDOP \quad (4)$$

The UERE provides the root sum square of a variety of errors and biases. Table I summarizes the accepted range of DOP values. IRNSS accuracy can be measured by a wide range of metrics. These most widely used IRNSS metrics include: CEP, stands for circular error probability, DRMS stands for distance root mean square error and sigma level error. The 'm' value defines the elliptical contour that lies within the "sigma level error". Sigma level error is given by $1\text{-}e^{\frac{-m^2}{2}}$. One-sigma (1-σ) determines the probability that the position is within the 1σ ellipse when m = 1 [1]. Equation (4) can be used to estimate the GNSS positioning accuracy at (1-σ) level. Equation (4), which states that the accuracy is better for lower GDOP, can be used to estimate the UERE using appropriate algorithms.

III. RESULTS AND DISCUSSION

For a typical day of 19th September 2021, processed data was recorded from a IGS dual frequency receiver. Based on the all-in-view method, the GDOP is computed by combining the ranging information from all visible satellites using two modes.

1. IRNSS satellites only
2. GPS + IRNSS satellites

TABLE I. RANGE OF DOP VALUE [1]

Range of DOP Value	Rating
1	Idyllic
2 to 4	Brilliant
4 to 6	Upright
6 to 8	Modest
8 to 20	Reasonable
20 to 50	Deprived

A. *GDOP Due to Only IRNSS Satellites*

By using only IRNSS satellites, the GDOP for 19th September 2021 at Hyderabad station is calculated for the whole day. GDOP computed using IRNSS satellites only over the entire day is shown in Fig. 1. Maximum GDOP observed at 00:15:30 h of the day is 8.104. Minimum GDOP observed at 18:00:00 h of the day is 5.191.

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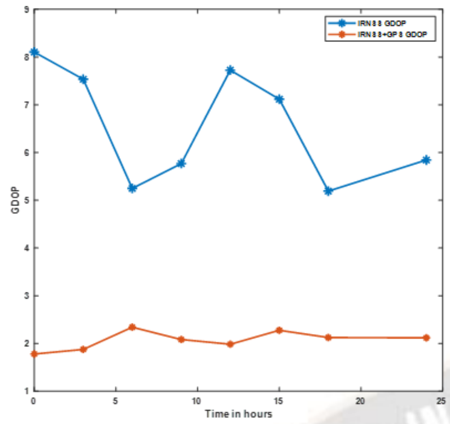

Figure 1. Variations in GDOP due to two different modes of operation.

B. GDOP due to IRNSS and GPS Combined Satellites

A variation of IRNSS satellite availability is combined with all visible GPS satellites to compute GDOP. GDOP computation takes into account different combinations of GPS satellites and IRNSS satellites as well. GDOP is due to both the IRNSS and GPS-IRNSS combined constellation is shown in fig. 1. Fig. 2 shows the bar graph of mean values GDOP of IRNSS only and IRNSS+GPS satellites.

From the IGS receiver data, the GDOP varies as satellite elevation angles change over time. As a result of this variation in the satellite-receiver geometry, positioning accuracy varies with time. Geometry between satellite and receiver is best when the GDOP is lowest, while poor geometry is indicated by a high GDOP. The values calculated for GPS and IRNSS satellite combinations are shown below in table II. The minimum GDOP value calculated using IRNSS only satellite is 5.191 and the maximum GDOP is 8.104 observed on the day. The computed GDOP values using IRNSS and GPS combined constellation, minimum is 1.473 and maximum is 3.911.

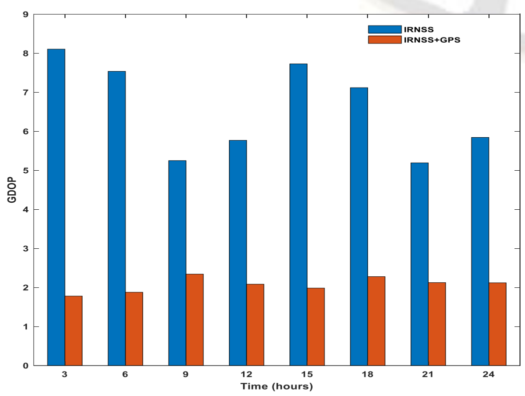

Figure 2. Mean values of GDOP.

From the above discussion, it is clear that the GDOP calculated with IRNSS and GPS combined constellation is least minimum (1.473) compared to IRNSS only satellites. In summary, GPS and IRNSS combined constellations have the potential to improve positioning accuracy.

TABLE II. STATISTICS OF GDOP

GDOP	IRNSS only	IRNSS+GPS
Minimum	5.191	1.473
Maximum	8.104	3.911
Standard deviation	1.811	0.369
Mean	6.463	2.077

Due to their geostationary and geosynchronous orbits, IRNSS satellites propagate in a different way than GPS satellites orbiting in MEO orbits. The propagation errors due to IRNSS satellite signals need to be modeled and mitigated using different techniques. The radiation pattern of the receiver antenna can be appropriately shaped in order to reduce multipath effects.

IV. CONCLUSION

The objective of the paper is to examine the GDOP for both the standalone IRNSS constellation and the combination of GPS and IRNSS constellations over the Hyderabad region. In a combined constellation of IRNSS and GPS, the mean value of GDOP is 1.473, a reduction from 6.463 due to the standalone IRNSS satellite constellation. Due to the combined constellation of IRNSS and GPS, the GDOP value is significantly reduced, which leads to a significant improvement in position accuracy. GPS and IRNSS combined constellations can improve positioning accuracy because GDOP is directly related to positioning accuracy.

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