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Improving the Position Accuracy of Rover Receiver using Differential Positioning in Indian Regional Navigation Satellite System

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A B S T R A C T

Navigation with Indian Constellation (NavIC) is the Indian Regional Navigation Satellite System (IRNSS) developed by Indian Space Research Organization (ISRO) to provide the position and navigation services for Indian region. NavIC or IRNSS is individual satellite constellation which has seven satellites covering the Indian subcontinent. Accuracy of NavIC standalone is insufficient in certain applications such as civil aviation. To improve the position accuracy performance of NavIC system, differential positioning technique is utilized. In this paper, differential positioning is carried out, considering two IGS (IRNSS-GPS-SBAS) receivers (one as reference station and the other as rover), which are capable of receiving IRNSS signals from 7 satellites, GPS signals from 12 satellites, SBAS signals from 2 satellites. Here, NavIC constellation alone is considered for the analysis. The differential positioning is carried out using the pseudorange measurements on L5 (1176.45 MHz), S1 (2492.028 MHz) and dual (L5 and S1 both) and accuracies are compared in terms of the statistical parameters Circular Error Probability (CEP), Distance Root Mean Square (DRMS), 2DRMS (twice the DRMS). The improvement in the horizontal accuracy (2DRMS) of the rover using pseudorange measurements on L5 is observed to be 78.81%, on S1 it is 69.14 % and using dual frequency (L5 and S1 both) it is 80.73% when compared to NavIC standalone.

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NOMENCLATURE

t_s	Time at which the signal departed from the satellite	t_r	Time at which the signal is received at the receiver
c	Speed of light	ρ	Pseudorange
r	Geometric range	$\Delta\rho$	pseudorange error,
δt_r	Receiver clock error	δt_s	Satellite clock error
I	Ionospheric delay	T	Tropospheric delay
ε	Other errors like receiver noise, multipath and antenna delay	(x_s, y_s, z_s)	Satellite position
(x_r, y_r, z_r)	Receiver position	$\hat{\rho}_r$	corrected pseudorange
σ_x, σ_y	Standard deviations of east and north components of the user position error		

1. INTRODUCTION

Standalone accuracy of NavIC system is insufficient in certain applications such as civil aviation. To improve the accuracy one of the methods is to accurately estimate the NavIC errors such as ionospheric error (as it is the most dominating error in satellite navigation applications) using appropriate models [1, 2]. This method may not provide sufficient accuracy in case of standalone receivers [3]. Differential positioning is the technique used to provide better accuracy for certain applications when compared to standalone accuracy of NavIC system [4]. A typical Differential IRNSS architecture is shown in Figure 1. Differential IRNSS consists of a reference receiver which is located at a well surveyed location. This system also consists of one or more rover receivers. The reference receiver and differential correction processing equipment together are called the reference station [5]. Satellite range measurement is affected by different errors. Some of them are slowly varying error

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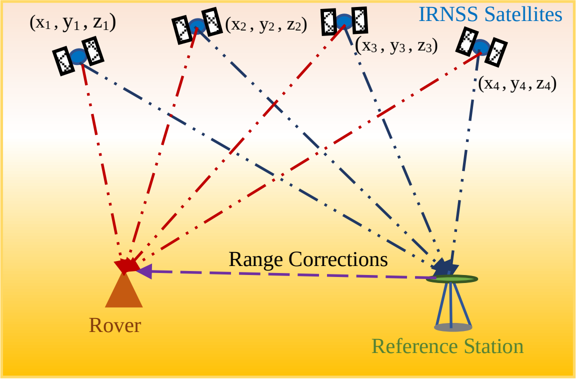

Figure 1. Differential IRNSS Architecture

components which are estimated by reference station [6]. Reference station also computes the range corrections for each IRNSS satellite in view. These corrections are called differential corrections. Differential corrections are transmitted to the rover receivers. The differential corrections are estimated by taking the difference between the pseudorange measurement and true range [7]. When both the receivers are nearby (within the vicinity of the reference station), they are affected by the errors which are common to both the receivers. These common errors can be eliminated completely or reduced by transmitting the differential corrections from the reference station to the rover receiver [8-10]. The ephemeris error and satellite clock error can be eliminated completely. The atmospheric errors such as ionospheric error and tropospheric error can be reduced [11, 12]. There will not be any change in the errors such as multipath error and receiver noise. Using these corrections, the rover accuracy is much improved. The improved accuracy is attained when the same set of satellites which are visible at the reference receiver are also visible at the rover receiver [4, 13].

2 CALCULATION OF PSEUDORANGE CORRECTIONS

The raw pseudorange can be measured by multiplying the speed of light c with the signal propagation time.

$$\rho = (t_r - t_s) * c \tag{1}$$

where t_s is the time at which the signal departed from the satellite and t_r is the time at which the signal is received at the receiver [14, 15].

The pseudorange measurement is affected by different errors such as ionospheric delay, tropospheric delay, satellite ephemeris error, receiver clock error and multipath.

The pseudorange measurement at the receiver can be represented as follows:

$$\rho = r + \Delta\rho = r + c * (\delta t_r - \delta t_s) + I + T + \varepsilon \tag{2}$$

where r is the geometric range, $\Delta\rho$ is the pseudorange error, δtr, δts are the receiver clock error and the satellite clock error respectively, I is the ionospheric delay, T is the tropospheric delay, ε the other errors like receiver noise, multipath and antenna delay [16, 17].

The geometric range r, can also be expressed by the following equation:

$$r = ((x_s - x_r)^2 + ((y_s - y_r)^2 + ((z_s - z_r)^2)^{0.5} \tag{3}$$

where (x_s, y_s, z_s) is the satellite position and (x_r, y_r, z_r) is the receiver position [18].

At the reference station the pseudorange corrections are computed as follows:

$$\Delta\rho = \rho - r \tag{4}$$

The corrected pseudoranges $\hat{\rho}_r$ at the rover for each epoch of observation is written as follows:

$$\hat{\rho}_r = \rho_r + \Delta\rho \tag{5}$$

If same set of satellites are visible at both the receivers, then the satellite clock error is identical and can be completely eliminated. The errors δI, δT, $\delta\varepsilon$ are negligible when the distance between the reference station and the mobile receiver is small [4, 18].

For the estimation of rover position at the mobile receiver these corrected pseudoranges are applied. This leads to the improvement in the mobile user position.

NavIC receivers here are dual frequency receivers. The frequencies used are L5 (1176.45 MHz) and S1 (2492.028 MHz). The pseudoranges on L5 and S1 are used for computing differential corrections and compare the positional accuracies.

3 ACCURACY MEASURES IN 2D

When the IRNSS data logged over the time, the measured positions are disseminated over an area because of the measurement error. These distributed points are called scatter plot, which is used to characterize accuracy of IRNSS receiver. The area within which the estimated parameters are likely to be is the confidence region [9, 10, 19]. The performance of IRNSS is statistically quantified by analyzing the confidence region. The probability with which the solution will be within the specified accuracy is described with the confidence region with certain radius [20].

3. 1. Distance Root Mean Square (DRMS)

DRMS is a number which signifies 2D accuracy of the NavIC receiver. To calculate the DRMS of horizontal position accuracy, the standard errors (σ) from the known position in the directions of the coordinate axis are required. DRMS refers to the radius of a circle in which 65% of the values occur [19, 21].

DRMS can be expressed as follows:

$$DRMS = \sqrt{\sigma_x^2 + \sigma_y^2} \quad (6)$$

where σ_x and σ_y are the standard deviations of east and north components of the user position error.

3. 2. Circular Error Probability (CEP) CEP is defined to be the radius of circle with center as the true position, containing the position estimate with probability of 50% [19].

CEP can be expressed as follows:

$$CEP = 0.62\sigma_x + 0.56\sigma_y \quad (7)$$

2DRMS is twice the DRMS of the horizontal position errors [20].

4 RESULTS AND DISCUSSION

Differential IRNSS consists two receivers, a reference station and a rover receiver. The two IGS (IRNSS-GPS-SBAS) receivers are considered (one receiver as a reference station and the other as a rover receiver) which are located at Advanced GNSS Research Laboratory (AGRL), Department of Electronics and Communication Engineering, University College of Engineering (UCE), Osmania University (OU), Hyderabad. These receivers are capable of receiving IRNSS signals from 7 satellites, GPS signals from 12 satellites, SBAS signals from 2 satellites. The two receivers' antennas are separated with a distance of 1.4 m. All the data from the receivers are obtained by considering the receivers to be static. The data obtained from both receivers are of the same date and time (i.e. on 15 September 2019 for 24 hours duration).

The receivers' proprietary data is converted to the Receiver Independent Exchange (RINEX) and Comma-Separated Values (CSV) formats. The reference receiver is set at a well surveyed location (the coordinates are 17.407°, 78.517°, 450 m). To get the reference receiver coordinates (surveyed location), the user coordinates in *(x, y, z)* are estimated for the duration of a week and averaged. These coordinates are then converted to latitude, longitude and height, which are used as reference station coordinates for computation of differential corrections.

4. 1. Differential IRNSS Corrections Differential IRNSS corrections are computed at reference station using the Equation (4) by taking the difference between the pseudoranges (obtained from IGS Receiver) and the true range. True range is computed using the Equation (3). The corrections are computed for satellites with PRN 2, 3, 4, 5, 6 ,7 (i.e. 6 satellites) with respect to time, individually. These corrections are applied at the rover station to improve the accuracy of the receiver.

The position accuracy using differential IRNSS is analyzed by considering the psuedoranges on L5, S1 and dual frequency (L5 and S1).

4. 2. Differential IRNSS Considering the Pseudoranges on L5 The pseudoranges on L5 are utilized for improving the horizontal accuracy of the rover. The pseudoranges on L5 are obtained from IGS receivers in CSV file format.

4. 2. 1. Position of Rover before and after Applying Corrections The position of rover receiver in Latitude, Longitude and Height (LLH) before applying corrections and after applying corrections is plotted as shown in Figure 2. Latitude, Longitude and Height are plotted here for the duration of 24 hours.

4. 2. 2. Rover Accuracy without Applying Corrections Accuracy of standalone IRNSS (using pseudoranges on L5) is plotted by considering east error on x-axis and north error on y-axis in meters. An East-North-Up (ENU) system is used to represent the IRNSS accuracy in terms of east error and north error in meters. The east error and north error are considered to represent the horizontal position error. The data considered is of 24 hrs duration. Accuracy is plotted with the horizontal accuracy parameters CEP, DRMS, 2DRMS. Figure 3 describes the horizontal accuracy plot with CEP, DRMS and 2DRMS values.

For standalone IRNSS, the CEP value is observed to be 5.31 m, which contain the position estimates with probability of 50%. The DRMS value observed is 7.36 m, which is radius of circle with the position estimates with the probability of 65%. The 2DRMS is twice the DRMS value and is observed to be 14.72 m, which is

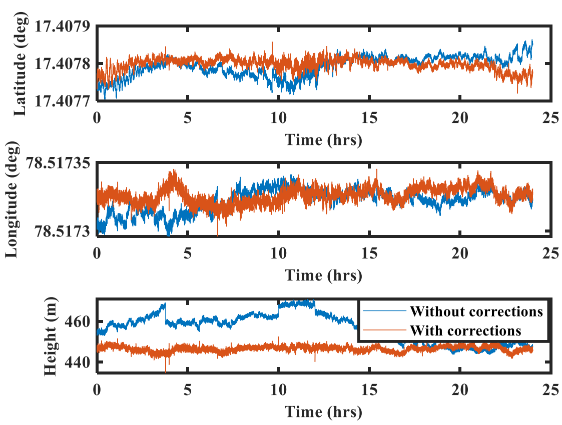

Figure 2. Rover position (LLH) (on L5) before and after applying corrections

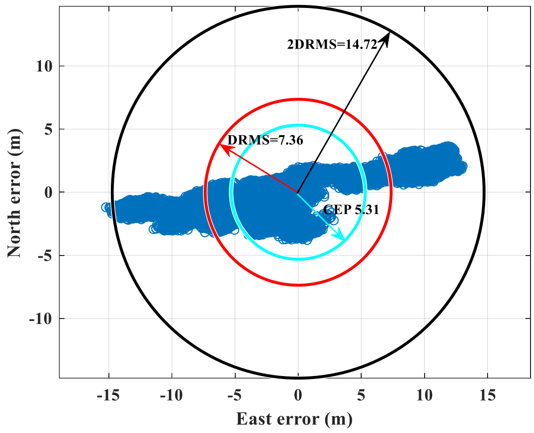

Figure 3. Rover receiver radial error CEP, DRMS and 2DRMS estimated over 24 hours before corrections (on L5)

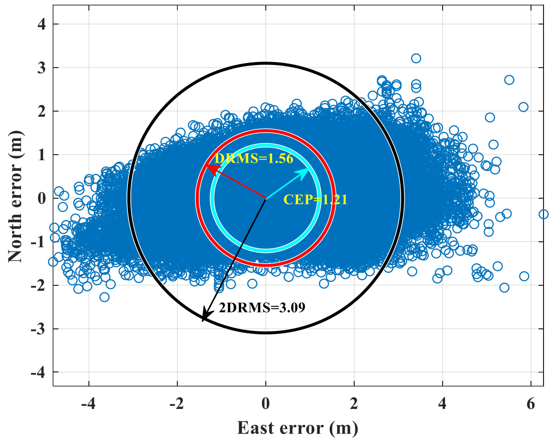

Figure 4. Rover receiver radial error CEP, DRMS and 2DRMS estimated over 24 hours with corrections (on L5)

radius of circle with the position estimates with a probability of 95%.

4. 2. 3. Rover Accuracy after Applying Corrections

Accuracy of IRNSS (using pseudoranges on L5) with corrections is plotted (Figure 4) by considering east error on x-axis and north error on y-axis in meters. When the corrections applied to rover, the 50% of the position fix errors which does not exceed respective CEP value. The radius of the confidence region 1.21 m matches the accuracy of receiver's position fix in horizontal plane with 50 % probability of estimation. The DRMS value observed is 1.56 m, which is radius of circle with the position estimates with the probability of 65%. The 2DRMS is twice the DRMS value and is observed to be 3.09 m, which is radius of circle with the position estimates with a probability of 95%.

Table 1 gives the comparison of standalone IRNSS and Differential IRNSS positional accuracies. The accuracy parameters are CEP, DRMS and 2DRMS. It is observed that there is an improvement in the accuracy when differential positioning technique is used. The percentage improvement in the accuracy observed is to be 77.21 and 78.81%. The percentage improvement in the accuracy parameter 2DRMS is the same as DRMS improvement.

TABLE 1. Accuracy parameters of rover receiver estimated over 24 hours for standalone and differential IRNSS and the percentage improvement in accuracy (on L5)

Accuracy Parameters	Standalone (without Corrections)	Differential (with corrections)	% improvement in accuracy
CEP (50%)	5.31 m	1.21 m	77.21 %
DRMS (65%)	7.36 m	1.56 m	78.81 %
2DRMS (95%)	14.72 m	3.1 m	78.81 %

The histogram plot and Gaussian distribution of the standalone IRNSS and differential IRNSS rover accuracy on L5 signal in terms of East error and North error in meters are shown in Figure 5. The Gaussian distribution with respective mean values and standard deviation values are represented in Figure 5 (a to d). The mean values for standalone and differential IRNSS accuracy plots are approximately zero for east error and north error in both cases. The standard deviation (STD) values for standalone east error and north error are 7.19 and 1.58, respectively and for differential IRNSS, east error and north error, they are 1.42 and 0.59, respectively. In Figure 5 (a, b) the error values are distributed widely from -10 m to 10 m when compared to Figure 5 (c, d) which are distributed from -5m to 5 m which is narrow, respectively for east error plot. For North error plot, the Gaussian distribution is from -4 m to 4 m when compared to and -2 m to 2 m which is narrow and are confined to zero for

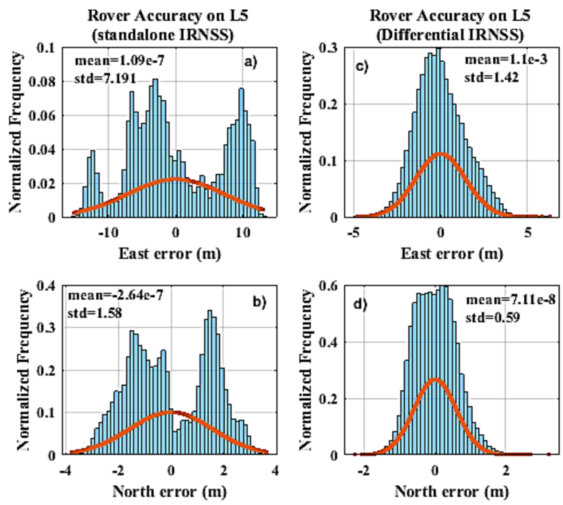

Figure 5. Histogram plot and Gaussian Distribution of IRNSS standalone and differential rover accuracy on L5

differential IRNSS. It is observed that the accuracy in case of differential IRNSS is improved when compared to standalone IRNSS rover accuracy.

4. 3. Differential IRNSS Considering the Pseudoranges on S1 The pseudoranges on S1 are utilized for the improvement in the horizontal accuracy of the rover. The pseudoranges on S1 are obtained from IGS receivers in CSV file format.

4. 3. 1. Position of Rover before and after Applying Corrections The position of rover receiver in Latitude, Longitude and Height (LLH) before applying corrections and after applying corrections is plotted as shown in Figure 6. Latitude, Longitude and Height are plotted here are by considering for the duration of 24 hours.

4. 3. 2. Rover Accuracy without Corrections Accuracy of standalone IRNSS (using pseudoranges on S1) is plotted by considering east error on x-axis and north error on y-axis in meters. Figure 7 describes the horizontal accuracy plot (radial error) with CEP, DRMS and 2DRMS values. For standalone IRNSS, the CEP, DRMS, 2DRMS values observed to be 3.86 m, 5.38 m, 10.76 m, respectively.

4. 3. 3. Rover Accuracy after Applying Corrections Accuracy of IRNSS (using pseudoranges on S1) with corrections is plotted (Figure 8) by considering east error on x-axis and north error on y-axis in meters. When the corrections applied to rover, the CEP, DRMS, 2DRMS are observed to be 1.31 m, 1.66 m, 3.32 m, respectively. The horizontal accuracy parameter 2DRMS is 10.76 m and is improved to 3.32 m after applying corrections.

The comparison of standalone IRNSS and Differential IRNSS positional accuracies on S1 is represented in Table 2. It is observed that there is an improvement in the accuracy when differential position is used.

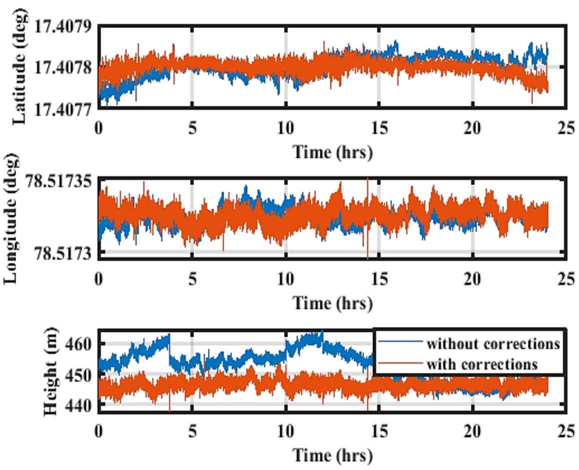

Figure 6. Rover position (LLH) (on S1) before and after applying corrections

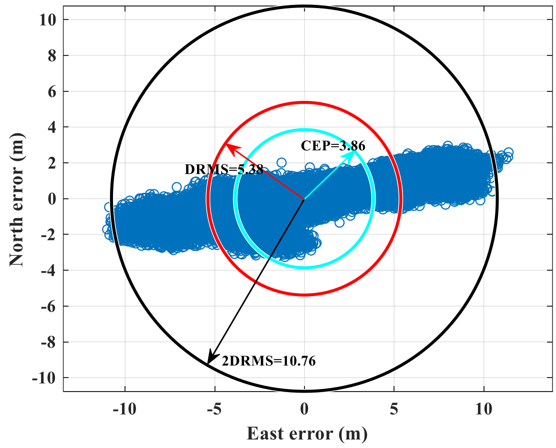

Figure 7. Rover receiver radial error CEP, DRMS and 2DRMS estimated over 24 hours without corrections (on S1)

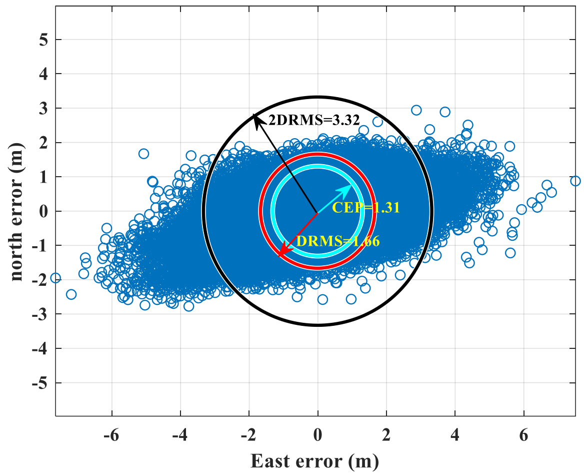

Figure 8. Rover receiver radial error CEP, DRMS and 2DRMS estimated over 24 hours with corrections (on S1)

The accuracy parameters CEP and DRMS, the percentage improvement in the accuracy observed is to be 66.06 % and 69.14 %. The percentage improvement in the accuracy parameter 2DRMS is same as DRMS improvement.

TABLE 2. Accuracy parameters of rover receiver estimated over 24 hours for standalone and differential with percentage improvement in accuracy (on S1)

Accuracy Parameters	Standalone (without Corrections)	Differential (with corrections)	% improvement in accuracy
CEP (50%)	3.86 m	1.31 m	66.06 %
DRMS (65%)	5.38 m	1.66 m	69.14 %
2DRMS (95%)	10.76 m	3.32 m	69.14 %

The histogram plot and Gaussian distribution of the standalone IRNSS and differential IRNSS rover accuracy on S1 signal in terms of East error and North error in meters are shown in Figure 9. The Gaussian distribution with respective mean values and standard deviation values are represented in Figure 9 for the accuracy plots on signal S1. The mean values for standalone and differential accuracy plots are approximately zero for east error and north error. The standard deviation (STD) values for standalone east error and north error are 5.26 and 1.1, respectively and for differential IRNSS, east error and north error they are 1.52 and 0.65, respectively. In Figure 9 (a, b) the error values are distributed widely from -10 m to 10 m when compared to Figure 9 (c, d) which are distributed from -5m to 5 m which is narrow, respectively for east error plot. For North error plot the Gaussian distribution is from -2 m to 2 m in both cases but most of the error values are confined to zero for Differential IRNSS. It is observed that the accuracy in case of differential IRNSS is improved when compared to standalone IRNSS rover accuracy.

4. 4. Differential IRNSS Considering the Combined Pseudoranges on L5 and S1 (Dual Frequency)

The pseudoranges on L5 and S1 (dual) are utilized together for the improvement of the horizontal accuracy of the rover.

4. 4. 1. Position of Rover before and after Applying Corrections

The position of rover receiver in Latitude, Longitude and Height (LLH) before applying corrections and after applying corrections is plotted as shown in Figure 10. Latitude, Longitude and Height are plotted here for the duration of 24 hours.

4. 4. 2. Rover Accuracy without Corrections

Accuracy of standalone IRNSS (using pseudoranges on

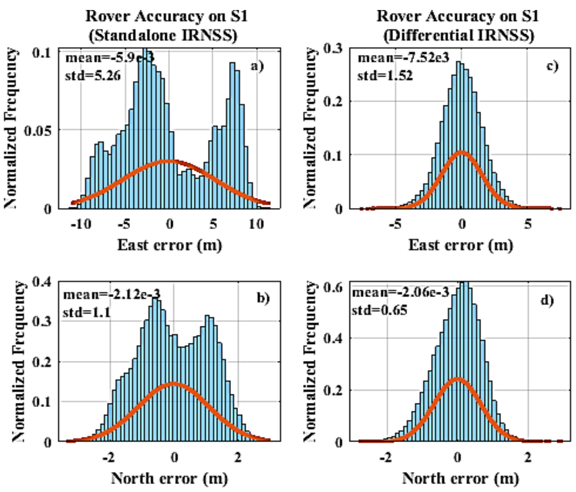

Figure 9. Histogram plot and Gaussian Distribution of NavIC standalone and differential rover accuracy on S1

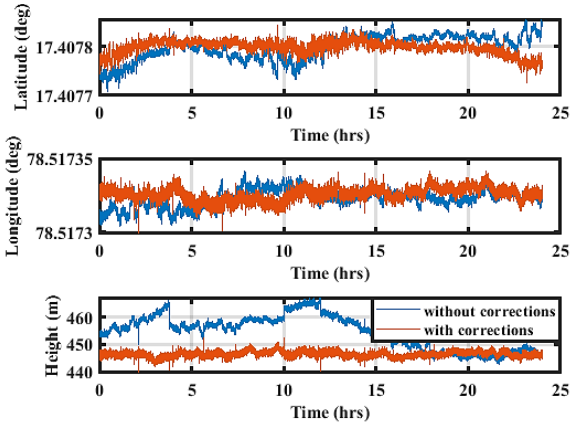

Figure 10. Rover position (LLH) (dual) before and after applying corrections

L5 and S1 both) is plotted by considering east error on x-axis and north error on y-axis in meters. Figure 11 describes the horizontal accuracy plot with CEP, DRMS and 2DRMS values. For standalone IRNSS, the CEP, DRMS, 2DRMS values observed to be 4.51 m, 6.28 m, 12.57 m, respectively.

4. 4. 3. Rover Accuracy after Applying Corrections

Accuracy of IRNSS (using pseudoranges on L5 and S1 both) with corrections is plotted (Figure 12) by considering east error on x-axis and north error on y-axis in meters. When the corrections applied to rover, the CEP, DRMS, 2DRMS are observed to be 0.95 m, 1.21 m, 2.41 m, respectively. The horizontal accuracy parameter 2DRMS was 10.76 m and is improved to 2.41 m after applying corrections.

The comparison of IRNSS standalone and Differential IRNSS positional accuracies on L5 and S1 both (dual frequency) is represented in Table 3. It is observed that there is an improvement in the accuracy

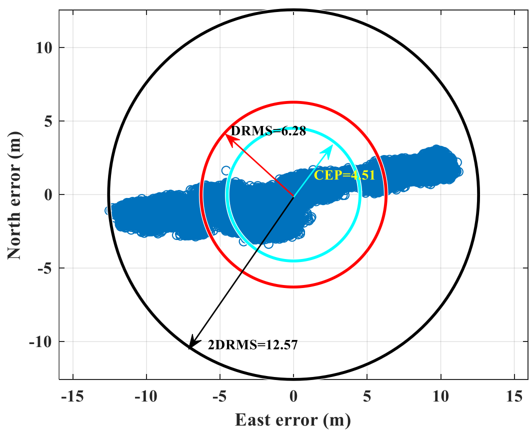

Figure 11. Rover receiver radial error CEP, DRMS and 2DRMS estimated over 24 hours without corrections (combined)

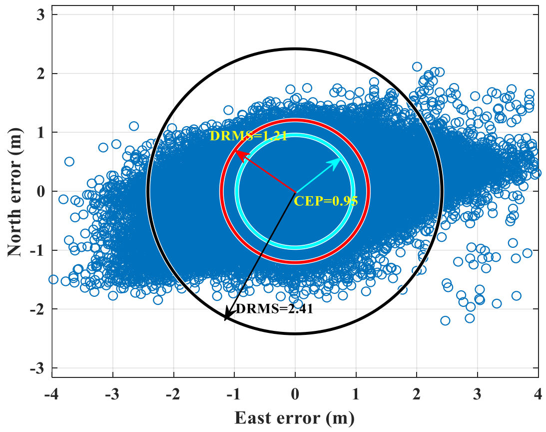

Figure 12. Rover receiver radial error CEP, DRMS and 2DRMS estimated over 24 hours with corrections (dual)

TABLE 3. Accuracy parameters of rover receiver estimated over 24 hours for standalone and differential with percentage improvement in accuracy (dual frequency)

Accuracy Parameters	Standalone (without Corrections)	Differential (with corrections)	% improvement in accuracy
CEP (50%)	4.51 m	0.95 m	78.93 %
DRMS (65%)	6.28 m	1.21 m	80.73 %
2DRMS (95%)	12.57 m	2.41 m	80.73 %

when differential position is used. The accuracy parameters CEP and DRMS. The percentage improvement in the accuracy observed is to be 78.93 % and 80.73 %. The percentage improvement in the accuracy parameter 2DRMS is the same as DRMS improvement.

The histogram plot and Gaussian distribution of the standalone IRNSS and differential IRNSS rover accuracy on dual frequency (L5 and S1) signals in terms of East error and North error in meters are shown in Figure 13.

The Gaussian distribution with respective mean values and standard deviation values are represented in Figure 13 for the accuracy plots on dual frequency signal. The mean values for standalone and differential IRNSS accuracy plots are approximately zero for east error and north error. The standard deviation (STD) values for standalone east error and north error are 6.15 and 1.3, respectively and for differential IRNSS, east error and north error they are 1.1 and 0.49, respectively. In Figure 13 (a, b) the east error and north error values are distributed widely from -10 m to 10 m and -2 m to 2 m, repectively, for standalone IRNSS, when compared to the Figure 13 (c, d) the east error and north errors are distributed from -2m to 2 m and -1 m to 1 m, which is narrow and are confined to zero for Differential IRNSS. It is observed that the accuracy in case of differential IRNSS is improved when compared to standalone IRNSS rover accuracy.

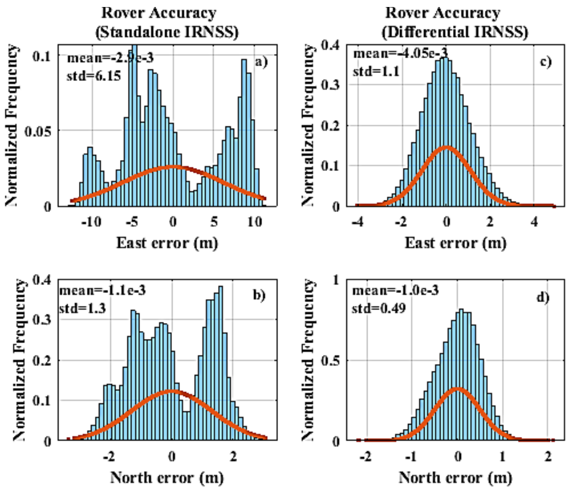

Figure 13. Histogram plot and Gaussian Distribution of NavIC standalone and differential rover accuracy on L5 and S1 (dual frequency)

5 CONCLUSIONS

Differential positioning is to improve the position accuracy of the rover receiver which is in the vicinity of the reference station. It is useful in certain applications where precise position accuracy is required. Here, the position accuracy on L5, S1 and dual frequency (L5 and S1) are analyzed and compared. Differential position accuracy improvement of 78.81 %, 69.14 % and 80.73 % in 2DMRS horizontal accuracy are observed on L5, S1 and dual frequency (both L5 and S1). The highest improvement in accuracy observed is 80.73 % which is when the rover receiver is in dual frequency mode.

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Persian Abstract

چکیده

ناوبری با صورت فلکی هند (NavIC)سیستم ماهواره ای ناوبری منطقه ای هند (IRNSS)است که توسط سازمان تحقیقات فضایی هند (ISRO)برای ارائه موقعیت و خدمات ناوبری برای منطقه هند توسعه یافته است. NavIC یا IRNSS یک صورت فلکی ماهواره ای است که دارای هفت ماهواره است که شبه قاره هند را پوشش می دهد. دقت NavIC مستقل در برخی کاربردها مانند هوانوردی غیرنظامی کافی نیست. برای بهبود عملکرد دقت موقعیت سیستم NavIC، از تکنیک موقعیت‌یابی دیفرانسیل استفاده می‌شود. در این مقاله، موقعیت یابی دیفرانسیل با در نظر گرفتن دو گیرنده (IGS IRNSS-GPS-SBAS)یکی به عنوان ایستگاه مرجع و دیگری به عنوان کاوشگر انجام شده است که قادر به دریافت سیگنال IRNSS از ۷ ماهواره، سیگنال GPS از ۱۲ ماهواره، سیگنال SBAS از ۲ ماهواره. در اینجا، صورت فلکی NavIC به تنهایی برای تحلیل در نظر گرفته شده است. موقعیت‌یابی دیفرانسیل با استفاده از اندازه‌گیری‌های شبه درL5 1176.45 مگاهرتز،) 2492.028S1مگاهرتز و دوگانه (L5 و S1 هر دو) انجام می‌شود و دقت‌ها از نظر پارامترهای آماری احتمال خطای دایره‌ای (CEP)*، میانگین ریشه فاصله مقایسه می‌شوند. مربع (DRMS)، ۲ DRMSدو برابر .(DRMS) بهبود دقت افقی ۲ (DRMS)مریخ نورد با استفاده از اندازه‌گیری‌های شبه L5در 78.81 درصد، S1در 69.14 درصد و با استفاده از فرکانس دوگانه (L5 و S1 هر دو) ۸۰.۷۳ درصد در مقایسه با NavIC مستقل است.