Position Error Calculations for IRNSS System Using Pseudo Range Method

SD. Nageena Parveen, P Siddaiahx

Abstract*: *The Indian Regional Navigation Satellite System (IRNSS) authorizes to determine the location of the user with the help of code measurements, called as pseudo ranges (PR). An alternate method, Differential IRNSS (DIRNSS) which improves the position accuracy of the user with the help of a reference known point by podcasting its correction among the local user. Hence, with the DIRNSS system the position error reduced when compare to IRNSS. In general satellite-navigation system, the Dilution of precision (DOP) unit will depend on parameters such as multipath effect and surrounding atmospheric condition. This precision value will be represented in terms of Geometric DOP, Position DOP, Vertical DOP, and Horizontal DOP. In this paper, positional errors (3D), Geometry Dilution of Precision (GDOP) of IRNSS system is calculated by viewing all operational IRNSS satellites instead of optimum four satellites, which diminishes the complexity and also gives the better value of a precision unit.

Index Terms*: *Orbit perturbations, Pseudo range, ionospheric delays, tropospheric delays, GDOP.

I. INTRODUCTION

The Indian Regional Navigation Satellite System (IRNSS) allows properly equipped users to determine their position based on the measured pseudo ranges to at least four satellites. IRNSS positioning accuracy is limited by measurement errors that can be classified as either common mode or non-common mode [1]-[3]. On all receivers operating in a limited geographic area (50 km) common mode errors have nearly identical effects. Non -common mode errors are distinct even for two receivers with minimal antenna separation. In civilian receivers, the common mode pseudo-range errors have a typical standard deviation on the order of 25 m.

A basic understanding of the operation of an IRNSS receiver will help to understand the corrupting effects of multipath. The receiver determines the IRNSS signal transit time by correlating an internally generated version of a pseudorandom code with the received satellite signal [4], [5]. Until maximum correlation occurs the internally generated signal is shifted in time. The time shift, relative to the known time at which the satellite-generated the signal, corresponding to the maximum correlation between the two signals is the measured transit time. Ideally, the correlation envelope is symmetric about its maximum value. The process of determining the peak correlation time shift will be simplified by this symmetric nature [6]-[8].

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DIRNSS uses a reference station at a known position to determine corrections that other local IRNSS receivers (within 50 km of the reference station) can use to reduce the effects of IRNSS common mode error sources. The quality of the design of the reference station depends on the extent to which the common mode errors are reduced. Therefore, the quality of the reference station affects the positioning accuracy that end users are ultimately able to achieve.

Ionospheric errors are not removed by the reference station, so that corrections are independent of any particular ionospheric model. If necessary, distant users can use the best available ionospheric model to correct both the correction and their measured range for the ionospheric error at the respective locations of the reference station and user. Tropospheric errors are not removed because the errors are altitude dependent. If the user and reference station are at different altitudes the user can correct both the corrections and the measured range at the respective locations of the reference station and user [9]-[10].

Reference station clock bias is removed to decrease the dynamic range of the broadcast corrections and to ensure the continuity of the corrections. Similarly, the calculated satellite clock errors are removed by the reference station to decrease the dynamic range of the corrections.

II. MATHEMATICAL DESCRIPTION

The pseudo range has been calculated using the equation below,

$$P=\rho+d\rho+c(dt-dT)+d_{ion}+d_{trop}+\varepsilon_{mp}+\varepsilon_{p} \qquad (1)$$

Where

P = the pseudorange measurement

ρ = the true range

$d\rho$ = satellite orbital error

c = the speed of light

dt = satellite clock offset from IRNSS time

dT = receiver clock offset from IRNSS time

d_{ion} = ionospheric delay

d_{trop} = tropospheric delay

ε_{mp} = multipath

ε_{p} = receiver noise

The pseudo range equations we wish to linearize are as described in the equation below,

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$$PR_1 - \Delta t_1 = \sqrt{(X - X_1)^2 + (Y - Y_1)^2 + (Z - Z_1)^2} + ct_B$$
$$PR_2 - \Delta t_2 = \sqrt{(X - X_2)^2 + (Y - Y_2)^2 + (Z - Z_2)^2} + ct_B$$
$$PR_3 - \Delta t_3 = \sqrt{(X - X_3)^2 + (Y - Y_3)^2 + (Z - Z_3)^2} + ct_B$$
$$PR_4 - \Delta t_4 = \sqrt{(X - X_4)^2 + (Y - Y_4)^2 + (Z - Z_4)^2} + ct_B \quad (2)$$

Using the above mentioned equations the satellite ECEF positions and receiver ECEF positions are been calculated [11].

The accuracy of position estimation in any navigation system is the key to the performance of the positioning system. The accuracy will be greatly affected by several factors like multipath effect, satellite clock biases, receiver clock biases and geometry of satellites as we saw from the receiver.

The positioning error by the effect of satellite receiver geometry can be determined by the Geometric Dilution of precision (GDOP).To compute GDOP, PDOP, VDOP the code measurement like pseudorange is used by taking all the satellites in view instead of minimum number four because of this, the complexity, time will be reduced and linearization will be easy [12], [13]. The entire simulation process is done in MATLAB.

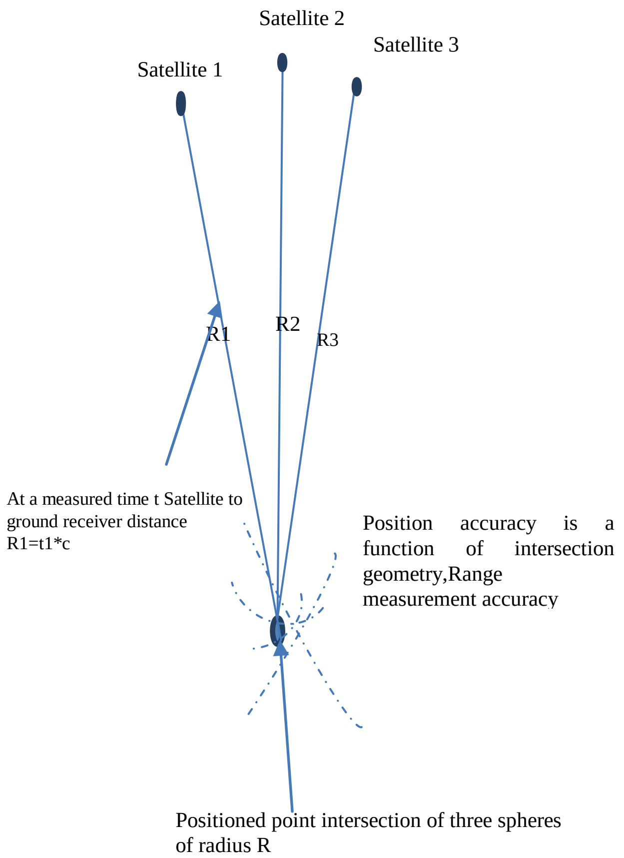

Figure. 1 General positioning concept

The pseudo range equation for 'n' satellites are represented in matrix form as

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \Delta P_3 \\ . \\ . \\ . \\ \Delta P_n \end{bmatrix} = \begin{bmatrix} u_{11} & u_{12} & u_{13} & 1 \\ u_{21} & u_{22} & u_{23} & 1 \\ u_{31} & u_{32} & u_{33} & 1 \\ u_{41} & u_{42} & u_{43} & 1 \\ u_{51} & u_{52} & u_{53} & 1 \\ u_{61} & u_{62} & u_{63} & 1 \end{bmatrix} \begin{bmatrix} \delta x \\ \delta y \\ \delta z \\ ct_b \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ . \\ . \\ \varepsilon_n \end{bmatrix} \quad (3)$$

In general representation $P = U * \Delta X + \varepsilon$

Where U represents the LOS vector of n*6 geometry matrix, ΔX is user position, ε represents the other error sources. The linearized format of approximation is

$$\Delta X = (U^T U)^{-1} U^T \Delta P \quad (4)$$

Therefore GDOP is

$$GDOP = \sqrt{trace(U^T U)^{-1}} \quad (5)$$

III. CONCEPTUALIZATION

There are numerous sources of measurement error that influence IRNSS performance. The range bias is nothing but the sum of all systematic errors or biases contributing to the measurement error. The observed IRNSS range, without removal of biases, is referred to as a biased range or "pseudo-range." Principal contributors to the final range error that also contribute to overall IRNSS error are ephemeris error, satellite clock and electronics inaccuracies, tropospheric and ionospheric refraction, atmospheric absorption, receiver noise, and multipath effects. Other errors include those induced by the Department of Defense (DOD) (Selective Availability (S/A) and Anti-Spoofing (A/S)) [14]. In addition to these major errors, IRNSS also contains random observation errors, such as unexplainable and unpredictable time variation. These errors are impossible to model and correct. The following paragraphs discuss errors associated with absolute IRNSS positioning modes. Many of these errors are either eliminated or significantly minimized when IRNSS is used in a differential mode. This is due to during simultaneous observing sessions the same errors being common to both receivers.

A. *Ephemeris errors and orbit perturbations*

The errors in the prediction of a satellite position which may then be transmitted to the user in the satellite data message are called satellite ephemeris error. Ephemeris errors are satellite dependent and very difficult to completely correct and compensate for because the many forces acting on the predicted orbit of a satellite are difficult to measure directly. Because the direct measurement of all forces acting on a satellite orbit is difficult, it is nearly impossible to accurately account or compensate for those error sources when modeling the orbit of a satellite.

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B. *Ionospheric delays*

IRNSS signals are electromagnetic signals when they transmitted through a highly charged environment like the ionosphere they may nonlinearly dispersed and refracted. Dispersion and refraction of the IRNSS signals are referred to as an ionospheric range effect because dispersion and refraction of the signal result in an error in the IRNSS range value. Ionospheric range effects are frequency dependent.

Resolution of ionospheric refraction can be accomplished by the use of a dual-frequency receiver (a receiver simultaneously records both L1 and L2 frequency measurements). These signals can be continuously counted and differenced during a period of uninterrupted observations of L1 and L2 frequencies. The resultant difference reflects the variable effects of the ionosphere delay on the IRNSS signal. Single-frequency receivers used in an absolute and differential positioning mode typically rely on ionospheric models that model the effects of the ionosphere [15]. Recent efforts have shown that using signal frequency receivers significant removing of ionospheric delays can be achieved.

C. *Tropospheric delays*

IRNSS signals in the L-band level are not dispersed by the troposphere, but they are refracted. The tropospheric conditions causing refraction of the IRNSS signal can be modeled by measuring the dry and wet components. The dry component is approximated best with the following equation:

$$D_c = (2.27 * 0.001) * P_0 \qquad (6)$$

Where

D_c =dry term range contribution in zenith direction in meters

P_0 =Surface pressure in millibar.

The wet component is considerably more difficult to approximate because its approximation is dependent not just on surface conditions, but also on the atmospheric conditions (water vapor content, temperature, altitude, and angle of the signal path above the horizon) along the entire IRNSS signal path. As this is the case, there has not been a well-correlated model that approximates the wet component.

D. *Differential corrections*

A reference receiver at an accurately calibrated location (x_0, y_0, z_0) can calculate the reference-to-satellite range as

$$\hat{R}_0 = ((\hat{x}_{sv} - x_0)^2 + (\hat{y}_{sv} - y_0)^2 + (\hat{z}_{sv} - z_0)^2)^{0.5} \qquad (7)$$

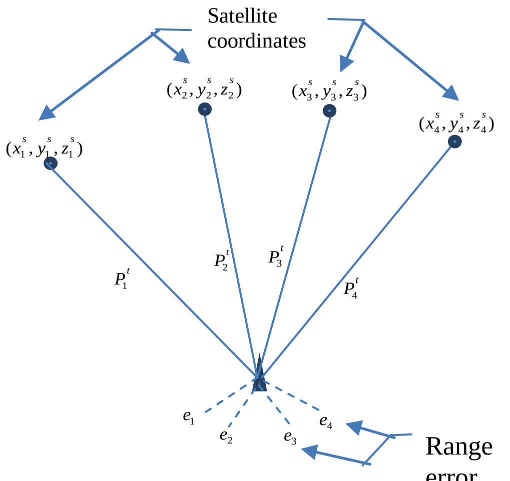

Figure. 2 Pseudorange concept

The basic range space differential correction (per satellite) is determined by differencing the calculated and measured reference-to-satellite ranges.

$$\hat{\Delta}_{irnss}(t) = \hat{R}_0 - \tilde{\rho}$$
$$= -(c\Delta t_0(t) + c\Delta t_{sv}(t) + SA(t) + E(t) + c\Delta t_a(t) + MP(t) + \eta(t)) \qquad (8)$$

Here the equation is also included with the bias of the reference receiver clock. The sign of is motivated by the DIRNSS standard which states that the correction will be added by the remote user. The broadcast corrections should be corrected to remove the reference receiver and satellite clock errors. Therefore, the broadcast corrections will take the form

$$\hat{\Delta}_{irnss}(t) = \hat{R}_0 + c\Delta\hat{t}_0(t) + c\Delta\hat{t}_{sv}(t) - \tilde{\rho}$$
$$= -(c\delta t_0(t) + c\delta t_{sv}(t) + SA(t) + E(t) + c\Delta t_a(t) + MP(t) + \eta(t)) \qquad (9)$$

IV. RESULTS AND DISCUSSIONS

To analyze the position error we took two receivers separated by 10 meters of distance and calculated each receiver position by using pseudorange method by incorporation ionospheric error, tropospheric error and common mode errors. By using the DIRNSS calculated the position error by differencing the two receiver positions calculated. By considering different satellite combination for pseudo range calculation the position errors observed are 5.44 meters 9.44 meters and 7.55 meters.

I. Comparison of Values observed in receiver 1 to the calculated values

S.No	Receiver Values	Calculated Value	Error Value
1	ECEF X(m) 1007532.88	ECEF X(m) 1007542.61	9.73 (0.0009%)
2	ECEF Y(m) 6037575.31	ECEF Y(m) 6037719.12	143.81 (0.0023%)
3	ECEF Z(m) 1786391.52	ECEF Z(m) 1786388.61	2.91 (0.0001%)

II. Comparison of Values observed in receiver 2 to the calculated values

S.No	Receiver Values	Calculated Value	Error Value
1	ECEF X(m) 1007537.10	ECEF X(m) 1007514.11	22.99 (0.0022%)
2	ECEF Y(m) 6037574.22	ECEF Y(m) 6037514.16	60.06 (0.0009%)
3	ECEF Z(m) 1786382.19	ECEF Z(m) 1786341.56	40.63 (0.0022%)

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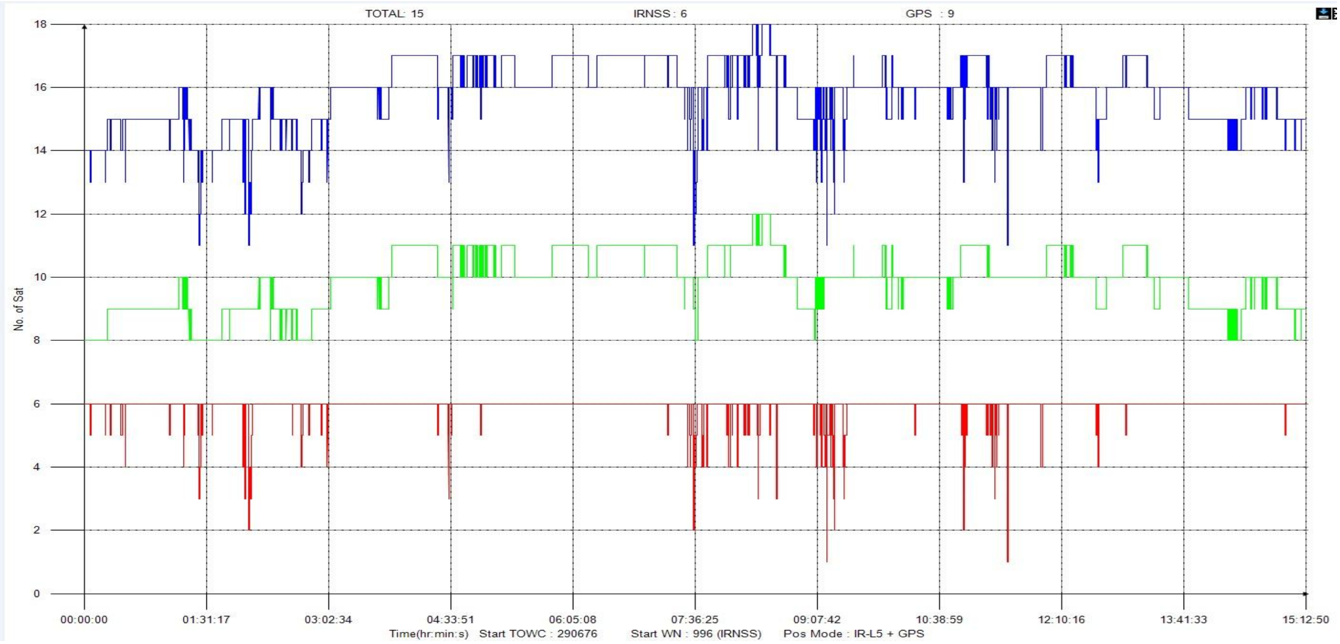

Figure. 4 Number of Satellites=19 of both GPS=9 and IRNSS=6 systems.

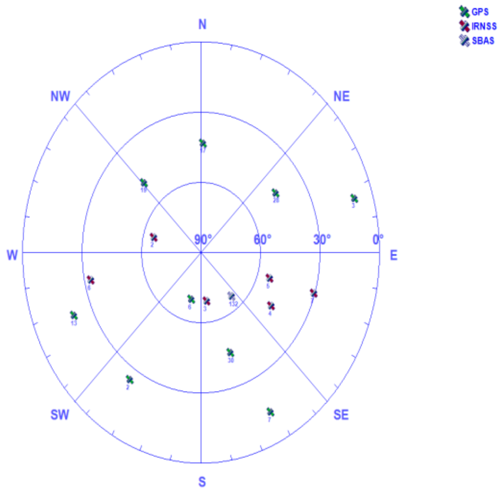

Figure. 3 Sky Plot of IRNSS, SBAS, GPS Satellites

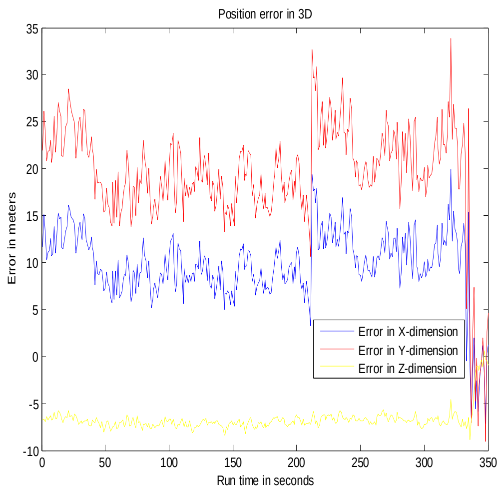

Figure. 5 Position error in 3Dimensional

Figure. 5 indicates the position error in three dimensions (X, Y, and Z) indicated in different colors. The results show meter level accuracy using the pseudorange method.

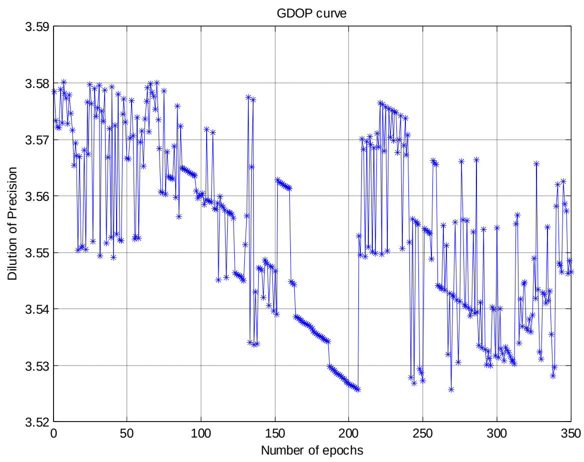

Figure. 6 Geometric Dilution of Precision

Figure. 6 indicates the GDOP of IRNSS system the maximum GDOP is obtained at 3.58 and minimum at 3.52 is as in table IV.

III. The Latitude and Longitude Values of receiver 1&2 with the baseline distance

<table>
<tr><th rowspan="2">Variables</th><th rowspan="2">Receiver 1 Values</th><th rowspan="2">Receiver 2 Values</th><th colspan="2">Distance between receivers</th></tr>
<tr><th>actual</th><th>measured</th></tr>
<tr><td>Latitude</td><td>$16^{0}22^{1}23^{11}.96$</td><td>$16^{0}22^{1}23^{11}.67$</td><td rowspan="3">10 mts</td><td rowspan="3">12.44 mts</td></tr>
<tr><td>Longitude</td><td>$80^{0}31^{1}33^{11}.41$</td><td>$80^{0}31^{1}33^{11}.26$</td></tr>
<tr><td>Altitude</td><td>-38.5398mts</td><td>-41.534 mts</td></tr>
</table>

IV. DOP ratings

DOP value	Ratings
1	Ideal
2-4	Excellent
4-6	Good
6-8	Moderate
8-20	Fair
20-50	Poor

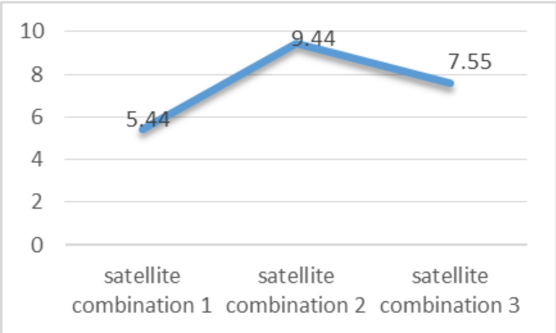

Figure. 7 Baseline error in meters for different combinations of satellites

V. CONCLUSION

Indian Space Research Organization (ISRO) has proposed to provide PVT services during all weather conditions the independent and regional satellite based navigation system over Indian subcontinent is IRNSS. This paper concentrates on pseudorange method .The positional errors and how the satellite-receiver geometry is affected by the positional error is observed and shown in results. The pseudo range is calculated by incorporating Ionosphere delay, tropospheric delay and satellite, and receiver clock offset. Errors are calculated and are shown in the above tables. By considering different satellite combination for pseudo range calculation the baseline errors observed are 5.44 meters 9.44 meters and 7.55 meters.

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