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Precise Rover Position Estimation Using Differencing Techniques in RTK-IRNSS System

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Abstract: Indian Regional Navigation Satellite System (IRNSS) is designed to provide Position, Velocity, and Timing (PVT) services, by taking the requirements of clients in India, as well as users/clients in region 1500km from the Indian boundary. Real Time Kinematic (RTK)-IRNSS is a standout amongst the most exact positioning innovation, with this user can acquire progressively centimeter-level accuracy. It forms the phase tracking estimations of IRNSS signals. In order to get the precise positioning information ambiguity resolution would be of interest; therefore the carrier ambiguity should be resolved ahead any position is computed. In precise positioning applications ambiguity resolution is still an exacting problem. The carrier phase (CP) measurement is limited by estimating an integer parameter, popularly termed as integer ambiguity estimation. On the brilliant side of this paper, the ambiguities are resolved using the antenna swapping strategy. When these ambiguities are effectively settled the high accuracy and precise user position can be evaluated. This paper first thinks CP estimation and their differencing systems to figure exact position of the user. The RTK-IRNSS system provides continuous services, and drill meter level standard positioning down to cm-level positioning. The single difference (SD) and double difference (DD) CP measurements are determined and afterward the baseline solution is watched. In this paper, firstly dispense with the noise parameters and making the spotless conditions of carrier phase (CP) measurements. Therefore, related these CP measurements (spot less) to a vector of unknown 3D position, and also computed the baseline solution between reference receiver and user receiver. The user positional error has computed and determines the 3D Root Mean Square Error (RMSE) in both the differencing techniques. The obtained RMSE is 2.6483 meters in single difference whereas in double difference is 2.3391 meters.

Keywords: Baseline Solution, Carrier Phase Measurement, Differencing Technique, RTK Algorithm.

1. Introduction

Currently, the Indian Regional Navigation Satellite system (IRNSS) has full serviceable potentiality and provides broadcasting in India and the region 1500km from its frontier. Positioning accuracy centimeter or even millimeter can be obtained with carrier phase measurements with a dual frequency IRNSS receiver.

The minimum number of satellites required for IRNSS constellation is 3Geo Stationary orbit (GEO) and 4 Geo Synchronous orbit (GSO), the three GEO's are located at 32.5^0E, 83^0E and 131.5^0E and the longitude crossing of 55^0E &111.75^0E by 4 GSO's [1]-[3].

The architecture of IRNSS consists of 3segments, namely Space segment (SS), Ground Segment (GS) and User Segment (US). The Space Segment is a seven lively satellite constellation. The User Segment provides two types of services (SPS and RS) with different carrier frequency's. The IRNSS SPS service is broadcasted on two bands namely L5 (1164.45 – 1188.45 MHz) and S (2483.5-2500 MHz) bands [4].

IRNSS is a self-governing provincial satellite route framework is utilized to give exact positioning. The IRNSS satellites continuously transmit electromagnetic signals to the earth and position of users can be defined by calculating the separation between satellite and receiver [5], [6]. This separation will be measured by using two types of tracking's either by tracking the code of the signal or carrier phase of the signals [7]-[9].

RTK-IRNSS (ongoing kinematic IRNSS) is a standout amongst the most exact situating advances, with which clients can get centimeter-level precision. It gives the standard arrangement progressively by handling transporter stage or CP estimations of IRNSS signals. Traditionally, RTK-IRNSS has been used for the restricted application like the geodetic survey [10], transportation etc., In present scenario, the use of RTK-IRNSS has been constantly extended to different zones like portable

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mapping framework, exact route of vehicles, development machine control, and agriculture etc.,. The exact situating innovations with RTK-IRNSS are relied upon to be utilized for a lot more extensive applications progressively later on [11], [12].

For research communities, the positioning of the target/user is a high-force subject in a GNSS system. The IRNSS system is a recently included in GNSS framework. Nowadays every examination network is focusing on the IRNSS system. A few examinations have been done and published on code tracking of the signals, i.e. pseudo-range. In code tracking the obtained position accuracy is only in meters.

In this paper the new investigation depends on carrier phase (CP) measurement is presented. With the CP measurements how biases are reduced thereby how this meter level accuracy will be a drill to cm-level is given. With the resolved ambiguities (antenna swapping strategy), the CP measurement for a single difference and double-difference has computed (cycles). After resolving the ambiguities (i.e. stabilize the integers), using the relative positioning concept the position of the user receiver is determined. Here, two elements have determined using phase tracking, first element is distance error between two receivers and second element is the position of the user/rover receiver. The determined distance error is also forwarded to the user/rover and deducted to get the accurate position information.

In this paper, the examinations of the Real-time kinematic calculation of IRNSS framework is discussed in section II. The idea of CP estimation and differencing techniques are introduced in section III. The proposed method is explained in section IV. Experimental results are demonstrated in section V and finally conclusion of work is discussed in section VI.

2. RTK-IRNSS FRAMEWORK DISCRIPTION

For RTK-IRNSS, clients typically need to get ready geodetic-grade receivers with firmware supporting RTK-IRNSS (or restrictive RTK-IRNSS programming on the receiver controller or the PC given by the receiver end user). The receivers or such software for RTK-IRNSS, however, are generally very expensive comparing to general-purpose IRNSS receivers. This is one of the reasons why RTK-IRNSS is still not popular and has limited applications. Many users, who require more precise position, are longing for much lower cost RTK-IRNSS receivers. With good high end antennas, the good accuracy in receiver position and cm-level accuracy in baseline solution can be obtained even with such low cost receivers.

The carrier phase measurements are normally less noisy than code measurements but it has integer cycle ambiguity [13]. The range in CP is calculated in terms of a number of cycles. Instead of meter level accuracy in code measurements to get the cm level accuracy carrier tracking is used, nothing but the measurement of the total phase (i.e. the number of wavelengths plus the fractional wavelength). With the rigorously equipped receivers, the user can get high precision and accuracy in IRNSS positioning using the differential technique. However, here the data is collected from more than two receivers and a more number of satellites to predict the user information.

The RTK Algorithm depends on CP measurements and their differencing methods. The features of the calculation are depicted in straight away. At a given epoch time, and for a given satellite, the streamlined carrier phase (CP) measurement (meters) [14]-[15] is accompanying as:

$$\Phi = r - I_d + Tr_d + c(b_r - b_i) + N_{12}\lambda + \varepsilon_\phi \tag{1}$$

Where:

I_d is the flag way delay because of the ionosphere (m);
Tr_d is the flag way delay because of the troposphere (m);
b_r is the receiver clock offset from the reference (IRNSS) time (ns);
b_i is the satellite clock offset from the reference (IRNSS) time(ns);
c is the vacuum speed of light (m/s);
$\lambda_{L5/S}$ is the IRNSS L5 or S1 signal wavelength;
N_{12} is the ambiguity of the carrier-phase (integer number in cycles);
ε_ϕ is the multipath effect;
r is the geometric range between the satellite and receiver/collector (m).

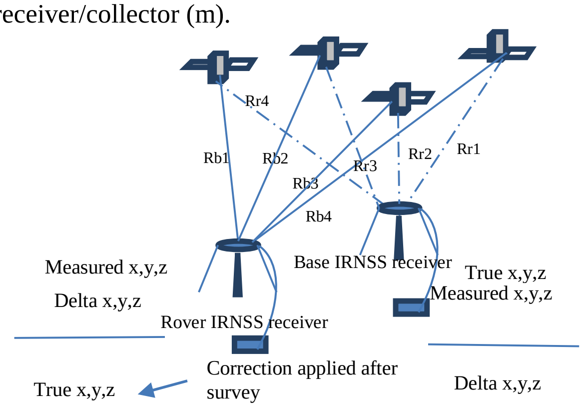

Figure 1. RTK-IRNSS framework

Figure 1, represents the RTK-IRNSS frame work. Out of two receivers one is base (known survey point) and other is rover (unknown). The calculated corrections (at base) are forwarded to rover receiver (for exact rover position).

Figure 2, represents the IRNSS/GPS/SBAS receiver and is manufactured by the Accord software &systems Ltd. The Screen shot of IRNSS GUI window indicates the C/N0 information of corresponding PRN Channel of

IRNSS (L5, S1) bands, GPS (L1) band and SBAS. This shot was taken on Sep09, 2019.

Figure 3 represents the output window plot of signal strength view in IRNSS- GPS- SBAS receiver GUI. Here it gives the information about satellite vehicle identity channel number (SVID Ch No) and corresponding C/N0 in (dB-Hz).

Figure 4 indicates the satellite constellation of the GNSS systems. In this sky plot there are 7 IRNSS, 8 GPS and other SBAS satellites locations are given.

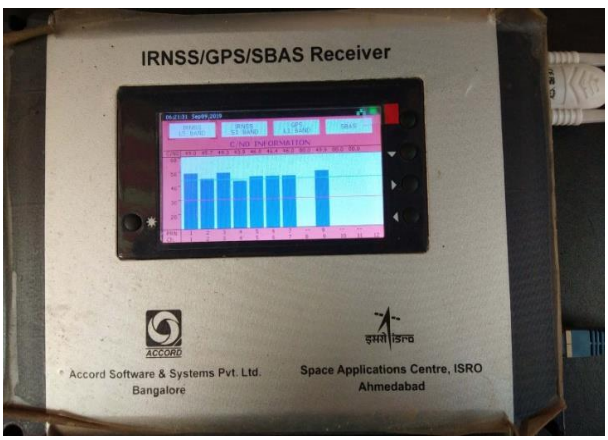

Figure 2. IRNSS/GPS/SBAS receiver

Figure 3. IRNSS-UX Graphical User Interface (GUI)

3. Differencing Techniques

Relative positioning is an alternative implementation for Differential IRNSS to determine precise position of a user. The user position is determined by taking the information from more number of satellites. To estimate the integer's one at a time by lucid treatment by Hatch (1996), [5]-[7] take a single difference and double difference measurements, from a specific satellite or a pair of satellites [16]. Here, the differences will be taken between the receivers or between the satellites or between the epochs. If we take the difference between the receivers and one satellite called the single difference. The difference between the two receivers and two satellites (one reference satellite which is having highest elevation angle and other satellite) or difference of single difference values is called double differencing.

A. *Single differencing technique*

A choice to take out the error terms and make the estimation error-free, take another receiver at a well-served-point and re-parameterization the unknown parameters; this process is probably known as relative positioning. At the same epoch time, the difference of carrier phase measurement between the base/reference receiver and the second/user receiver is called a single difference.

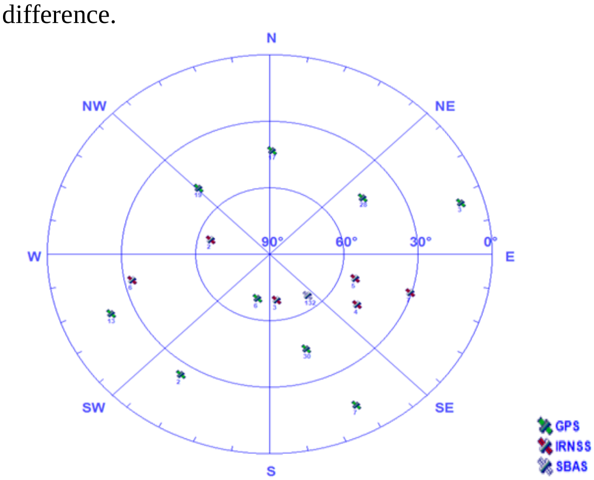

Figure 4. GNSS satellite constellation

If the distance between the two receivers is short called short baseline the impact of ionosphere, troposphere and ephemeris errors on measurements are small. After compensating the satellite clock bias, ionosphere troposphere errors and introducing time epoch t for a short baseline (superscript *m*-th satellite) carrier phase measurement (cycles) is denoted as

$$\phi^m(t)=\lambda^{-1}[r^m(t)-I^m+T^m]+c\delta t_r+N^m+\varepsilon_{\Phi}^m(t) \qquad (2)$$

The obscure terms in equation (2) like ionosphere, troposphere delays, satellite, receiver clocks, and whole number uncertainty are basically annoyance parameters. To figure out the interesting parameters for example the positional coordinates of the user/rover & CP measurements the noisy parameters must be assessed effectively. To decrease the effect of these noisy parameters, errors between receivers like equipment delay, initial phase offsets and multipath should be modeled or ignored. The satellite clock offset, satellite ephemeris errors are cancelled out in a single differencing technique. The size of these errors would depend on the distance between two receivers or baseline length.

In the following sections CP measurement in single difference, double difference is given and how the user/rover position is estimated from these measurements is demonstrated.

Suppose take two IRNSS receivers (one is base receiver and other is user/rover receiver) which likewise measures the carrier phases and fixed one receiver at a good survey position (this receiver will be called as reference receiver or base receiver).

Now compute the measurements between two receivers and satellite 'm' (called SD).

The single difference carrier phase measurement is characterized as

$$\phi^m(t) = \lambda^{-1}[r^m(t) - I^m + T^m] + c\delta t_r + N^m_{rx1rx2} + \varepsilon^m_\Phi(t) \tag{3}$$

Where

$$r^m = \sqrt{(x - x^m)^2 + (y - y^m)^2 + (z - z^m)^2} \tag{4}$$

$X = [x, y, z]^T$ is the receiver position in ECEF frame and $X^m = [x^m, y^m, z^m]^T$ is the position of the *m*-th satellite in ECEF frame.

Figure 5 represents the positioning mode of IRNSS-L5+GPS for a week number 996 of TOWC count 290676 (hour: minutes: seconds) with the satellite number. Here total 15 satellites are showed in that 7 IRNSS satellites & remaining eight are GPS satellites.

The estimated geometric range and the updated receiver's position is represented as

$$r^m_{est} = \sqrt{(x_{est} - x^m)^2 + (y_{est} - y^m)^2 + (z_{est} - z^m)^2}$$
$$x = x_{est} + \delta x, y = y_{est} + \delta y, z = z_{est} + \delta z \tag{5}$$

In linear format

$$y^m = \phi^m(t) - \lambda^{-1} r^m_{est}(t) \tag{6}$$

$$y^m = \begin{bmatrix} l^m_{x,est} & l^m_{y,est} & l^m_{z,est} & 1 & 1 \end{bmatrix} X - \varepsilon^m_\Phi(t) \tag{7}$$

Where

$$X = [\delta x, \delta y, \delta z, N^m_{rx1rx2}, b_r(t)]$$

Further extend the equation and for multiple satellites (i=1, 2, .m) in linearized format

$$y^m = AX + \varepsilon^m_\Phi(t) \tag{8}$$

The ambiguity term N^l_{ab} is a single difference ambiguity it may be positive or negative integer. This term is yet an integer and a challenging parameter, yet to be illuminated to get the exact position of the user. In a single differencing concept, the satellite clock errors between two receivers are same therefore, it will be cancelled out. The ionosphere, troposphere delays, ephemeris error sizes relay on baseline length between two receivers. If the distance between two receivers is short (<10km) called short baseline and these errors are neglected.

On the brilliant side of this paper, the ambiguities are resolved using the antenna swapping strategy. When these ambiguities are effectively settled the high exactness and precise user position can be evaluated.

B. Double differencing technique

The relative receiver clock bias is still has some effect on the measurements, to eliminate this noisy parameter impact on CP measurements, considered the difference between two receivers and two satellites (reference satellite and other satellite) called double differencing.

$$\phi^{km}_u - \phi^{km}_r = \lambda^{-1}[(\rho^{km}_u - \rho^{km}_r) - (I^{km}_u - I^{km}_r) +$$
$$(Tr^{km}_u - Tr^{km}_r)] + (N^{km}_u - N^{km}_r) + \varepsilon^{km}_{\phi_u} - \varepsilon^{km}_{\phi_r} \tag{9}$$

In equation (9), the new ambiguity term N^{km}_{ur} is called double-difference ambiguity [16] which is an integer (cycles). This parameter was determined from the swapping of the receivers/antenna strategy. Therefore, standard RTK fixes the ambiguities [16]-[20] to whole number figures.

Figure.7 indicates the double difference CP measurements between two receivers and two satellites. Here, assumed that the *l*-th satellite is highest elevated, therefore it will be the reference satellite. The baseline length is indicated with X. Consider a case, when the data is continuously loading from satellites, suddenly if the satellite moves from its original location the measurement may get change. This change in measurement produces the changes in the user receiver position. Therefore the change in the distance between two receivers is called baseline solution or distance error calculation. The distance error is indicated with Δd , and is directly related with the carrier phase measurements [21]-[22].

At a particular time epoch *t*, for *l*-th satellite and the two receivers the single difference equation is

$$\phi^{(l)}_{ur} = \phi^{(l)}_u - \phi^{(l)}_r$$
$$= \lambda^{-1} r^{(l)}_{ur} + \rho \delta t_{ur} + N^{(l)}_{ur} + \varepsilon^{(l)}_{\phi,ur} \tag{10}$$

Here the geometric range is, the actual distance between the satellite and two receivers given as

$$r_{ur}{}^l = r_u{}^l - r_r{}^l \tag{11}$$

Where

$$X_u = [x_u, y_u, z_u]^T, X_r = [x_r, y_r, z_r]^T$$

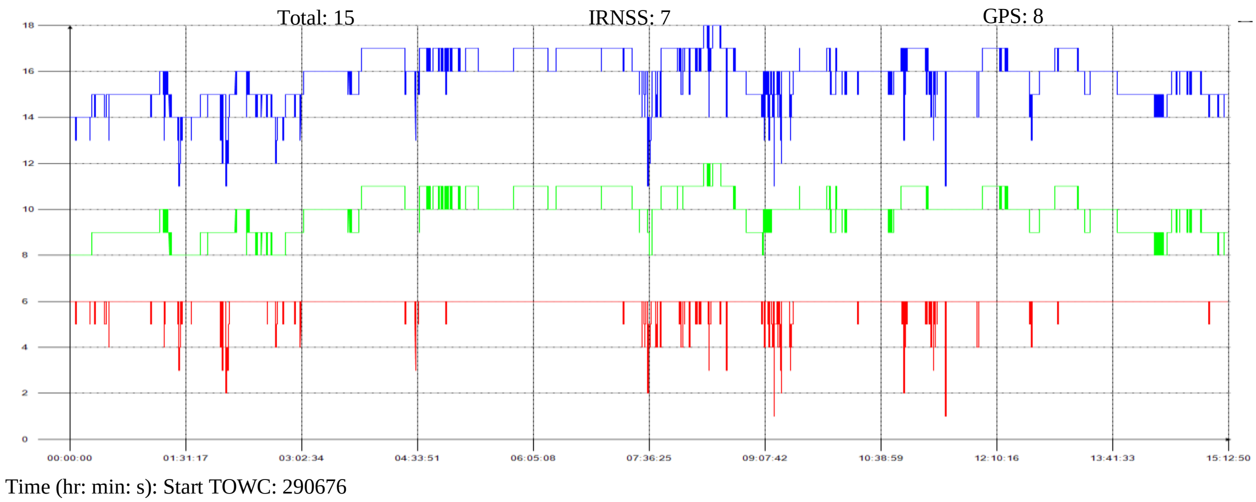

Figure 5. Time with total number of satellites for a positioning mode of IRNSS-L5+GPS

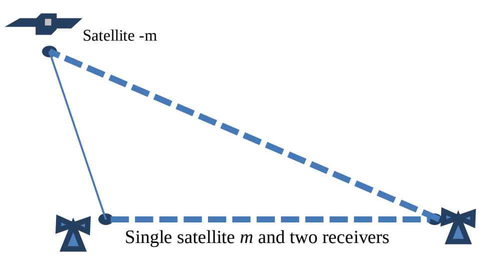

Figure 6. Single differencing between two receivers and one satellite S_m

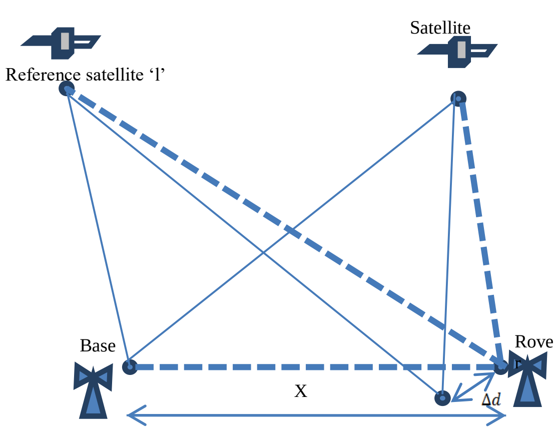

Figure 7. Double difference measurements

are the receivers position in ECEF frame and $X^l = \left[x^l, y^l, z^l\right]^T$ is the position of *l*-th satellite in ECEF frame.

If we take the difference of SD for satellites *k*-th and *l*-th, the satellite & receiver clock error terms will be cancelled out. The DD measurements of two satellites taking one satellite (*l*-th) as reference is defined as

$$\phi_{ur}^{(kl)} = \phi_{ur}^{(k)} - \phi_{ur}^{(l)}$$
$$= \lambda^{-1} r_{ur}^{(kl)} + N_{ur}^{(kl)} + \varepsilon_{\phi,ur}^{(kl)} \quad (12)$$

In single frequency (*q=L5 or S*), the double difference (DD) with k satellites in view for an epoch time '*i*' is (reference satellite is *l*-th) given as

$$\phi_q^{(1l)}(i) = \lambda^{-1} r_q^{(1l)}(i) + N_q^{(1l)} + \varepsilon_{\phi,q}^{(1l)}(i)$$
$$\phi_q^{(2l)}(i) = \lambda^{-1} r_q^{(2l)}(i) + N_q^{(2l)} + \varepsilon_{\phi,q}^{(2l)}(i)$$
$$\vdots$$
$$\phi_q^{(kl)}(i) = \lambda^{-1} r_q^{(kl)}(i) + N_q^{(kl)} + \varepsilon_{\phi,q}^{(kl)}(i) \quad (13)$$

In simplify notation

$$\phi^{kl} = \lambda^{-1} r_0^{(kl)} + N^{(kl)} + \varepsilon_\phi^{(kl)} \quad (14)$$

Relative position vector calculation:

The relative position vector X_{ur}, can be determined by

$$X_{ur} = \mathrm{X_u} - \mathrm{X_r} \quad (15)$$

Where X_r is known position of stationary reference base station vector, and X_u is the unknown user position vector.

The relative position with respect to initial estimate is

$$X_{ur} = \mathrm{X_0} + \delta \mathrm{x}$$

Where X_0 is an initial estimate vector, and $\delta\mathrm{x}$ is incremental value of position.

In linear format around the current best estimate

$$X_0 = [x_{est}, y_{est}, z_{est}]^T$$

The estimated geometric range between satellite and the receiver's position can be denoted as

$$r_{uest}{}^{l} = \sqrt{(x_{est} - x^l)^2 + (y_{est} - y^l)^2 + (z_{est} - z^l)^2}$$

$$x = x_{est} + \delta x, y = y_{est} + \delta y, z = z_{est} + \delta z \qquad (16)$$

Substituting all the above estimations to get $r_0^{\ l}$ and enabling to rewrite the equation as

$$\phi^l(t) - \lambda^{-1} r_0^l = \lambda^{-1}[(1_{est}^l)^T]\delta X + N^l + \varepsilon_\phi^l(t) \qquad (17)$$

Where 1^l_{est} is the estimated LOS vector.

The estimated line of sight vector has to be taken from a satellite to the midpoint between base and rover/user receiver.

Therefore to find relative position vector, X_{ur} the corresponding measurement geometry is

$$r_{ur}^{(kl)} = -(1_r^k - 1_r^l).X_{ur} \qquad (18)$$

For multiple epochs: in matrix format

$$\begin{bmatrix} y(i) \\ y(i+1) \end{bmatrix} = \begin{bmatrix} g(i) \\ g(i+1) \end{bmatrix} \delta X + \begin{bmatrix} 1 \\ 1 \end{bmatrix} N + \begin{bmatrix} \varepsilon_\phi(i) \\ \varepsilon_\phi(i+1) \end{bmatrix} \qquad (19)$$

In general case for multiple epochs the linearized double difference observation equation is [13], [16]:

$$Y = G\delta X + AN + e \quad \text{or}$$
$$Y = Bb + Aa + e \qquad (20)$$

For short baselines A is the unitary matrix of dimension (n x n), δX is incremental positional vector of the rover (3 x 1), Y is the difference between measured and computed carrier phase double difference for the initial position estimate (n x 1), G is the design matrix for base line co-ordinates of dimension (n x 3), N is the vector of n double difference ambiguities (n x 1) and e is the multipath effects and noise (n x 1).

4. Working Methodology

a) The information was gathered from the SAC Ahmadabad, for a baseline length of 10meters. The two IRNSS receivers taken here are made by Accord software & systems Pvt. Ltd. The time interval for the gather data is one second.
b) At first, both the receivers are at rest positions. Take the base receiver position at a decent study point. Move the receiver 2 a good ways off of 10 meters from receiver 1 along the x- direction.
c) Utilizing antenna swapping strategy take the carrier cycle estimations of receiver1 and receiver2 before swapping and after swapping. In this manner settle the ambiguities as fixed whole numbers.
d) Take these settled whole numbers framework (nx1), ionosphere, and troposphere delays; process the CP (nx1) estimations. To figure the user position (3x1) utilize these estimations with a blend of six satellite data, and the set of nonlinear equations are obtained. The satellite which is having the highest elevation angle is taken as a reference satellite. For example in the event that the satellite number 2 is highest elevated then take the mix of combinations as 32, 42, 52, 62, 72 etc..
e) Take the receiver1 and receiver2 readings from a Log document at a specific TOWC, determine the position of user for both the differencing methods. Therefore tally the determined and analyzed outcomes.
f) Calculate single difference (SD) CP, double difference (DD) CP measurements and then Linearize the equations to determine the user position using least-squares estimations (refer section III). Also, find the distance error between two receivers.
g) Here, in order to show the fluctuations in rover position nearly 350 seconds TOWC counts are taken. Hence draw diagrams from obtained values of rover position in 3D, positional errors in x, y, z directions. And also compute the separation error or distance error. The distance error is related with the CP measurement using the following eq. (21).

$$\Delta d \text{ (meters)} = (\lambda * \Delta\phi(meters))/2\pi \qquad (21)$$

Where Δd is path difference, and $\Delta\phi$ is phase difference.

If the true distance and distance error (using CP) is known then the measured (or calculated) distance is the subtraction of true with the distance error. Therefore this will be the original distance between the two receivers.

h) Complete work is implemented in MATLAB programming.

5. Results and Discussion

For a particular epoch, the incremental positional error (Table I) is determined & looked at SD and DD techniques. Because of diminished irritation parameters and biases, the DD has less error contrast with SD. Here the true rover position is taken from IRNSS IGS software. The estimated rover position (is obtained from double-difference measurement) and is compared with the true position.

The rover position will be updated by its incremental value at every epoch is given in equation (16). The baseline solution is likewise processed and compared. The measured baseline is contrasted with the true baseline (distance 10 meters). The distance error values need to be subtracted from the actual receiver position to get the exact position of the rover/user IRNSS receiver.

Figures 8-10, indicates the rover position between true range and calculated range in 3D from SD and DD measurements. Due to fewer noise impacts in double difference measurements, the estimated and true positions are about the equivalent. The error is less in double-difference measurement, subsequently, the baseline error, position estimation is smarter to contrast with single difference. For comparison, the position of user in SD, DD are computed and the obtained results are presented. These graphs are drawn for 350 second interval time of TOWC's count start from 280812 to 281161.

The comparison of error in position of rover for SD and DD techniques are shown in Table I. It shows that the error is more in SD measurements when compared to Double difference measurements, reading are noted down for a single epoch of TOWC=280850.

TABLE I. COMPARISON OF INCREMENTAL ROVER POSITIONAL ERROR IN SD AND DD TECHNIQUES

Coordinate position	Single Difference position Error for a TOWC 280850	Double Difference position Error for a TOWC 280850
X	-3.7549	-2.1259
Y	-1.0357	-0.9510
Z	5.5712	3.2560

Figure 8-10 Indicates the comparison of true range and calculated range from SD & DD carrier phase measurements of rover/user position in X, Y, Z directions for a total of 350 seconds, the x-axis indicates run time in seconds and y-axis indicates the rover position (meters) in 3D.

For a 10meters baseline length using IRNSS-UR software, the data was collected from both the receivers for a couple of hours. The SD & DD ambiguities have resolved and calculated the CP measurements; finally (at long last) the position of the user receiver is determined. The carrier wavelength for L5 is about 25.5cm, and by adding an error of 5cm (to get the cm precision the additional error ought to be in centimeters) the good accuracy in position is gotten. The double difference over a 350-seconds time intervals is plotted for L5 signal by taking the mix of six satellites (one reference satellite and five other satellite).

The carrier phase measurement obtained here is in cycles. It can be converted into units of length by multiplying the wavelength (λ). The L5 signal wavelength is 25.5cm $\Phi = \phi(\text{cycles})/4$

For a short baseline length (<10km) line of sight vector has to be taken from a satellite to the midpoint between base and rover/user receiver.

Figure 11-13 represents the position incremental value of user/rover $(\delta x, \delta y, \delta z)$ in 3D view, the x-axis indicates run time in seconds and y-axis indicates error in the rover position (meters) in 3D.

For the same 10meters baseline length because of brevity of pattern length, there is a little fluctuation in 350seconds. This distinction is due to noise and integer ambiguity. Utilizing double difference measurements, less error in the position estimation is acquired. This is the upside of utilizing DD measurements. The DD equations also eliminate (at both the receiver ends) some common error terms like path delays of satellite and receiver etc for short baselines.

In Figure 14 the blue line indicates true baseline (10m), black and red lines indicates the measured baseline (true- Δd) in SD and DD measurements. In graph x-axis represents baseline distance (meters) and y-axis represents satellite numbers, in DD technique because of less distance error the measured baseline is resembles the true baseline.

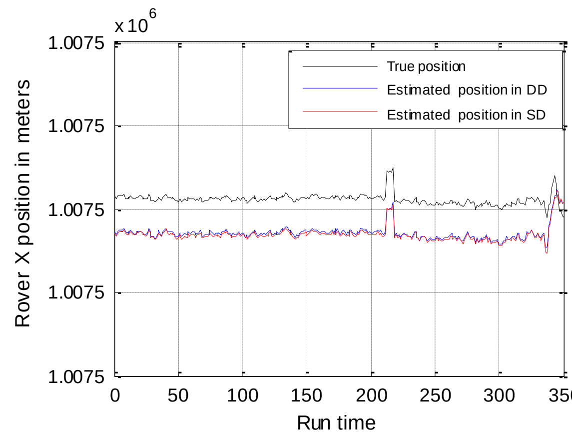

Figure 8. SD (single difference) & DD (Double difference) user position comparison in X-direction.

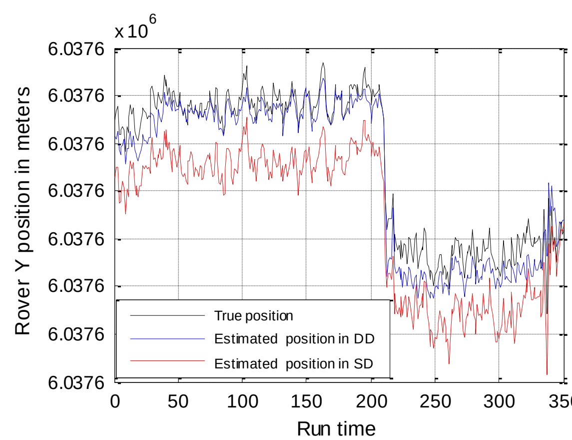

Figure 9. SD (single difference) & DD (Double difference) user position comparison in Y-direction.

The Table II indicates comparison of carrier phase measurement for SD and DD techniques, reading are noted down for a single epoch (TOWC=280850). As shown in Tables the ϕ_{SD} (cycles) is more in SD measurements when compared to Double difference measurements therefore, DD carrier phase measurement gives better solution.

The Table III indicates the comparison of distance error measurement for SD and DD techniques, readings are noted down for a single epoch (TOWC=280850). In Table IV the distance error is more in SD measurements, when compared to double difference measurements. Therefore DD carrier phase measurement gives better solution.

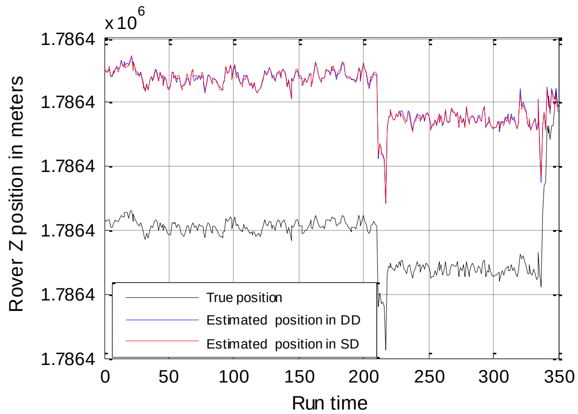

Figure 10. SD (single difference) & DD (Double difference) user position comparison in Z-direction.

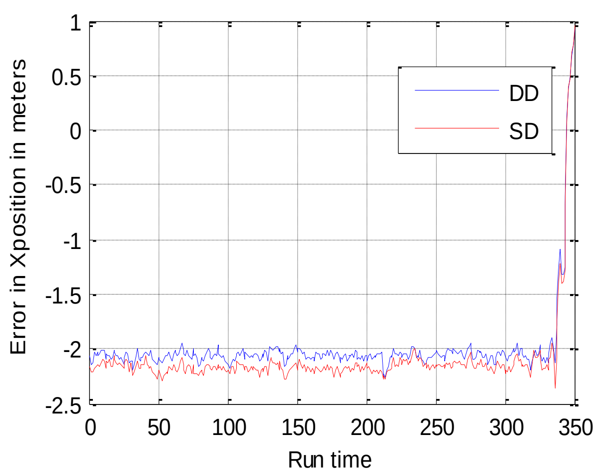

Figure 11. SD & DD rover positional error comparisons in X-direction

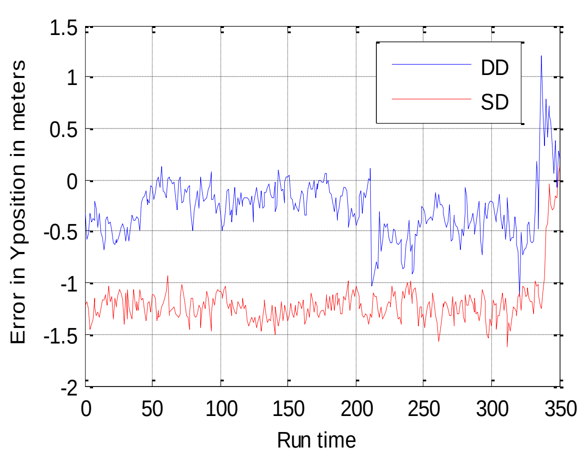

Figure 12. SD & DD rover positional error comparisons in Y-direction.

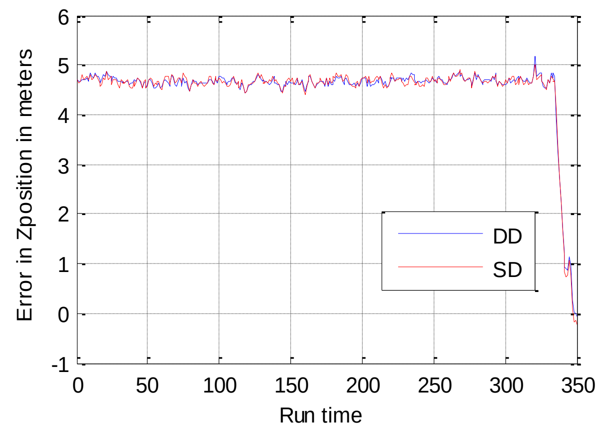

Figure 13. SD & DD rover positional error comparisons in Z-direction

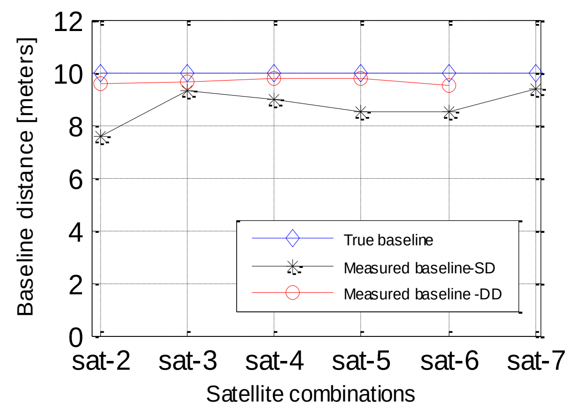

Figure 14. Baseline solution comparisons in SD & DD

TABLE II. COMPARISON OF CARRIER PHASE VALUES OF SD AND DD TECHNIQUES OBSERVED TO THE CALCULATED VALUES

S.no	ϕ_{SD} (Cycles) (For L5 Band) (single satellite)	ϕ_{DD} (Cycles) (For L5 Band) Different satellite combinations
1	Satellite 2 (PRN2) 61.6336	Satellite combinations 32 10.9711
2	Satellite 3 (PRN3) 17.7512	Satellite combinations 42 9.1239
3	Satellite 4(PRN4) 25.1380	Satellite combinations 52 5.8231
4	Satellite 5(PRN5) 38.3416	Satellite combinations 62 5.7892
5	Satellite 6 (PRN6) 38.4772	Satellite combinations 72 11.3847
	Satellite 7(PRN7) 16.0948	

In Table III, IV it demonstrates that the distance error is directly related with the carrier phase measurements. In single difference the ϕ_{SD} is maximum for satellite 2 (refer table III), therefore the Δd is maximum (2.4525m) and minimum for satellite 7 (0.6405m). Similarly in DD measurements maximum distance error 0.4711m $(\phi_{DD} = 11.3847)$ for satellite combination 72 and minimum 0.2375m $(\phi_{DD} = 5.7892)$ for satellite combination 62.

TABLE III. COMPARISON OF BASELINE SOLUTION OR DISTANCE ERROR OF SD AND DD TECHNIQUES

S.no	Distance Error in meters (SD) Δd (single satellite)	Distance Error in meters (DD) Δd Different satellite combinations (reference satellite is 2)
1	Satellite 2 (PRN 2) 2.4525	Satellite combinations 32 0.4430
2	Satellite 3(PRN 3) 0.7064	Satellite combinations 42 0.3748
3	Satellite 4(PRN 4) 1.0003	Satellite combinations 52 0.2437
4	Satellite 5 (PRN 5) 1.5257	Satellite combinations 62 0.2375
5	Satellite 6 (PRN 6) 1.5311	Satellite combinations 72 0.4711
	Satellite 7(PRN 7) 0.6405	

TABLE IV. COMPARISION OF ACTUAL BASELINE DISTANCE AND MEASURED BASELINE DISTANCE FOR SINGLE DIFFERENCE AND DOUBLE DIFFERENCE TECHNIQUES

Actual baseline distance	Measured baseline distance (SD)meters	Measured baseline distance (DD)meters
10meters	7.5475	9.5570
	9.2936	9.6252
	8.9997	9.7563
	8.4743	9.7625
	8.4689	9.5289
	9.3595	

6. CONCLUSION

The unknown user position and distance error using carrier phase measurements are investigated for baseline length of 10 meters. The carrier phase is estimated by joining ionosphere, troposphere, and pseudo ranges. These parameters are noted down from the log files (or IRNSS-UX programming window) of the receivers in .CSV format. The data of receiver 1 and receiver 2 is taken for almost three fifty TOWC's. In RTK-IRNSS, framework at a specific 280850 TOWC, the 3D positional error and distance error is determined and looked at by utilizing the reference satellite concept. In 3D the obtained positional errors at a specific TOWC is [-3.7549m -1.0357m 5.5712m] in SD, and [-2.1259m -0.9510m 3.2560m] in DD. The least distance error 0.2375m gotten by DD and most extreme distance error 2.394m for SD are obtained. The distance errors are subtracted from the calculated position to get the precise position of the user. The 3D RMSE in single difference is 2.6483 meters whereas in double difference is 2.3391 meters. This decrease in error is due to wiping out of offsets of base positional errors, and distance errors in DD method. The position error for SD and DD is in meter level. In this manner utilizing differencing strategies, obtained meter level precision in position estimation and centimeter-level exactness in separation distance error. The double difference measurement gives the better solution contrasted with single differencing in IRNSS system.

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