Reference Satellite Strategic Methods to Improve Position Accuracy of Rover with Resolved Integer Ambiguities Using Linear Combination in DIRNSS System

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1. INTRODUCTION

The Indian Space Research Organization has started implementing India’s indigenous regional (IRNSS) navigation system. The IRNSS system is designed to provide navigation services to the Indian geographical area. The basic idea behind this regional system is an alternative to the Global Positioning System, in any land, air, sea, and navigational type of applications. The main objective of the IRNSS system is to provide an accurate position in all circumstances with 24/7 coverage.

The IRNSS provides two types of services to the users, such as Standard Positioning Services (SPS) and Restricted Services (RS) [1]. The regular civilian users are serviced with SPS. The authorized (military) users are serviced with RS. In its primary service area, it is designed to provide accuracy better than 20 meters.

In the last few years, researchers have concentrated on India’s indigenous IRNSS system. The positioning topic is high interest of the research communities for a newly added GNSS system i.e. IRNSS. The main intent of the positioning topic is, to determine the user/rover position by measuring the distance between the satellite and receiver (range). This range is calculated either by the travel time (pseudo-range) of the signal or in terms of a number of cycles (phase measurement). In this paper, the Carrier Phase (CP) measurement is used to estimate the position.

The IRNSS is a Dual Frequency (DF) receiver (L5/S1 bands), however, in most of the investigations solely Single Frequency (SF) (either L5 or S1) is considered. In IRNSS system depending on the adopted...
application either the SF or DF is selected. The adopted SF resulted in an inaccurate position and unstable ambiguities. However, the expensive DF receivers have an advantage of a shorter time for ambiguity resolution.

In this work, the ambiguities are fixed using WL, Wide Lane linear mix (Wide-Narrow-Lane, or WNL), and observed the reliability. The RBARS algorithm is developed to estimate the user position in WL technique. The convergent time is going to be reduced if these ambiguities are quickly fixed. This paper presents an amalgamate approach, to compute a 3D user/rover position. With this linear combination, the 3D RMS errors are computed and compared for WL classified measurements.

In Section 2, a detailed description of WL is presented. In Section 3, a detailed concept of position estimation using the RBARS algorithm is explained. In section 4, the results are discussed and concluded the paper in Section 5.

2. DESCRIPTION OF WIDE LANE TECHNIQUE

Differential IRNSS (DIRNSS) is the most acquainted and well-liked methodology that works based on correction information of Carrier Phase (CP) measurement and forwarding this correction to end-users. Figure 1 shows the setup of DIRNSS system for user/rover position estimation. The DIRNSS system consists of two receivers which simultaneously track the same IRNSS satellites. In the DIRNSS system with more than two satellites and two receivers, the CP measurement can achieve accuracy in a few centimeters.

In this work, the CP measurement is used to estimate the position. The CP based positioning technique provides a more accurate positioning solution compare to the code-based positioning technique [2]. But the CP measurement included with integer ambiguity as an extra parameter. In CP measurements, the ambiguities have to resolve for the desired accuracy in user position. Once the ambiguities are correctly fixed, the time required to determine the user position is decreased. The IRNSS navigation message file contains the data, included with the satellite positions, receiver-satellite range, ionosphere delay, satellite clock bias, and receiver position. The information of these parameters is collected either from a data file or from the video record. The data sets are noted and the proposed algorithm is practically implemented in MATLAB software. The estimated reference receiver positions are validated with respect to the survey location. The positional errors and their RMS values are calculated using the DIRNSS system. The obtained RMS errors are compared for SF and DF combinations.

The frequencies of L5 and S bands are considered as (1176.45 MHz and 2492.028 MHz). The corresponding WL frequency is 3155.78 MHz and NL frequency is 3668.478 MHz [1].

Table 1 shows the various parameters of WL and NL techniques. The WL frequency is less compare to NL frequency therefore the WL wavelength is longer compare to NL wavelength. The better integer estimate is obtained with the longer wavelength ($f_{WL}$). Therefore, to resolve ambiguities the WL is best to compare to NL. It is harder to determine the Ambiguity Resolution (AR) in NL technique. In position estimation, the combination of WNL is used popularly known as WL linear mix [3]. This combination is very helpful for the determination of ambiguities. Therefore, with this combined technique more accurate results are obtained than individual measurements.

### Table 1. Comparison of WL and NL calculations

| Parameter         | NL       | WL       |
|-------------------|----------|----------|
| Frequency         | $f_{NL}$ = $f_{L5} + f_{S}$ | $f_{WL}$ = $f_{L5} - f_{S}$ |
| Wavelength        | $\lambda_{NL}$ = 81.8cm | $\lambda_{WL}$ = 0.2280m |
| Integer Ambiguity | $N_{NL} = N_{L5} + N_{S}$ | $N_{WL} = N_{L5} - N_{S}$ |
| CP                | $\phi_{NL} = \phi_{L5} + \phi_{S}$ | $\phi_{WL} = \phi_{L5} - \phi_{S}$ |
|                   | $r_{L5S} = N_{NL}$ | $r_{L5S} = N_{WL}$ |
| Integer (fixed)   | $\tilde{N}_{NL} = \frac{\phi_{NL} - r_{L5S} \lambda_{NL}}{\lambda_{NL}}$ | $\tilde{N}_{WL} = \frac{\phi_{WL} - r_{L5S} \lambda_{WL}}{\lambda_{WL}}$ |

where $\lambda_{L5S}$ is the wavelength of L5 and S bands, $r_{L5S}$ is the pseudo range of L5 and S signals, $I_{L5}$ and $T_{L5}$ is WL ionosphere, troposphere delay, $N_{L5S}$ is the WL DD integer ambiguity, and $\epsilon_{L5S}$ is the effects due to multipath.
2. 1. Amalgamate of WL, NL and IF Mode In this section to dispense with the ionosphere delay on estimations, the IF model straight amalgamate is used. In this combined linear technique, WL and NL are useful in ambiguity determination. The estimations of ambiguities are determined for individual satellites by utilizing WL and NL techniques. These obtained real number ambiguities are assessed to compute the user/rover position. To acquire centimeter precision, the precise IGS IRNSS satellite orbital parameters, satellite clock offsets, etc. are required. With this combined augmentations, the equipment delays, comparative offsets of receiver, satellites, and other different errors are reduced. In this amalgamate, the IF model is utilized to decrease the effect of the ionosphere and a WL linear mix is utilized, for ambiguity resolution. This combined amalgamate is termed as RBARS algorithm. This algorithm is used for position estimation. The required accuracy is achieved with this linear combination. Three amalgamations of WL, NL, and IF model are utilized for position estimation [3]. With the accurate IGS IRNSS satellite orbital parameters, the cm-level accuracy in the IRNSS system is achieved. To get the benefit of every one of these strategies, the three methods are combined and solved together with the least-squares modification [4]. Therefore, the ambiguities are resolved for the corresponding CP measurement, and the baseline solution is determined. When the ambiguities are settled, the carrier phase is expressed in the units of length for position estimation. The computed results of fixed ambiguities and the baseline errors are forwarded to the reference base position to get the precise user/rover position.

3. POSITION ESTIMATION USING RBARS ALGORITHM

In DIRNSS system, due to differential measurements, these errors are greatly reduced or eliminated. To reduce the impact of ionospheric delay in this paper IF linear combination is used [4]. In IF method, the first-order effect of the ionosphere is eliminated. In addition to the IF combination, the proposed RBARS algorithm eliminates the effects of multipath, receiver/satellite offsets etc. Due to the differentiation of two receivers, the hardware delays are also reduced. The convergent time is greatly reduced, and thereby the position accuracy is improved. Therefore, this is the advantage of using of RBARS algorithm. The following are the steps to determine the positional errors in RBARS algorithm.

a. Initially, the two IRNSS receivers (manufactured by Accord software Pvt limited) are kept a few meters distance away from each other at known coordinates. Measure the baseline length and collect the data sets in RINEX/CSV format from IGS IRNSS-GUI.

b. Select the WL classified type: SFSD/SFDD /DFSD/DFDD.

c. Apply the integer fixing using WL/WNL calculations and compute the fixed ambiguity and averaging of cycles (Table I). [5]

d. The carrier phase measurement also contains the hardware delay, phase bias, and receiver, satellite offsets. The WL phase observables of Single Difference (SD) between two receivers and a single satellite is written as

\[
(\Phi L S^3)^{\text{WIDE}} = L S^5 + \lambda N S^N L S^5 \frac{f L S^I L S}{f L S} + \frac{f L S^I L S}{f L S}
\]

(2)

where, \( L S^5 \) and \( I S \) are the WL ionosphere delay in the IF model, \( i \) represents the satellite number, \( c \) is the speed of light in m/s, \( \delta_{xik} \) is receiver offset and \( \delta_{rik} \) is the satellite offset [6].

e. The straight mix of the WL, NL, and without ionosphere is used to fix the ambiguities (\( N_{WZ}, N_{NL} \)). Here, for a couple of satellites, the position of user/rover is determined with these fixed ambiguities. The unknown state vector of size 13x1 is defined as

\[
X = [x, y, z, N_{WZ}, N_{NL}]^T
\]

(3)

where \( x, y, z \) are the unknown user/rover position in 3D plane.

f. The Line of sight vector of estimated rover position and satellites ephemeris for the design matrix is defined as:

\[
U = \begin{bmatrix}
(u_{xyz})_{nf,i} & 0 & 0 \\
(u_{xyz})_{nf,i} & 1 & 0 \\
(u_{xyz})_{nf,i} & 0 & 1
\end{bmatrix}_{(15x1)}
\]

(4)

\[
(u_{xyz}) = \frac{[(x_{est} - x'), (y_{est} - y'), (z_{est} - z')]^T}{\sqrt{(x_{est} - x')^2 + (y_{est} - y')^2 + (z_{est} - z')^2}}
\]

(5)

where \( n \) is the number of satellites.

The size of vector \( u_{xyz} \) is (\( n-1 \)) x 3 and identity matrix of size \((n-1) \times (n-1)\).

g. The refreshed covariance lattice at each epoch is given as

\[
P(t) = U^T P U + P(t)^{-1} + \epsilon_{\text{noise}}
\]

(7)

where, \( P \) is a weight lattice for wide path mixes.

This designed weight lattice depends upon two factors like the correlation between satellite and receiver, and the standard deviation of WL/NL estimations. Therefore, the weight lattice is characterized as:
\[ DRD = D\sigma_{\text{WL} ID}^2 \]  

The \( D \) indicates the correlation between individual receivers and satellites. The size of \( D \) depends on the type of differencing technique (SD/DD). The \( D = [-I]_{15 \times 15} \) is a unitary matrix of size \((15 \times 15)\) and \( \sigma_{\text{WL}} \) is the standard deviation of WL estimations. The characterization of NL weight grid is similar to WL. Therefore, by considering all these characteristics the weight grid is written as:

\[ P = (DRD)^{-1} \]

h. The adjustment in the incremental rover position is characterized as:

\[ \nabla X = [(U^T P U) + (P_t)^{-1}] U^T P L \]

where, \( P_t \) is the initial estimated covariance matrix and \( L \) is a miscellaneous vector obtained from WL, NL measurements.

i. Finally, the assessed rover position is equivalent to a steady position and prior positional vector. Therefore, the final rover position is estimated using the least square modified method as:

\[ x = x_{\text{est}} + \nabla x, y = y_{\text{est}} + \nabla y, z = z_{\text{est}} + \nabla z \]

DFDD for both WL and WNL measurements. In WL the standard deviation is reduced from 4.7403 to 1.5749 cycles, whereas in WNL linear mix it is reduced from 1.3293 to 0.2354 cycles.

Figure 2 represents the RBARS algorithmic steps. The first step in this algorithm includes the selection of frequency, selection of differeniation techniques, and correlation vector. The size of matrices depends on the type of differencing technique (SD/DD).

### 4. RESULTS AND DISCUSSIONS

The IF linear method eliminates the impact of the first-order ionosphere effect on the measurements. This linear combined IF method can stop the full ambiguity value determination. Therefore, to see the full ambiguity values and fixing these ambiguities as integers, the mixture of the WL and NL is used \([7-8]\). In this analysis, to fix the ambiguities the WNL is employed, and it doesn’t have a direct impact on the positional error determinations \([3]\).

In this section, the ambiguities are fixed by WL and WNL combination techniques. The uncorrelated estimations from many epochs would lessen the standard deviation of estimation \([9]\). These results are obtained using MATLAB software.

Table 2 represents the comparison of standard deviation with successive epochs for WL and WNL ambiguities (cycles). By averaging process, the deviation in ambiguities is decreased from SFSD to SFDD measurement of carrier phase.

#### Table 2. Standard deviation of ambiguities in cycles

| Parameter | SFSD | SFDD | DFSD | DFDD |
|-----------|------|------|------|------|
| WL (cycles) | 4.7403 | 3.6934 | 3.578 | 1.5749 |
| WNL (cycles) | 1.3293 | 1.0024 | 0.6283 | 0.2354 |
The rover position incremental values are assessed in 3D (X, Y, Z) using RBARS algorithm and forwarded this error to get the precise user/rover position [12-13]. The improvement in position occurred after fixing the ambiguities. In Table 3, the positional errors are calculated and compared for proposed WL classified methods. The RMS errors are listed in 3D (X, Y, Z) plane for a short baseline. The minimum RMS error is obtained in DFDD (50.32 cm).

From Figures 6-8, it is observed that about 30 seconds the error values are [1.5 1.2 -0.5] meters in 3D plane for DFDD, thereafter this error is diminished to
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ar, the DFDD is reliable and best technique because of fewer error impacts.

Therefore, due to decreased convergent time the high reliable position is obtained for DF compare to SF.

The linear combination of WNL and IF with CP measurements is implemented. These models help to resolve the ambiguities and to reduce the first-order ionosphere impact on measurements. Therefore, due to decreased convergent time the high reliable position is obtained for DFDD.

5. CONCLUSION

In this paper, the WL and WNL techniques are used for AR. Using WL, WNL ambiguities are fixed, and their standard deviation is compared. The least standard deviation of 0.2354 cycles is obtained in DFDD using WNL linear mix. Therefore, a reduction in the standard deviation of carrier cycles ends up in higher position accuracy. With the averaging process, the least distance error ~3 cm is obtained for DFDD. To estimate the position combination of WL, NL, and IF CP estimations are utilized. Hence with direct amalgamate of the three methods, the incremental rover positional error in (x, y, z) 3D plane is resolved with modified least squares.

Thereby, the precise rover position in latitude, longitude, height is computed. Due to fewer error impacts in baseline solution and AR, the DFDD is reliable. This RBARS algorithm is implemented by the MATLAB software and this gives the user position at the highest accuracy. The average obtained RMS errors in the 3D position are compared for different types.

6. REFERENCES

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Persian Abstract

چکیده

یک سیستم منطقه ای طراحی شده برای برای تهیه موقعیت دقیق کاربر در هر شرایط با پوشش 24/7 است. این سیستم در طیف وسیعی از برنامه ها با دقت بهتر از 20 متر در منطقه سروس اولیه استفاده می شود. خدمات موقعیت، سرعت و زمان بندی IRNSS برای کاربران هندی و همچنین 1000 کیلومتری مرز هنگ برای کاربران متفاوت است. موقعیت با یک دقت در تکنیک اندامه کلیه فاز به حل ابهامات بستگی دارد. در این مقاله، تمرکز اصلی بر حل موتر ابهامات و در نتیجه تخمین موقعیت است. در این مقاله، موقعیت خودکار و تخمین روشهای دو دقت به دست آمده. در این مقاله از الگوریتم Wide Lane (WL) استفاده شده است. برای رفع ابهامات، موقعیت روشهای طبقه بندی شده‌ای مبتنی بر تفاوت فاز حامل (CP) پیشنهاد شده است. برای تخمین تک فرکانسهای فازی WL، از الگوریتم Reference Base و Reference Satellite (RBARS) استفاده می‌شود. بدین ترتیب، تخمین‌های سه بعدی موقعیت محاسبه می‌شود. میانگین خطاهای مربع ریشه محاسبه می‌شود.