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NavIC Carrier-Phase Based Relative Positioning using L5 Single Frequency Measurements

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ABSTRACT

India's satellite navigation system NavIC is transmitting precise carrier phase measurements at L5 (1176.45 MHz) and S (2492.028 MHz) band frequencies which is required by the users for very precise positioning applications. However, to have full advantage of precise carrier phase measurements other error sources such as ephemeris & clock errors, ionospheric & tropospheric errors needs to be eliminated from the carrier ranges. One prevalenttechnique is to use two NavIC receivers in differential or relative mode by designating one receiver as reference or base receiver whose position is known very accurately and other one as rover whose position is to be estimated. Common errors are eliminated using differenced carrier phase measurements from reference & rover when both receivers are tracking common visible satellites and user is only required to resolve integer ambiguity which is still present in the differenced measurements. Therefore, in this study, carrier- phase based relative positioning algorithm is developed and implemented in C language using NavIC receivers in base-rover configuration at L5 frequency. Double differenced carrier phase data with Least Squares Ambiguity Decorrelation Adjustment (LAMBDA) technique for integer ambiguity resolution is used for this purpose. Major highlight of the paper is implementation of end to end approach and LAMBDA method in C-language using NavIC measurements. Validation of the developed algorithm is done for 5.92 meter baseline(distance between base & rover)in base-rover configurationwith rover receiver in static condition in post-processing mode using 24 hour data of 7th September 2017 collected at SAC Ahmedabad. Processing of the data is done for different set of epochs. Centimetre (cm)-level relative position accuracy is achieved with horizontal, vertical and RMS 3D error estimates as 11 cm, 30 cm and 32 cm respectively for 2700 epochs. This development may be very useful for the applications such assurvey and land records,5G technology for determining the cm level sensor positions, driverless vehicles, geodesy, disaster monitoring such as landslides etc. in which cm level positioning accuracy is required.

KEYWORDS

Relative positioning, Differential NavIC, Carrier-Phase, Double difference, Integer Ambiguity, LAMBDA, SVD

INTRODUCTION

Navigation with Indian Constellation (NavIC) formerly known as IRNSS, designed & developed by Indian Space Research Organization (ISRO), transmits dual frequency signals on L5 (1176.45 MHz) and S (2492.028 MHz) band frequencies and is a promising system for its all-time and all weather coverage [1, 2]. NavIC receivers are able to generate code phase based ranges (pseudo-ranges) and very precise carrier ranges after receiving the transmitted signals from NavIC satellites. Pseudo-ranges are robust but are not very accurate due to presence of severe code noise and multipath. However, carrier ranges are very precise but initial number of integer cycles between satellite and receiver, known as integer ambiguity, is never known. Resolving integer ambiguity is difficult and time consuming process. If integer ambiguity is resolved correctly NavIC receivers may provide cm level position accuracy using very precise carrier-range measurements. One way to explore precise carrier ranges is to use them in differential or relative mode. Relative positioning concept works in base-rover configuration in which one receiver is kept at very well-known position designated as reference or base and other one is designated as rover. The idea is to eliminate the common sources of error present in the carrier range by taking double difference (between satellites & between receivers) of the two data sets from base and rover as shown in Figure 1. These common error sources mainly include ephemeris & clock errors, ionospheric & tropospheric errors and relative receiver clock bias.

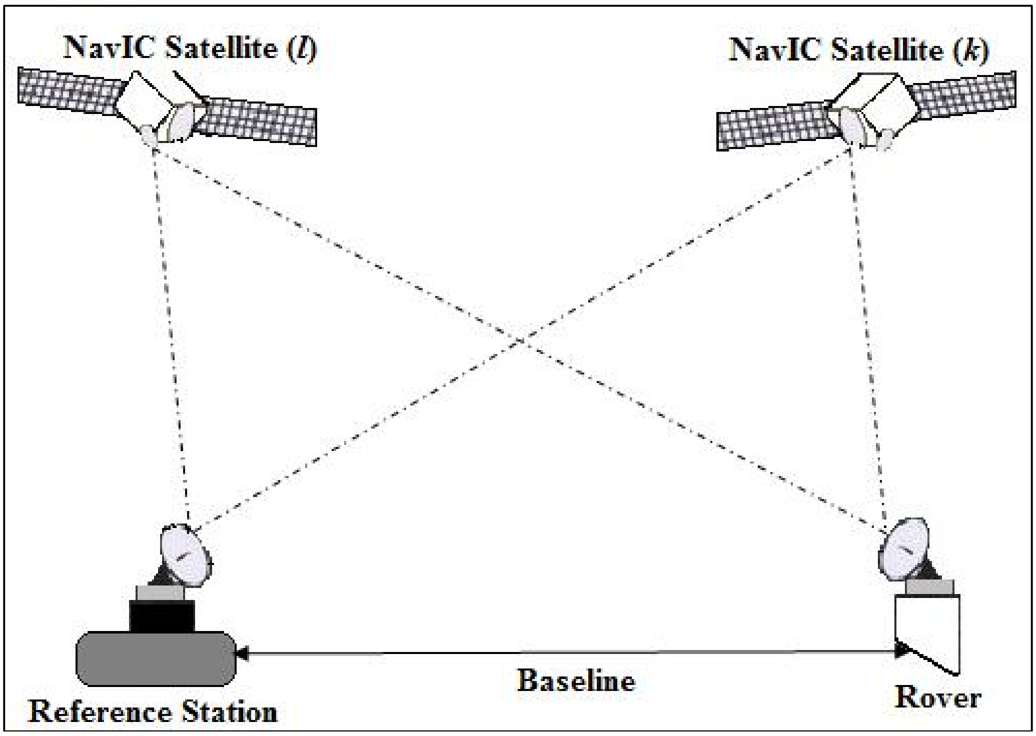

Figure 1: Concept of the Relative Positioning System

Therefore, in this study, single frequency L5 NavIC receiver data is used from base-rover set-up installed for continuous data collection and measurement generation at SAC, Ahmedabad. Integer ambiguity term is tackled using LAMBDA method. LAMBDA method was developed by Delft University Netherlands in MATLAB [6] and is available on university website for download. However, authors have implemented LAMBDA method in C languagewhich has reduced the processing time almost by half in comparison to MATLAB implementation. Testing of the concept has been done for baseline of 5.92 meter at Ahmedabad, India. The results are then compared and validated using Surveyed locations.

METHODOLOGY

The basic equation of the carrier phase range measurement in cycles is,

$$\emptyset = \lambda^{-1}[r - I + T] + f(\delta t_u - \delta t^s) + N + \varepsilon_\emptyset \quad (1)$$

Where$\lambda$is the wave length of the signal, r is the true range between user position and satellite position, I and T are ionospheric and tropospheric propagation delays,f is the carrier frequency,$\delta t_u$is receiver clock bias and $\delta t^s$is the satellite clock bias, N is integer ambiguity and ε_ϕ is noise error.

The carrier phase measurements from NavIC receivers are used in differential mode (between reference and rover receivers) for the algorithm. The double difference carrier range will automatically take care of the common sources of errors like ionospheric delay and clock biases for short baseline (< 10 km) [4].

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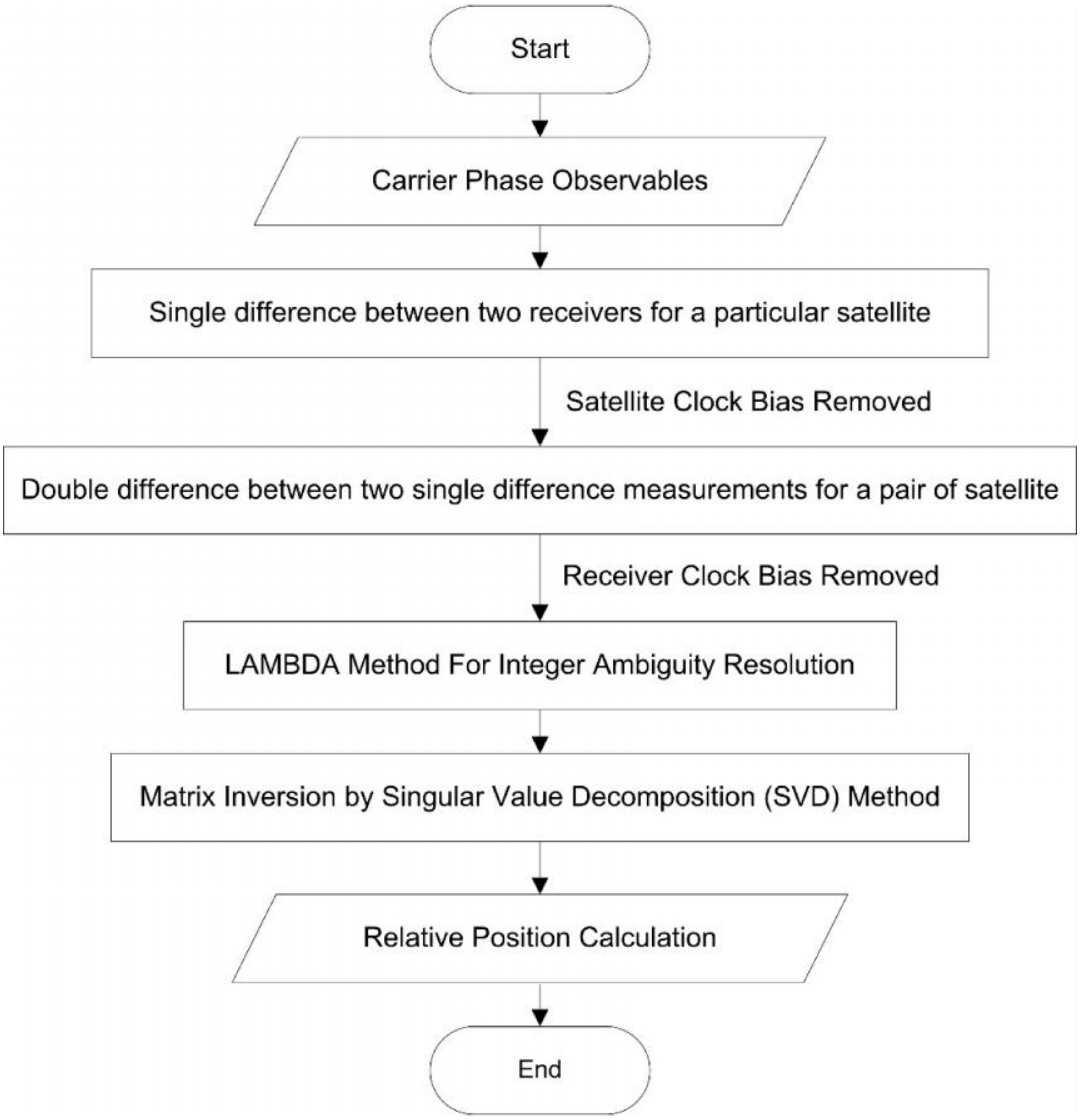

Figure 2: Flow Chart of Carrier-Phase Based Relative Positioning

After performing double difference by taking measurement difference between two satellites and two receivers at the same epoch, Satellite and receiver clock bias and satellite ephemeris error is removed [4]. The resulting equation between carrier phase and range will be,

$$\boldsymbol{\phi}_u^k = \boldsymbol{\lambda}^{-1}\boldsymbol{r}_u^k + \boldsymbol{N}_u^k \qquad (2)$$

$$\boldsymbol{r}_u^k = -(\mathbf{1}_r^k - \mathbf{1}_r^l)\boldsymbol{x}_u \qquad (3)$$

Where, $\boldsymbol{\phi}_u^k$, $\boldsymbol{r}_u^k$ & $\boldsymbol{N}_u^k$ denotes the double difference of carrier phase, range and integer ambiguity between receiver $\boldsymbol{u}$ and $\boldsymbol{r}$ and satellite $\boldsymbol{k}$ and $\boldsymbol{l}$, respectively. $\boldsymbol{x}_u$ is the baseline vector between two receivers and $\mathbf{1}_r^k$, $\mathbf{1}_r^l$ are the unit direction vector from receiver $\boldsymbol{r}$ to satellite $\boldsymbol{k}$ and $\boldsymbol{l}$, respectively.

The integer ambiguity term $\boldsymbol{N}_u^k$ is then estimated using LAMBDA method which is a proven optimal technique for integer ambiguity resolution [3, 4, 5]. The float solutions with its variance covariance matrix of the equation for implementation of LAMBDA method is calculated by solving linearized double difference observation equations via normal equations. The system of normal equations is $\boldsymbol{N} \quad = \boldsymbol{r}$, with $\boldsymbol{N}$ the normal matrix and $\boldsymbol{r}$ the right hand side [6, 7]. The Cholesky factorization [8] of the normal matrix is made, i.e $\boldsymbol{N} = \boldsymbol{C}\,\boldsymbol{C}^*$, with matrix $\boldsymbol{C}$ a full rank lower triangular matrix. The system $\boldsymbol{C}\boldsymbol{C}^*\boldsymbol{x} = \boldsymbol{r}$ is then solved by forward and backward substitution. Once the integer ambiguities are computed, they are used to correct the "float" estimate to obtain the fixed solution of baseline vector.

SOFTWARE IMPLEMENTATION

The C code was developed for precise relative positioning and was optimized to process the data for different epochs to resolve integer ambiguity in more accurate way for getting better position accuracy. Code for Singular Value Decomposition (SVD) has also been implemented in C language for matrix inversion. C language was chosen for its better performance and faster execution.

DATA PROCESSING AND RESULTS

Relative position between reference and rover receivers was obtained using NavIC carrier range measurements. Relative position errors are highly dependent on the distance between base & rover receivers known as base line vector and geometry of the satellites.In this study, Relative positioning was done for 5.92 m baseline at Ahmedabad, India. Analysis was done in post-processing mode with rover receiver in static mode. Data was collected using Accord NavIC receivers at every 1 second interval. Single frequency carrier phase measurements on L5 (1176.45 MHz) were used for the analysis.

Validation of the results was done by comparing the obtained position vector magnitude with accurately known position vector between reference and rover stations.

Online positioning service of the US National Geodetic service OPUS [9] was used for obtaining the accurate positions of the rover receiver. Table 1 shows the true Earth Cantered Earth Fixed (ECEF) positions of reference and rover receivers.

Table 1. True ECEF Positions for Reference & Rover Receivers

	X (m)	Y (m)	Z (m)
Reference receiver	1764203.720	5601789.514	2479086.662
Rover receiver (6 m baseline)	1764207.992	5601790.248	2479274.625

Integer ambiguity in carrier phase measurements has been resolved by taking 1800, 2640, 2700, 3000, 3300 and 3600 epochs at a time and relative errors in x, y and z coordinates have been estimated. The reason for taking these epochs was that below 1800 epochs the success rate of integer ambiguity resolution is low and higher than 3600 epochs does not improve the results. Analysis was done taking into account 24 hours data. Relative position error in ECEF coordinates has been calculated using magnitude of the estimated and true baseline vectors. Horizontal and vertical relative positions errors have been computed using a matrix conversion from ECEF to ENU (East, North and Up) frame.

The test results with two NavIC Accord receivers with sampling time of 1 second for 7th September 2017 at SAC campus have been presented here. Baseline length between reference receiver and SAC station is 5.92 m.

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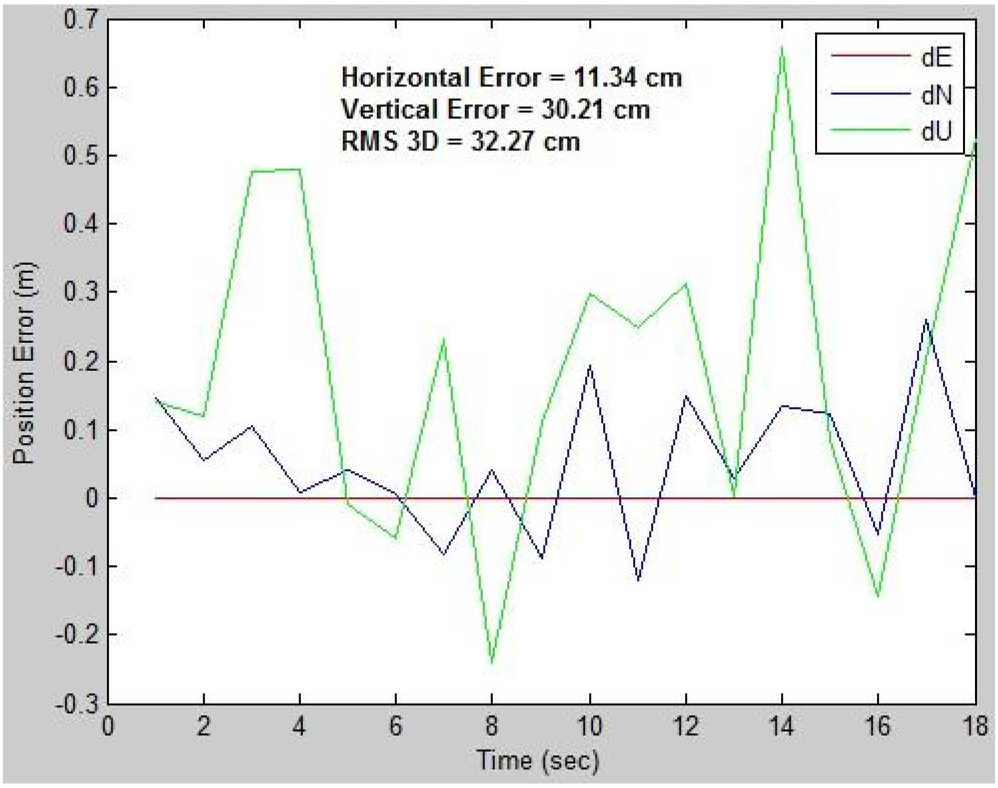

Figure 3: Relative Position Error using NavIC data of 7th September 2017 for 2700 epoch for 5.92 m baseline

Figure 3 shows the Estimated Horizontal errors, estimated vertical errors and RMS 3D Errors between two receivers for 7th September 2017 Data for 2700 epochs.

Table 2: Horizontal, Vertical and RMS 3D errors for different epochs

No. of Epochs (in Sec)	1800	2640	2700	3000	3300	3600
Horizontal Error(m)	0.31	0.28	0.11	0.28	0.29	0.28
Vertical Error(m)	0.47	0.46	0.30	0.36	0.43	0.47
RMS 3D Error(m)	0.57	0.54	0.32	0.46	0.52	0.54

Table 2 shows the horizontal, vertical and RMS 3D errors of relative position errors in baseline vector magnitude.

CONCLUSION

NavIC carrier phase based relative positioning algorithm was developed and implemented in C-language. Major contribution of the paper is to develop and implement end to end approach and integer ambiguity resolution algorithm LAMBDA (Least Square Ambiguity Decorrelation Adjustment) in C language and carry out the analysis using NavIC L5 carrier phase measurements using data collected for 5.92 m baseline at SAC. Integer ambiguity resolution was carried out for different epochs such as 1800, 2640, 2700, 3000, 3300 and 3600 and Horizontal, vertical and RMS-3D errors were estimated with respect to the known baseline of 5.92 m. It is concluded from the analysis thatleast relative position errors are obtained by processing 2700 epochs at a time. Horizontal, vertical and RMS 3D error estimates achieved in relative position error with 2700 epochs are 11 cm, 30 cm and 32 cm respectively for the 24 hour data of 7th September 2017.

APPLICATIONS

The applications for the developed algorithm are in Landslide monitoring system, 5G technology for determining the centimetre level sensor positions, driverless vehicles, Validation of terrestrial navigation system, Aviation, Precision Agriculture, Mining, Survey and Land Records etc.

FUTURE PROSPECTS

Based on the cm level accuracy results obtained from 5.92 m baseline, same algorithm can be tried with other different baselines. Same algorithm can also be worked with different set of epochs to optimize the results further.

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