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Implementation and Analysis of Grid-Based Ionospheric Correction Technique and Positioning Errors of NavIC + GPS ARAMIS SDR Receiver

Mehul V. Desai, Darshna Jagiwala & Shweta N. Shah

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Implementation and Analysis of Grid-Based Ionospheric Correction Technique and Positioning Errors of NavIC + GPS ARAMIS SDR Receiver

Mehul V. Desai [a], Darshna Jagiwala [b] and Shweta N. Shah [b]

[a]Government Polytechnic for Girls, Athwagate, Surat, India; [b]Sardar Vallabhbhai National Institute of Technology, Surat, India

ABSTRACT
In this paper, our main work is to observe the performance of the Indian Navigation Constellation (NavIC) + GPS ARAMIS SDR receiver. The ARAMIS receiver performances are observed in terms of acquisitions, tracking, ionospheric correction techniques (Klobuchar and grid-based GIVD model), and positioning errors results. Implementation of the GIVD model is validated by comparing the results of the Accord receiver. From the comparative analysis of positioning error, we observed that NavIC + GPS gave better results than NavIC and GPS alone.

KEYWORDS
Acquisition; Ionospheric delay; NavIC signal; Positioning accuracy; Post-processing parameters

1. INTRODUCTION

Global Navigation Satellite Systems (GNSS) play a vital role in many applications that demand high accuracy and precision positioning [1]. Satellite signals can be affected by many sources of error, such as ionospheric irregularities, multipath, interference, and more [2]. NavIC is an autonomous regional satellite navigation system developed by the Indian Space Research Organization (ISRO), which covers India and a region extending 1500 km (930 mi) around it [3,4].

Many start-ups are emerging in India, and it will provide opportunities for a significant modernization of the existing infrastructure. India's space industry is increasingly opening up to the private sector, which will lead to many GNSS-based solutions [5]. With such a scenario, NavIC or any GNSS receivers should exploit future applications' possibilities. From this perspective, a Software-Defined Receiver (SDR) can be a convenient tool for researchers. The SDR-based NavIC receiver has its importance. SDR is defined as having a front-end, where received navigation signals are digitized processed with the help of software [6]. SDR allows users to access, visualize, and possibly modify signal acquisition, tracking, and processing approaches. The important thing is that it can enable extreme customization by replacing the dedicated hardware components through software modules [7]. Hence, SDR solutions have become popular. They can provide complete control of receiver modules, so the researchers can integrate and test their methods or algorithms without redesigning all receiver chains [8]. Few pieces of works of literature have been studied here to emphasize the importance of the SDR approach in the navigation field.

- In [9], the authors have developed MATLAB-based NavIC Software Receiver (NavICSR). The preliminary results of the acquisition, tracking, and navigation solution is presented along with the performance evaluation of the developed NavICSR framework for the real-time capability.
- Furthermore, the same authors [10] have developed a module to decode 1A short broadcast messages of the L5-band with NavICSR.
- The SDR integrations provide research capabilities for many purposes, such as indoor and vehicular navigation in GPS denied areas [11].
- The SDR solutions provide access to tracking correlators for multipath studies in urban canyons [12].
- Along with this, the authors have presented a LabVIEW (LV) and C/C++-based GPS L1 receiver platform with real-time capabilities using SDR [13].
- Recently, the SDR-based alternative spatial processing method has been proposed to detect and suppress spoofing signals [14].
- Similarly, NavIC SDR receiver is used to analyze the influence of RFI on NavIC tracking loop parameters [15], interference detection and mitigation using a Vector Tracking [16], and spatial processing method to detect and suppress spoofing signals [17] with the help of SDR platform. This article [17] describes the ION GNSS SDR metadata standard and associated.

Figure 1 shows the general block diagram of the navigation SDR receiver. The RF front-end is designed by IP Solution Japan [18], which is customized to work with the antenna of Accord dual-frequency NavIC receiver [19]. Accord receiver is provided by Space Applications

Centre (SAC), Indian Space Research Centre (ISRO), Ahmedabad for funded AO project (NGP-08). A detailed description of the Accord receiver is available in [4]. The customized ARAMIS SDR receiver supports the signals of the NavIC L5- band and GPS L1-band.

The RF front-end receives the NavIC + GPS composite signals using an antenna. It modulates it to an Intermediate Frequency (IF). It passes to the different blocks like a filter, Analog to Digital Converter (ADC), Automatic Gain Control (AGC), acquisition, tracking, and navigation processor. The output of the RF front-end of NavIC + GPS ARAMIS SDR receiver is raw digital IF data, recorded by the streamer software shown in Figure 2. The streamer software has two active tabs for recording and decompressing Digitized Intermediate Frequency (DIF) data files. The recorded DIF data is further processed through the software part to acquire the results.

After the signal is acquired, the satellites are tracked through their dedicated channel. In the NavIC + GPS ARAMIS SDR receiver, the GPS satellites are set to 1–14 (Channels), and the Indian Regional Navigation Satellite System (IRNSS)/NavIC satellites are set to 57–70 (Channels). After the receiver tracks the visible satellites, and after determining the frequency and phase of the carrier, it extracts navigation data, which is called course information.

Since the signal received from the antenna is affected by many intentional and unintentional error sources, the pseudorange should be corrected before the position estimation to improve the system's positioning accuracy. Among all the sources of error, the ionospheric effect is the main factor [20–22]. Therefore, we have implemented and observed the impact of various ionospheric error detection and correction techniques, such as dual-frequency correction, single-frequency Klobuchar, Grid Ionospheric Vertical Delay (GIVD) [2], Taylor Series Expansion (TSE) [21], and Multivariate Polynomial Regression (MPR) Method [22] for NavIC + GPS. The impacts of unintentional interference [23] and intentional interference (Jamming) [24] is available.

Here we have implemented the single-frequency ionospheric corrections models (Klobuchar and GIVD) for the L5-band NavIC ARAMIS SDR receiver. The GIVD model is more efficient compared to Klobuchar model, and its performance is very similar to dual-frequency correction [2]. To implements the GIVD model, the ARAMIS receiver was customized having the specifications like High-quality code and carrier phase observables (carrier sigma: 10–15 mm, CCD: 5–15 cm), Position fix update rate up to 50 Hz, Cold start ~ 40s, BGPS start < 1s, Coherent and adaptive tracking algorithms, Positioning accuracy ~ 3 m for code and 10 cm for the carrier.

The ARAMIS SDR receiver allows us to implement our algorithms using Navigation Application Program Interfaces (API), which provides access to navigation processor source code and raw data.

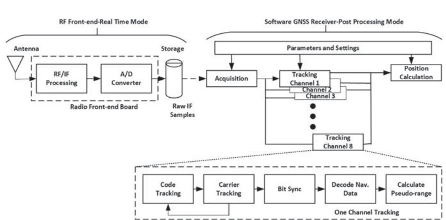


Figure 1: Functional block of SDR receiver

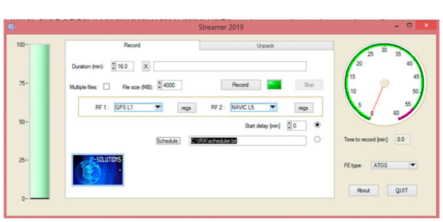


Figure 2: Streamer data recorded utility [14]

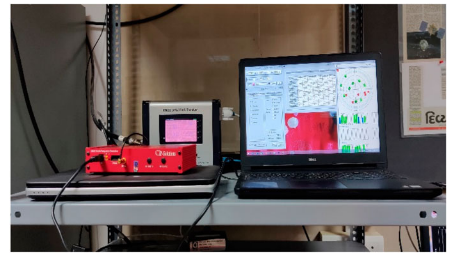


Figure 3: NavIC (L5-Band) + GPS (L1-Band) ARAMIS SDR receiver experimental setup at SVNIT, Surat (21° 9′ 50.04″ N., Latitude: 72° 47′ 1.26″ E., Longitude) station

2. EXPERIMENTAL SETUP AND RESULT ANALYSIS

Figure 3 depicts the experimental setup of NavIC + GPS ARAMIS SDR receiver at the Communication Research Lab (CRL) of the Electronics and Communication Engineering Department (ECED), Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat (21° 9′ 50.04″ N., Latitude: 72° 47′ 1.26″ E., Longitude). The antenna is installed on the terrace of the same building. The ARAMIS RF front-end (red color device in Figure 3) uses the antenna to receive the NavIC + GPS composite signal. The ARAMIS receiver has the software API (Navigation API), which is run on the Visual Studio platform with SDK 8.1 support (refer to 4). GUI is Window-based real-time user interface.

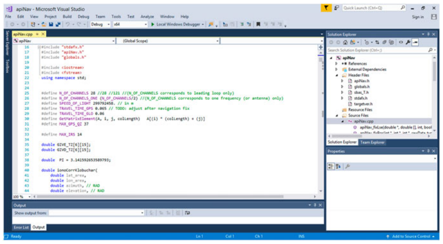


Figure 4: Navigation API of NavIC (L5-Band) + GPS (L1-Band) ARAMIS SDR receiver on visual studio platform

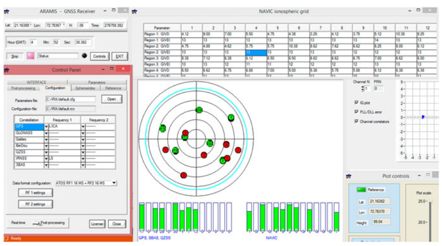


Figure 5: GUI of NavIC (L5-Band) + GPS (L1-Band) ARAMIS SDR receiver on visual studio platform

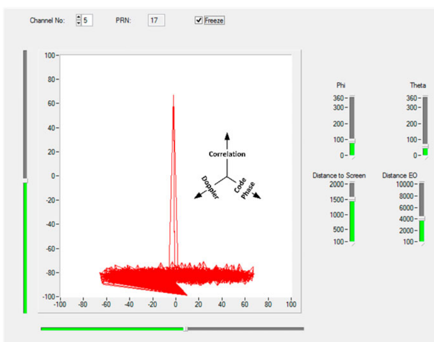


Figure 6: Acquisition plot of GPS (L1-Band) satellite (Channel-5, PRN-17) using ARAMIS SDR receiver on visual studio platform

The receiver will run in real-time and post-processing mode using the recorded digital raw IF data. The GUI of the ARAMIS SDR receiver is shown in Figure 5. The recorded samples are stored in the IRX folder of the working directory with a.bin extension.

After receiving the digital IF from the front-end, the receiver acquires the satellites. Sample 3D acquisition plots of GPS and NavIC satellites are depicted in Figure 6 (GPS, Channel-5, PRN-17) and Figure 7 (NavIC, Channel-64, PRN-5), respectively.

Doppler frequency and code phase estimates are generated by the correlation between the in-phase (I) and quadrature (Q) components of the input signal in the acquisition block and the local replica of the GNSS code. Here signal tracking follows signal acquisition, and on each receiver channel, a Delay-Locked Loop (DLL) is used to synchronize the received spreading code with the local replica, while a Phase-Locked Loop (PLL) is typically used to track the phase input carrier. Signal tracking is the basis for demodulating navigation messages, it relies on signal correlation and estimates distances between users and satellites.

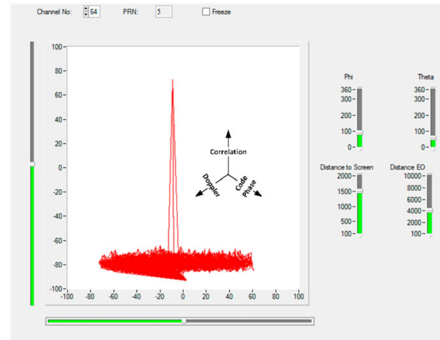


Figure 7: Acquisition plot of NavIC (L5-Band) satellite (Channel-64, PRN-5) using ARAMIS SDR receiver on visual studio platform

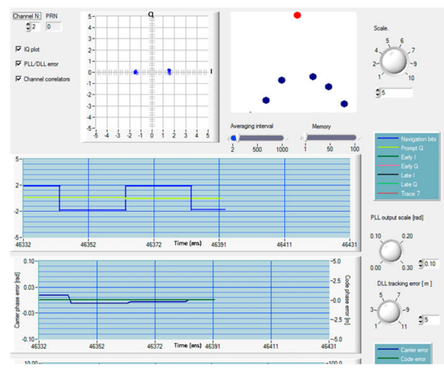


Figure 8: GPS (L1-Band) PRN-28 (Channel-2) satellite performance using ARAMIS SDR receiver on visual studio platform

Both plots show the correlation between code phase and Doppler shift. In these two acquisition graphs, the maximum value (peak) is the center, which shows that the quality and intensity of the signal are excellent.

After the acquisition, the satellites will be tracked, locked, and navigated for further pseudorange and other parameter estimations. For example, GPS PRN-17 (Channel-5) and NavIC PRN-5 (Channel-64) tracking I/Q plots, PLL/DLL errors, channel correlators, code errors, and carrier errors are depicted in Figures 8 and 9, respectively. Both graphs show that the satellites tracking is good. Carrier phase error and code phase error values may vary based on PLL and DLL discriminators, respectively.

The various estimated parameters values like PRN/ Channel No., lock-time, Doppler frequency, C/N_0, Azimuth, Elevation angle, and Ionospheric and Tropospheric errors of GPS and NavIC satellites are shown in Figures 10 and 11, respectively. In both figures (Figures 10 and 11), the navigation tracking status indicates that satellite data is used for the positioning measurement (GPS-09 and NavIC-07 satellites). After the correction is

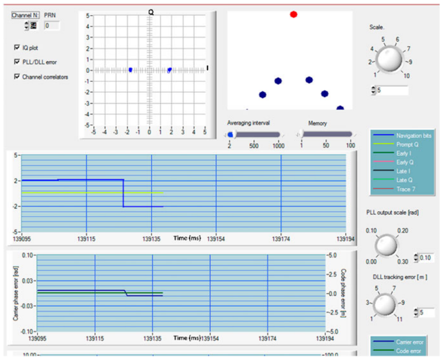


Figure 9: NavIC (L5-Band) PRN-4 (Channel-64) satellite performance using ARAMIS SDR receiver on visual studio platform

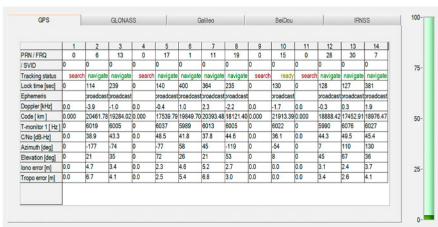


Figure 10: GPS (L1-Band) satellites performance using ARAMIS SDR receiver on visual studio platform

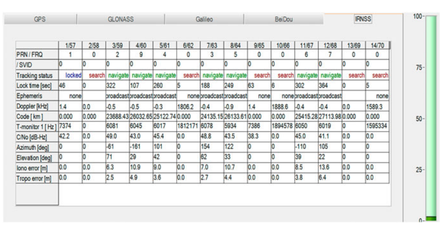


Figure 11: NavIC (L5-Band) satellites performance using ARAMIS SDR Receiver on visual studio platform

applied, the satellites with navigation status will be used for position estimation.

The ionospheric delay is estimated using the conventional Klobuchar and GIVD models, introduced in the next section.

2.1 Ionospheric Delay Comparison

Here, we have implemented the Grid-based GIVD model to estimate the ionospheric delay of NavIC satellites. The Klobuchar and GIVD model (mathematical algorithm) [2] is available in our published work. The corrections (90 grid points' values) of the GIVD model are updated every 5 minutes. The 90 grids are divided into 6 regions, each of which contains 15 grid values [2,3]. Hence its performance is more accurate in comparison to the conventional Klobuchar model. The 90 grid values (GIVD) and Grid Ionospheric Vertical Error Indicator (GIVEI) for NavIC ARAMIS SDR receiver are shown in Figure 12.

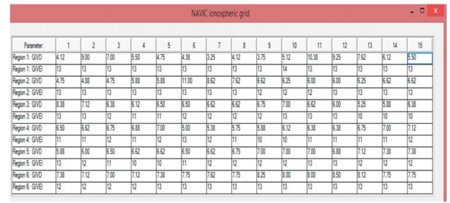


Figure 12: Grid parameters for NavIC satellites on NavIC ARAMIS SDR receiver

The Accord receiver antenna uses to run the NavIC + GPS SDR ARAMIS receiver. Therefore, we cannot run both the receivers together to compare both (Accord and ARAMIS) receivers. But we run both the receivers one after another (back to back) for a one-hour duration to observe the range of computed ionospheric values.

Here, the ionospheric delay is measured on 11/06/2019, Tuesday for the Time of Week Count (TOWC) = 189743 (UTC = 04:42:05, HH:MM:SS) to 197723 (06:55:05, HH:MM:SS) seconds for ARAMIS receiver and the 199683 (07:27:45, HH:MM:SS) to 203725 (08:35:07, HH:MM: SS) for Accord receiver.

First, the NavIC + GPS SDR ARAMIS receiver runs on real-time mode for a TOWC = 189743–197723 s and computed ionospheric delay for NavIC L5-band satellites using Klobuchar and GIVD stored in.csv files for further post-processing. The graphs are generated with MATLAB tools, depicted in Figures 13–16 for 1B, 1C, 1D, and 1F NavIC satellites. All results are shown for local time (IST (Indian Standard Time) = UTC + 5:30).

Similarly, after the ARAMIS receiver, the Accord receiver is also run on real-time mode for the TOWC = 199683–203725 s and computed ionospheric delay for NavIC satellites using the grid data stored in the SATBL5.csv file.

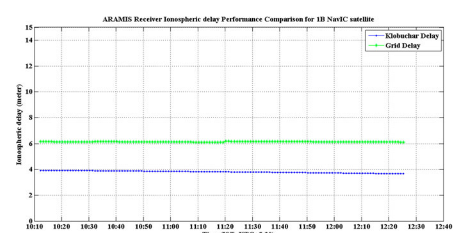


Figure 13: NavIC ARAMIS SDR receiver ionospheric delay comparison for PRN 1B

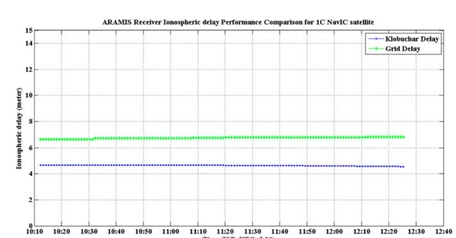


Figure 14: NavIC ARAMIS SDR receiver ionospheric delay comparison for PRN 1C

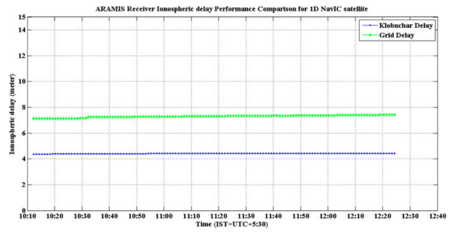


Figure 15: NavIC ARAMIS SDR receiver ionospheric delay comparison for PRN 1D

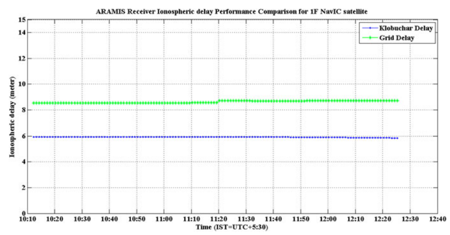


Figure 16: NavIC ARAMIS SDR receiver ionospheric delay comparison for PRN 1F

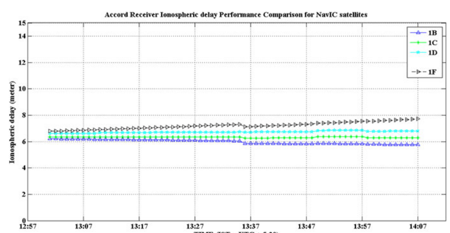


Figure 17: Accord receiver ionospheric delay comparison estimated using GIVD model for NavIC satellites

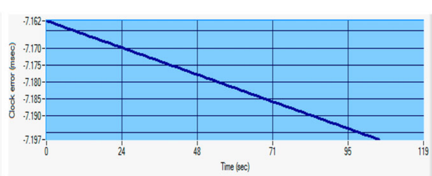
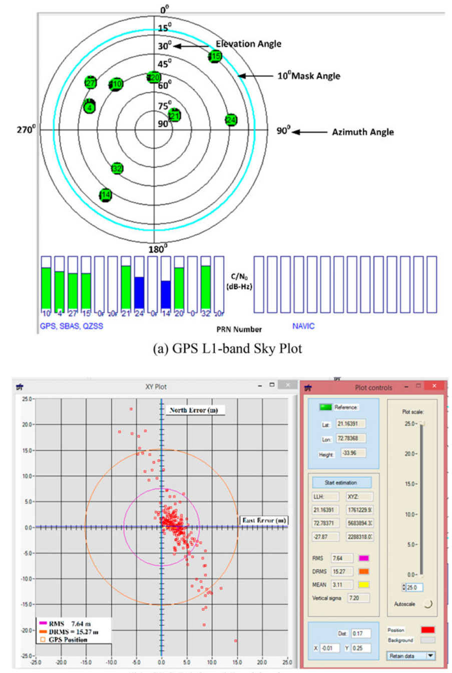


Figure 18: A clock error of NavIC + GPS ARAMIS SDR receiver

The SATBL5.csv is read on the MATLAB platform, and the generated graph is depicted in Figure 17. We observed that ionospheric delay computed using the GIVD model in both receivers (Accord and ARAMIS) are within in same range.

2.2 Positioning Accuracy Analysis

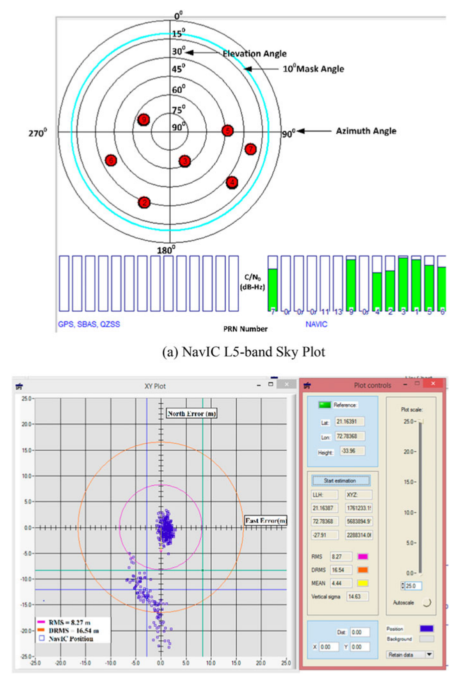
Here, the position is estimated after correcting the pseudorange from atmospheric (Ionospheric and Tropospheric) and clock corrections. The receiver's built-in clock is not as accurate as the atomic clocks on board the satellites, and it is not perfectly synchronized with the satellite onboard clock; hence a variable clock offset is observed between receiver and satellite clocks. The clock error of the NavIC + GPS ARAMIS SDR receiver is depicted in Figure 18.



(a) GPS L1-band Sky Plot

(b) GPS L1-band Positioning error

Figure 19: GPS L1-band ARAMIS SDR receiver (a) sky plot (b) positioning error plots

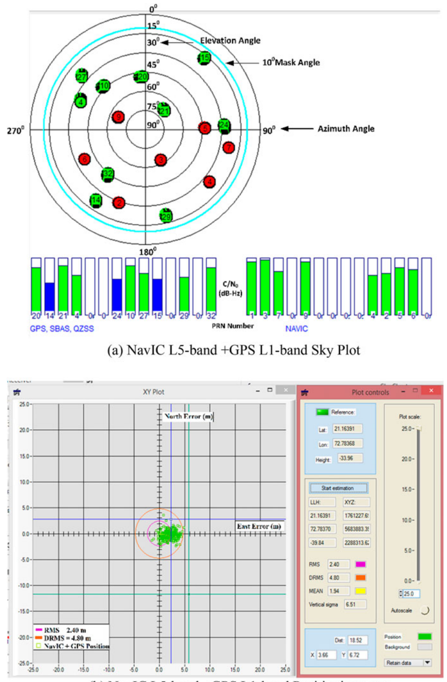


(a) NavIC L5-band Sky Plot

(b) NavIC L5-band Positioning error

Figure 20: NavIC L5-band ARAMIS SDR receiver (a) sky plot (b) positioning error plots

The ARAMIS SDR receiver positioning accuracy (Root Means Square (RMS), Distance Root Mean Squared (DRMS) and Mean) for GPS L1-band, NavIC L5-band, and NavIC L5-band + GPS L1-band are estimated and compared in Figures 19–21, respectively. Figures 19(a), 20(a) and 21(a) are sky maps with 90 degrees at the zenith (center of the figure) and 0 degrees at the outer circle.



(b) NavIC L5-band +GPS L1-band Positioning error

Figure 21: NavIC L5-band + GPS L1-band ARAMIS SDR receiver (a) sky plot (b) positioning error plots

Table 1: ARAMIS SDR receiver positioning error components

Cases	RMS (meter)	DRMS (meter)	Mean (meter)
NavIC L5-Band	8.27	16.54	4.44
GPS L1-Band	7.64	15.24	3.11
NavIC L5-Band + GPS L1-Band	2.40	4.80	1.54

The black circles are spaced 15 degrees apart and represent the elevation angle. The blue circle is the mask angle, set to 10 degrees. Figures 19(b), 20(b) and 21(b) Scatter plots show the East-North errors in meters. From Figures 19–21, note that as the number of satellites increases, NavIC L5-band + GPS L1 band gives better results and therefore better positioning accuracy.

RMS is the square root of the average of the squared error; it will correspond to vertical error. For the horizontal error, this measurement value is called DRMS (two-dimensional accuracy). Here, the positioning accuracy is computed by considering 600 samples, which is recorded on 11/06/2019. The precise positioning accuracy is shown in Table 1.

We observed that positioning accuracy is better for NavIC + GPS (DRMS = 4.80 m) (16 satellites) system compared to NavIC (DRMS = 16.54 m) (7 satellites) and GPS (DRMS = 15.24 m) (9 satellites) system. The same observations for the RMS and Mean values also.

3. CONCLUSION

The primary purpose of this work is to study the behavior of the NavIC satellites in the L5-band and the GPS satellites in the L1-band used for the ARAMIS SDR receiver on the Visual Studio platform. This paper discussed the performance of NavIC L5-band and GPS L1-band signal acquisition, tracking, and various post-processing parameters. The GIVD model based on the regional grid is also implemented (NavIC satellites) on the ARAMIS SDR receiver. The Accord receiver has verified the estimated GIVD results of the ARAMIS receiver, and similar results were found as expected. After correcting the pseudorange, the positioning errors of NavIC, GPS, and NavIC + GPS systems are estimated. The observation is that as the number of satellites used for position estimation increases, the error decreases. Therefore, NavIC + GPS performs better compared to NavIC and GPS systems alone. To implement our proposed MPR algorithm on SDR-based receiver is our future research work, and for that, we have implemented NavIC + GPS SDR receiver.

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DISCLOSURE STATEMENT

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ORCID

Mehul V. Desai http://orcid.org/0000-0002-6594-6951
Darshna Jagiwala http://orcid.org/0000-0002-7779-7156
Shweta N. Shah http://orcid.org/0000-0002-0105-5359

REFERENCES

1. The interoperable global navigation satellite system space service volume, United Nation, Vienna, ISBN 978-92-1-130355-1, Oct. 2018.
2. M. V. Desai, and S. N. Shah, "The GIVE ionospheric delay correction approach to improve positional accuracy of NavIC/IRNSS single-frequency receiver," *Curr. Sci.*, Vol. 114, pp. 1665–1676, 2018.
3. IRNSS signal in space ICD August 2017, ISRO-ISAC V1.1. Available: http://www.isro.gov.in/irnss-programme/.
4. M. V. Desai, D. Jagiwala, and S. N. Shah, "Impact of dilution of precision for position computation in Indian regional navigation satellite system," in *2016 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, Jaipur, 2016, pp. 980–986.

5. Market and Technology Trends 2021, Edition 3. Available: The latest edition of the Market and Technology Trends Report is out now! – GNSS.asia The latest edition of the Market and Technology Trends Report is out now! – GNSS.asia.
6. K. Borre, and I. Kudryavtsev, "Software defined GNSS receiver," *Procedia. Eng.*, Vol. 104, pp. 9–14, 2015.
7. I. G. Petrovski, and T. Tsujii, *Digital Satellite Navigation and Geophysics: A Practical Guide with GNSS Signal Simulator and Receiver Laboratory*. Cambridge: Cambridge University Press, 2012.
8. I. G. Petrovski, *GPS, GLONASS, Galileo, and BeiDou for Mobile Devices: From Instant to Precise Positioning*. Cambridge: Cambridge University Press, 2014.
9. C. Srinu, and L. Parayitam, "A post processing based IRNSS/NavIC software receiver for analysis and development of new algorithms and signals," in *Proceedings of the 33rd International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2020)*, 2020, pp. 2822–2835.
10. C. Srinu, and L. Parayitam, "Low-cost real-time software receiver for IRNSS/NavIC short broadcast messaging services," in *Proceedings of the 34th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2021)*, 2021, pp. 549–558.
11. G. De Angelis, *et al.*, "An indoor AC magnetic positioning system," *IEEE Trans. Instrum. Meas.*, Vol. 64, no. 5, pp. 1267–1275, May 2015.
12. P. Xie, and M. G. Petovello, "Measuring GNSS multipath distributions in urban canyon environments," *IEEE Trans. Instrum. Meas.*, Vol. 64, no. 2, pp. 366–377, Feb. 2015.
13. E. Schmidt, D. Akopian, and D. J. Pack, "Development of a real-time software-defined GPS receiver in a LabVIEW-based instrumentation environment," *IEEE Trans. Instrum. Meas.*, Vol. 67, no. 9, pp. 2082–2096, 2018.
14. W. Feng, J.-M. Friedt, G. Goavec-Merou, and F. Meyer, "Software-Defined radio implemented GPS spoofing and Its computationally efficient detection and suppression," *IEEE Aerosp. Electron. Syst. Mag.*, Vol. 36, no. 3, pp. 36–52, 1 Mar. 2021.
15. A. Dey, K. Iyer, and N. Sharma, "S-band interference detection and mitigation using a vector tracking-based NavIC software receiver," in *Proceedings of the 34th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2021)*, 2021, pp. 3464–3476.
16. A. Dey, P. Singh, and N. Sharma, "Performance Evaluation of Tracking Loop under RF Interference using NavIC Software-Receiver," in *2019 IEEE Asia-Pacific Microwave Conference (APMC), 2019*, pp. 1050–1052.
17. S. Gunawardena, A. Rügamer, M. S. Hameed, M. Arizabaleta, T. Pany, and J. Arribas, "ION software-defined radio metadata standard final report," in *Proceedings of the 32nd International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS)*, Sept. 2019, pp. 3785–3800.
18. iP-Solutions, Japan, Available: http://www.ip-solutions.jp/aboutiP Solutions.html.
19. Accord Software and Systems, Bangalore, INDIA, Available: http://accord-soft.com/GNSSnavigation systems.html.
20. M. V. Desai, and S. N. Shah, "An observational review on influence of intense geomagnetic storm on positional accuracy of NavIC/IRNSS system," *IETE Tech. Rev.*, Vol. 37, no. 3, pp. 1–15, 2020.
21. M. V. Desai, and S. N. Shah, "Estimation of ionospheric delay of NavIC/IRNSS signals using the Taylor series expansion," *J. Space Weather Space Clim.*, Vol. 9, pp. 1–17, 2019.
22. M. V. Desai, and S. N. Shah, "A local multivariate polynomial regression approach for ionospheric delay estimation of single frequency NavIC Receiver," *SN Appl. Sci.*, Vol. 2, no. 9, pp. 1–13, 2020.
23. D. D. Jagiwala, and S. N. Shah, "Impact of Wi-Fi interference on NavIC signal," *Curr. Sci.*, Vol. 114, no. 11, pp. 2273–2280, June 2018.
24. P. L. Lineswala, and S. N. Shah, "Jamming: The probable menace to NavIC," *IET Radar Sonar Navig.*, Vol. 13, no. 6, pp. 1039–1044, 2019.

AUTHORS

Mehul V Desai is a lecturer at Government Polytechnic for Girls, Surat, India. He has received master's degrees and doctoral degrees in electronics from SVNIT, Surat in 2014 and 2020, respectively. He is a member of ISTE and IEEE.

Corresponding author. Email: mvd.svnit@gmail.com

Darshna Jagiwala received master's and doctoral degrees in electronics from the SVNIT, Surat, in 2014 and 2020, respectively. She is a member of ISTE and IEEE.

Email: darshna12@gmail.com

Shweta N Shah is working as an assistant professor at Electronics Engineering Department, SVNIT, and Surat, India. She has received master's and doctoral degrees in Electronics from the SVNIT, Surat, in 2008 and 2015, respectively. She is a member of ACM, ISTE, and IEEE.

Email: snshah@eced.svnit.ac.in