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CDAC Navigation Tool Kit for GNSS Satellites Receiver

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Abstract:- From high speed missile to air fighter plane, everywhere, consumer is operating a Global Positioning System (GPS) navigation system in routine services and GPS technology is being used in a wide variety of applications. As new innovation continues to drive GPS receivers for better performance, software techniques are widely adopted to characterize & validate their performance against industry standard benchmarks for higher precision and better accuracy.

The aim of this research work is to study & explore the need of an automated testing tool for enhancing GNSS receiver's validation, performance and key metrics. Presently, the receiver devices are manually tested with the configuration made on simulator for checking the Graphical User Interface (GUI)/output of receiver device. Hence, it is evident that there is need to develop an automated application testing device which removes the manual intervention and at the same time provide easily verifiable test results on the dynamic test setup made in simulator without any manual intervention.

The software application, emphasizes on the approaches to automate a variety of GNSS receiver performance measurements including sensitivity, noise figure, position accuracy, and position deviation, in future and captures the real time navigational signal and generate various metric oriented graphs.

Keywords:- *GPS, GNSS, NavIC, IRNSS, NMEA, DOP, CNR.*

I. INTRODUCTION

Indian Regional Navigation Satellite System (IRNSS), popularly known & recognized as "Navigation with Indian Constellation (NavIC)", is a regional navigational service which gives real time location. It is a scalable system and primarily covers India and the surrounding area over 1500 km. It is public autonomous satellite service. It uses two frequencies, one in the L5 (1,176.45 MHz) and other in the L1 (1575.42 MHz) bands. On the other hand, the GPS satellites uses the carrier frequencies of L1 (1575.42 MHz), L2 (1227.6 MHz), with the modernization effort resulting in the newer satellites operating on the L5 band (1176 MHz) as well. The through put of NavIC is superior as it gives a positioning accuracy of 10 meters compared to the GPS accuracy of 20 meters.

Our research work covers IRNSS (L5 and L1) & GPS L1(C/A) bands under GNNS. GNSS encompasses various technologies and their infrastructure including GPS of the United States, GLONASS of the Russia, GALILEO of the EU, BDS of China and IRNSS of India.

As increasing number of users depend on satellite navigation services (e.g. smartphones, cars, vehicles, fleet movement, roadside assistance, retail, health, location tracking, maps, and traffic route), this tool will play a major role in the future allowing automated testing and validation of the specifications & features of the NavIC/GPS receiver.

This research paper provides a comprehensive overview of the tool's operations, applications and benefit. It was developed to fulfill the following objectives

- Evaluate past & present performance of satnav receivers.
- Useful for reducing the time and human effort for testing GPS & NavIC receiver modules
- Allow for better testing accuracy by reducing human errors and repeatable test cases
- Comparison between GPS and NavIC.
- Performance Prediction
- Visualize spatially and time-based performance.

GNSS receivers are based on digital techniques, i.e. the analog to digital conversion takes place. Receiver first step start with down conversion, RF component and then after signal is digitized. Tracking and acquisition of the modulated signal and carrier wave is fully digital and implemented in a digital baseband signal processor.

The receiver channel is tuned to track a particular frequency. To find a location, signals from multiple satellite may be required. Earlier receiver was limited with only one channel and the same channel was switched between the Satellite Vehicles (SVs) for monitoring SVs. As per the current trend in receiver design multiple channels may be accommodated which can run simultaneously.

Nowadays, GNSS receivers are required to have various performance evaluation functions, apart from accuracy. The receiver may be vulnerable & may perform low in various use cases e.g. adverse environmental & weather conditions, jamming, low power operations. Spoofing is very tough to handle and it can result in incorrect location & time. It increases the risk of any time critical applications where the results can be catastrophic. Also to maintain the data integrity & security becomes extremely tough in such circumstances.

II. LITERATURE REVIEW

Navigational tool kit plays a pivotal role in evaluating the satellite performance. As the satellite navigational services is going complex, with additional parameters, the tool performance becomes challenging. However, prior to design & develop any tool a sound understanding is required of the GPS, being the core technology in any satellite navigation system & the related work done in this domain. Kaplan E[9] has illustrated the GPS fundamentals, overview, system components, signal characteristics, acquisition, tracking, data demodulation, interference, GNSS and related applications.

M. Goswami [14] has emphasized on the need of a state of the art satellite navigation system, i.e. NavIC, an initiative taken by ISRO, as a way ahead for country missile, strategic programs & other milestones. This indigenous system is need of the hour, to take care of the design aspects, security aspects and defence applications. NavIC has proven the capability, independency and supported by the test results. D. Goswami [11] describes the constitution & background of NavIC. It also covers the frequencies used of NavIC, the 2 broad services and the noble purpose for implementation of the roadmap of India.

C. J. Hegarty [5] has studied & provided the overview of 2 major constellations of GNSS, namely, GPS & GLONASS of USA and Russia respectively. It covers the signal characteristics and the futuristic enhancement of GNSS.

C. J. Hegarty [6] has provided the status of satellites and future scalability and necessary augmentation, including the configuration of equipment’s & applications. Parkinson [7] has explained the operational concepts of the entire system, including connections of the sub elements, the work flow of the ground network & the required equipment for operations.

Misra [10] holistically describe the GPS signals, signal tracking, signal acquisition, signal conditioning & transformation, ephemeris and timing data, various parameters for analysis, the measurements and estimation techniques used by the GPS receivers for accuracy, the sources of error and their mitigation techniques.

The accuracy is the prime feature of the GPS receiver. Raj Gusain [1] analyzed the performance of NavIC satellites in the North India where the altitude was not high using statistical methods. This use case will have issues like signal fading, interference or an absence. Hence here circular error probability (CEP) is used accuracy. The system produced outliers as elevation angles were below 50° which resulted in incorrect CEP calculation. A result of 1.35 was obtained during the CEP calculation at year end. This means the NavIC has underperformed due to the position.

The crucial factors which can impact the accuracy of positioning are latitude, longitude, altitude & low elevation. It is assumed that, in order to get better results of this use case, where the elevation angle is low & there are significant fluctuations in the ionsphere, one need to put more effort to obtain the accuracy. For estimation of the receiver the measurements of VTEC and STEC are very crucial. The CEP value may be higher for GNSS receiver compared to the NavIC receiver.

R. Gusain [2] has explored the Precise Point Positioning (PPP) technique as a way out for increasing the precision of the location accuracy. This is indeed always emphasized and increases the value addition of many applications whose accuracy is sensitive attribute. Statistical methods are used for determining the standard deviation, mean, median, mode etc. it also covers the run time errors in the feed provided by GNSS satellite which may affect the accuracy e.g. ionosphere error.

Deepti Ayaagiri [12] has studied & explored the NavIC’s performance in ionosphere based on the region covering Indian subcontinent. The data set considered was of one year (2017–18) and a consistency was found between the GPS data & NavIC data. It was found that the results are in the range from -20 to +20% of the VTEC of NavIC. The study covered 2 major storms which proved that NavIC signals are relied upon in stormy weather conditions also. Additionally, the integration of GPS and NavIC data can be used for ionosphere studies.

S.C. Bhardwaj [3] has done research to improve the accuracy of Vertical Total Electron Content (VTEC). The VTEC estimation at the low elevation is executed by putting thick shell mapping resulting in reducing the vertical delay. On the contrary the thin shell is not suitable as it is error prone. The exercise was done at Dehradun (in northern India) which falls in the middle latitude region.

The exercise needed to investigate the L (1-2 GHz) and S (2-4 GHz) bands as the aim was to understand the characteristics of time zones, days and seasons for the ionosphere vertical delay for a year. This primarily covers all the seasons. As per the test results the vertical delay was found to be less then at the L band frequency without any fluctuation. To improve the accuracy, the Grid Ionosphere Vertical Delay (GIVD) map can be used for estimation.

The GPS signal strength is affected by building, trees and other blockers. Normally, the differential GPS is used to find the accuracy. S. C. Bhardwaj [4] used the AI based models to predict the accuracy. The models used are Recurrent Neural Network (RNN), Artificial Neural Network (ANN), Long Short Term Memory-Recurrent Neural Network (LSTM-RNN) are used to solve this limitation and for better accuracy.

There are primarily two comparisons; If we compare the Mean Absolute Percentage Error (MAPE) and Root Mean Squared Error (RMSE) of the RNN model with the ANN model they are reduced by 1.54% and 3.59%, respectively. If we compare the MAPE and RMSE of the LSTM-RNN model with the RNN model, they are reduced by 21.16% and 14.81%, respectively. Hence the LSTM-RNN is more suitable in the prediction model.

John W. Lavrakas [13] has developed a tool, namely “Navigation Tool Kit”, which uses “user defined scenarios” to check the results. The target users are community called GPS satellite navigation (SATNAV). The toolkit is a result of joint development of Overlook Systems and M/s AGI. The accession of the 2 services, namely precise positioning service (PPS) and standard positioning service (SPS) of the satellite was evaluated using this tool. A MATLAB prototype was used to validate the toolkit.

III. OVERVIEW OF THE TOOL KIT

The *CDAC Navigation Tool Kit* can be used to check the performance & analysis GNSS satellite navigation. It is based on open-architecture. It can be installed on a normal windows based PC and is designed to support GPS & NavIC based receivers. *CDAC Navigation Tool Kit* had tested receiver based on the Accord chipset. More receivers are expected from Manzeera and Signalchip. Python is the primary programming language used to generate the tool.

CDAC Navigation Tool Kit includes the industry-standard algorithms & user defined algorithms too. National Marine Electronic Association (NMEA), formatted data is received from GNSS receiver, which is used by the software as the primary input. The software is not only capable of parsing standard NMEA sentences received from the receiver but also proprietary NMEA sentences implemented by various OEMs. The parsed NMEA sentences are then used by the algorithms implemented by the test tool for visualization, testing and validation against the specified benchmarks. Typical fields are position data including the 3 dimensional coordinates, solution status, total number of satellites used, and other data like GSA, GST, GSV, RMC, VTG, ZDA etc.

IV. COMPONENTS OF TOOL KIT

The software can be started in 3 modes: live mode, Configuration mode & Replay mode. Through configuration mode user can always configuration the serial port, baud rate. The software is capable to develop various graphs.

- *GUI*

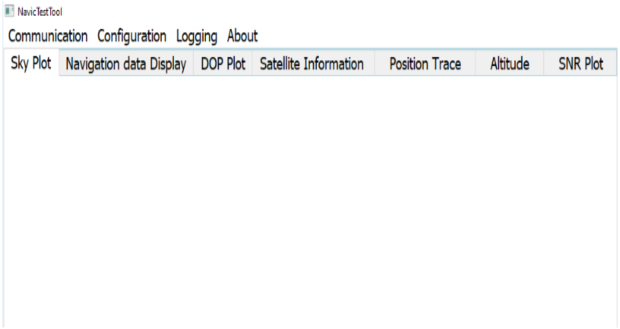


Fig 1: GUI of the toolkit

- *SKY plot*

The sky plot provides a holistic comparison of the Satellite Azimuth & elevation angle of the satellite as computed by the GPS and NavIC modules. The Sky Plot shows the satellite's position, short-term orbit, and an indication of whether the satellite is suitable for polar projection. The calculations for the visibility of satellite are done as per the data provided by Ephemeris.

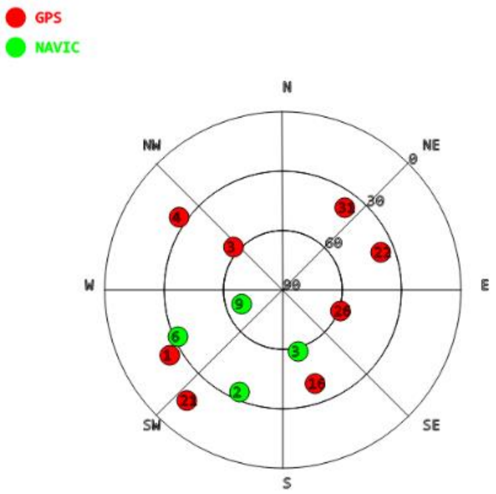
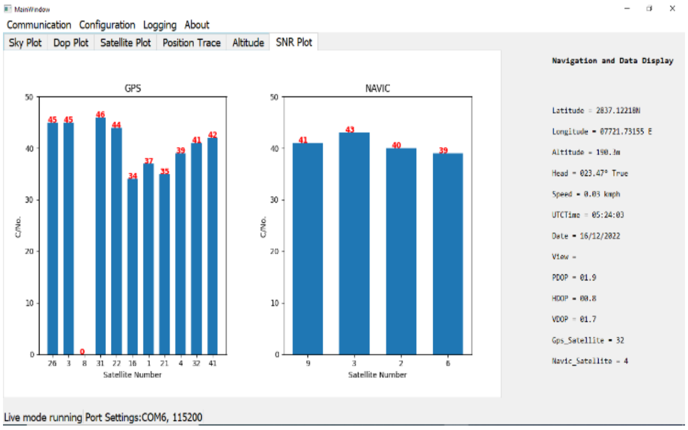


Fig 2: SKY plot

The plot directions are depicted at the figure above. We fetch NMEA Data from UART port select GPGSV, GIGSV Parameter from NMEA parameter which is continuously updating on UART port. To plot the SKY plot we need to select AZIMUTH and ELEVATION angle from GPGSV and GPGSA parameter. AZIMUTH angle will vary from 0 to 360 degrees of GPS & NavIC satellite. ELEVATION angle will vary from 0 to 90 degree of GPS & NavIC satellite.

- *Navigational Data*

This is essentially the receiver GPS location (latitude, longitude, altitude) where 4 satellites are used. The positions are received from 3 satellites and correction is done by 1 satellite. These Navigation Data display indicating how many satellite are tracked by GNSS Receiver as well as it will provide the data of latitude, Longitude and altitude of GNSS Receiver. It will read the NMEA Data for giving latitude and longitude value of the user.



Latitude = 2837.12210N

Longitude = 07721.73155 E

Altitude = 190.3m

Head = 023.47° True

Speed = 0.03 kmph

UTCTime = 05:24:03

Date = 16/12/2022

View =

PDOP = 01.9

HDOP = 00.8

VDOP = 01.7

Gps_Satellite = 32

Navic_Satellite = 4

Live mode running Port Settings:COM6, 115200

Fig 3: Navigational Data

- *DOP Plot*

For Dilution of precision (DOP), all ranges are affected by noise which is random in nature. Noise introduce are uncertainty of region. If satellites are located wide apart, uncertainty region is small. If satellites are close together, uncertainty region is large. This Range error translated into position error by factor is called dilution of precision(DOP), which can be presented in the three ways-

- Position (3D) dilution of precision (PDOP)
- Horizontal dilution of precision (HDOP)
- Vertical dilution of precision (VDOP)

Lesser DOP Values means it is the better position accuracy. If DOP will be more than 5 meter then position accuracy performance will be decrease. We fetch NMEA parameter GNGSA for indicating the DOP value with respect to time scale (varying from 0 to 1000 second).

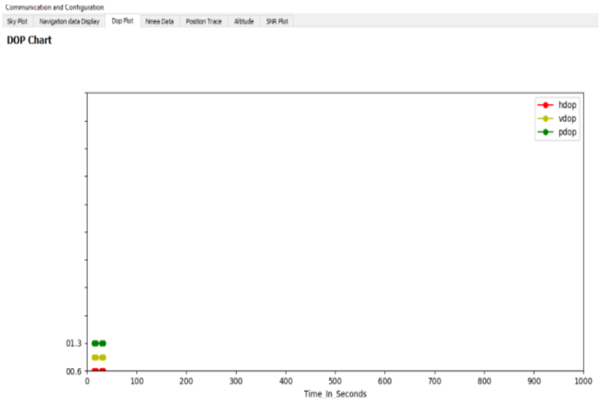
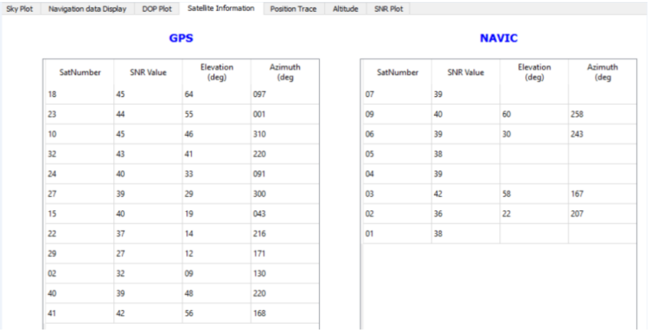


Fig 4: DOP plot

➢ *Satellite information*

The tabular view under the “Satellite Information” tab provides a comprehensive overview of the basic information of the satellites tracked by the satnav receiver.



GPS

SatNumber	SNR Value	Elevation (deg)	Azimuth (deg
18	45	64	097
23	44	55	001
10	45	46	310
32	43	41	220
24	40	33	091
27	39	29	300
15	40	19	043
22	37	14	216
29	27	12	171
02	32	09	130
40	39	48	220
41	42	56	168

NAVIC

SatNumber	SNR Value	Elevation (deg)	Azimuth (deg
07	39		
09	40	60	258
06	39	30	243
05	38		
04	39		
03	42	58	167
02	36	22	207
01	38		

Fig 5: Satellite Information

➢ *Position Trace*

It will indicate the latitude, longitude of user in continuous manner.

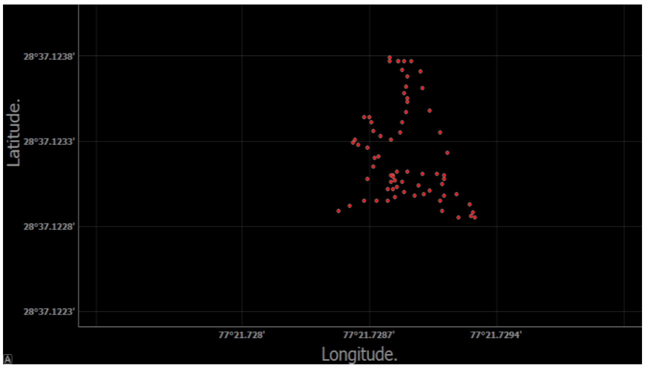


Fig 6: Position Trace graph

➢ *Altitude*

It will plot with respect to time. Altitude of the user will be taken from sea level

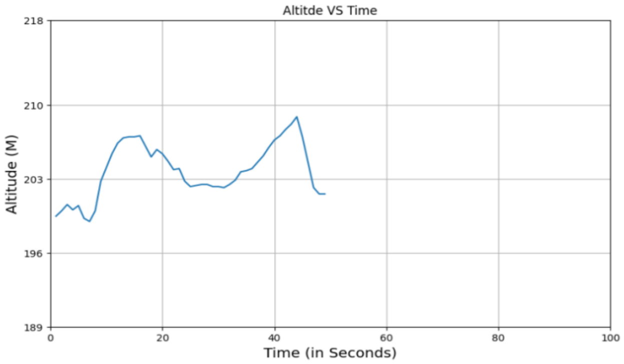


Fig 7: Altitude graph

➢ *CNR*

The Carrier to Noise Ratio (CNR) plot will indicate the Carrier to Noise Ratio & satellite PRN ID. It will extract the NMEA string GPGSV & GIGSV and indicate CNR value on horizontal position. It will extract PRN ID from GSV sentence & indicate the PRN ID on horizontal position.

The unit of SNR is decibels. SNR basically represents the ratio of the signal power to the noise power.

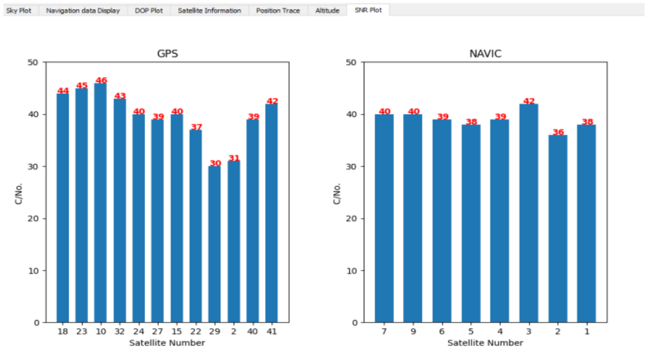


Fig 8: CNR/SNR plot

➢ *Error Calculation Report(L1)*

We fetch NMEA Data from GPS & NavIC satellites. We separated data only for GPS satellite & only for NavIC satellite. Accordingly, we have calculated 2-D and 3-D RMS value for both the satellite.

Table 1 : For only GPS Satellites

Geodetic Coordinates	
Mean Latitude (Degrees)	23.02508314285714
Max Latitude (Degrees)	23.025086166666668
Min Latitude (Degrees)	23.02508033333334
Mean Longitude (Degrees)	72.51892706782108
Max Longitude (Degrees)	72.5189305
Min Longitude (Degrees)	72.51892383333335
Mean Altitude (Meters)	6.62683982683983
Max Altitude (Meters)	9.400000000000006
Min Altitude (Meters)	4.900000000000006
Altitude Spread (Meters)	4.5

ECEF Coordinates	
Mean X (Meters)	1764203.4146553199
Max X (Meters)	1764204.329960791
Min X (Meters)	1764202.8000440917
X Spread (Meters)	1.529916699277237
Mean Y (Meters)	5601790.182104424
Max Y (Meters)	5601792.553434924
Min Y (Meters)	5601788.563381466
Y Spread (Meters)	3.9900534581393003
Mean Z (Meters)	2479278.674022025
Max Z (Meters)	2479279.795100144
Min Z (Meters)	2479277.977327806
Z Spread (Meters)	1.817772338166833
RMS 2D position Error (Meters)	0.2160932836050735
RMS 3D position Error (Meters)	0.7819359492135513 02

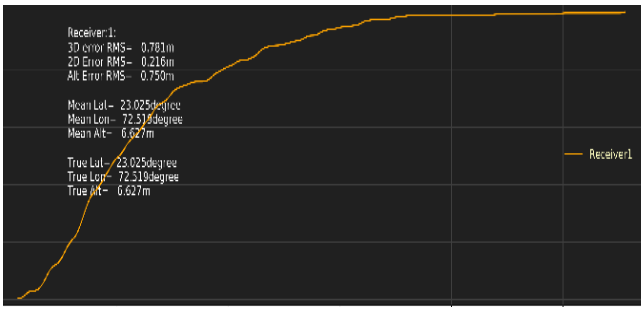


Fig 9: - Error cumulative probability for GPS satellite only

Table 2: for only NavIC satellites (L5)

Geodetic Coordinates	
Mean Latitude (Degrees)	23.025083724118318
Max Latitude (Degrees)	23.025090833333337
Min Latitude (Degrees)	23.0250795
Mean Longitude (Degrees)	72.51892286120592
Max Longitude (Degrees)	72.51892616666667
Min Longitude (Degrees)	72.51891966666666
Mean Altitude (Meters)	6.175085324232084
Max Altitude (Meters)	8.5
Min Altitude (Meters)	2.7000000000000003
ECEF Coordinates	
Mean X (Meters)	1764203.693479589
Max X (Meters)	1764204.4651514527
Min X (Meters)	1764202.705870263
Mean Y (Meters)	5601789.631999495
Max Y (Meters)	5601791.674633321
Min Y (Meters)	5601786.486580861
Mean Z (Meters)	2479278.556568658
Max Z (Meters)	2479279.816793116
Min Z (Meters)	2479277.4293063423
RMS 2D position Error (Meters)	0.3467804225850928
RMS 3D position Error (Meters)	1.0224875829391469

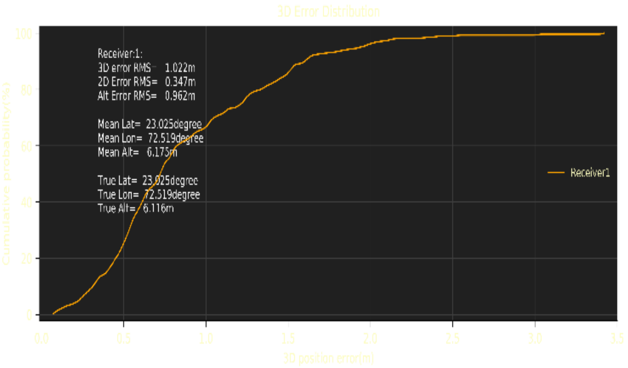


Fig 10: - Error cummulative probability for NavIC satellite only

Following are the formulas for calculation for RMS 2D & 3D Error and Geodetic co-ordinates to ECEF Values

- ➢ *Latitude, Longitude, Height to ECEF xyz: -*

There is a closed form solution for this transformation. Given geodetic latitude is represented as phi Φ, longitude(λ) and ellipsoidal height H, then

$x = (Rn + H) \text{ COS } \Phi * \text{COS } \lambda$
$Y = (Rn + H) \text{ COS } \Phi * \text{SIN } \lambda$
$Z = (1 - E2) \, Rn + h) \text{ SIN } \Phi$

- ➢ *RMS 2D Error calculation: -*

POSITIONAL RMS 2D ERROR = STDDEV (SQRT (X-X2) + (Y-Y2)
POSITIONAL RMS 3D ERROR = STDDEV (SQRT (X-X2) + (Y-Y2) + (Z-Z2)

V. CONCLUSION

The "*CDAC Navigation Tool Kit*" is an outcome of the establishment of the lab in CDAC, where emphasis was on automated testing of the GNSS receiver considering various test scenarios instead of manual based testing. The mandate of position accuracy of NavIC was better than of 10 meters across the Indian subcontinent, compared to the accuracy of 20 meters, as computed by GPS and the final result shown above were much better than the indicated range. The tool was capable to compare the results between simulator output and receiver data and check the accuracy level of the receiver data & saves the testing time.

The tool kit catered the requirement for IRNSS (L5 & L1) & GPS L1 (C/A) bands. The Software Architecture of the automated application is open and scalable to cater any future requirements in terms of number of users and test the various features of the receiver e.g. sensitivity, noise, position accuracy and deviation. We look forward for its usage by various applications e.g. smart phones, vehicles, transport, roadside assistance, retails, health, location tracking, & other navigational services.

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