A Project Report on

NavIC Performance Analysis

Using Raw Multi-GNSS Receiver Data

Winter Internship

Department of Electrical Engineering

Indian Institute of Technology Jodhpur

(Rajasthan)

By:-

Yuvraj Singh Tanwar

Indian Institute of Science Education and Research, Bhopal(IISERB), (Madhya Pradesh)

Under the Supervision of :-

Assistant Professor

Dr. Akshay Moudgil

EE department

IIT Jodhpur (Rajasthan)

Table of Contents

Aknowledgement

I would like to express my sincere gratitude to **Dr. Akshay Moudgil**, Department of Electrical Engineering, Indian Institute of Technology Jodhpur, for his invaluable mentorship, technical guidance, and continuous support throughout this project.

His insights into GNSS systems and research methodology were instrumental in shapithe experimental design and analysis.

I extend my special thanks to **Mr. Rupesh Kumar**, PhD researcher at IIT Jodhpur, for his constant support, technical discussions, and hands-on guidance, particularly in GNSS hardware integration and Raspberry Pi–based data logging.

I am thankful to the faculty members of the Department of Electrical Engineering, IIT Jodhpur, for providing a stimulating research environment and essential resources that facilitated this work.

I also acknowledge the open-source GNSS community for the tools and documentation that enabled the integration of a NavIC-capable multi-GNSS receiver with a Raspberry Pi–based data logging platform.

I am grateful to my home institution, the Indian Institute of Science Education and Research, Bhopal, for its academic support, and to my **parents** for their unwavering encouragement and patience throughout this journey.

Abstract

This project presents an experimental analysis of India's NavIC (IRNSS) system using raw observations collected from a multi-GNSS receiver under real-world operating conditions. The study primarily focuses on evaluating NavIC satellite availability and signal strength characteristics, rather than making claims regarding standalone positioning accuracy. Position solutions, including latitude, longitude, and altitude, are computed by the receiver through a combined multi-GNSS approach that incorporates signals from multiple constellations. NavIC satellites are subsequently isolated and analyzed independently at the observation level to assess their individual behavior and performance within the broader GNSS framework.

Data collection was carried out using a NavIC-capable GNSS receiver interfaced with a Raspberry Pi–based portable data logging system, deployed during real walking and cycling trajectories across open-sky and semi-obstructed environments. The Raspberry Pi was operated in headless mode and remotely accessed from a laptop using VNC, enabling real-time monitoring and control of the data logging process during field experiments. Satellite availability was determined by tracking the temporal visibility of NavIC satellites, while signal quality was assessed using signal-to-noise ratio (SNR) values extracted directly from raw NMEA sentences. No post-processing techniques such as smoothing, filtering, or interpolation were applied, ensuring that the results reflect true receiver-observed behavior in field conditions.

The analysis explicitly separates position computation from satellite-level performance evaluation to maintain methodological clarity. Recorded position fixes are visualized using dense two-dimensional latitude–longitude trajectory plots derived from the multi-GNSS solution, while NavIC-specific performance is examined through satellite visibility timelines and signal strength distributions. This distinction avoids over-attribution of positioning performance to NavIC alone and enables a transparent, data-driven assessment of its observability and signal behavior. Overall, the study contributes to a realistic understanding of regional GNSS performance in practical deployment scenarios, grounded in actual field measurements rather than idealized conditions.

Chapter 1. Introduction

Satellite-based navigation systems have become indispensable for modern positioning, navigation, and timing (PNT) applications, serving critical roles across civil, scientific, and strategic domains. While Global Navigation Satellite Systems (GNSS) such as GPS have been extensively studied and deployed worldwide, regional navigation systems require dedicated performance evaluation under practical operating conditions. India's Navigation with Indian Constellation (NavIC), formerly known as IRNSS, was developed to provide reliable regional navigation services over the Indian subcontinent and surrounding areas. As NavIC continues to mature and gain wider adoption, it becomes essential to examine its real-world behavior through systematic experimental observation.

NavIC operates as a regional GNSS with a distinctive constellation architecture comprising geostationary (GEO) and geosynchronous (GSO) satellites. This unique design results in signal characteristics and visibility patterns that differ significantly from those of global GNSS constellations. While NavIC compatibility is increasingly integrated into commercial multi-GNSS receivers, its operational performance—particularly in terms of satellite availability and signal quality—must be assessed using raw field data collected under realistic conditions. Understanding these characteristics is especially important for navigation research, signal analysis, and regional GNSS studies, where system behavior across diverse environmental settings plays a crucial role in evaluating practical utility and reliability.

Beyond its technical significance, NavIC contributes to enhancing national self-reliance in satellite-based navigation infrastructure. Dependence on foreign GNSS constellations can introduce uncertainties related to service availability, continuity, and policy-level constraints. A regionally controlled navigation system such as NavIC provides India with greater autonomy over critical positioning and timing services, particularly for applications requiring assured and uninterrupted access. Evaluating NavIC performance under real-world conditions is therefore essential not only from a scientific and engineering perspective but also as a step toward strengthening technological independence and resilience in navigation infrastructure.

In addition to raw data collection, the recorded position fixes are visualized using two-dimensional latitude–longitude trajectory plots and interactive map-based representations ,3D maps. These visualizations aid in interpreting receiver behavior and movement patterns observed during real-world walking and cycling experiments conducted in open-sky and semi-obstructed environments. NavIC-specific performance is further examined through satellite visibility and signal strength information extracted from the same dataset, without applying any smoothing, filtering, or post-processing techniques, thereby preserving the integrity of the receiver-observed data.

.

Chapter 2.Background & GNSS overview

2.1 Global Navigation Satellite Systems (GNSS)

• GNSS are satellite-based systems that provide Positioning, Navigation, and Timing (PNT) services to users worldwide.

• GNSS determines user position by processing signals transmitted simultaneously from multiple satellites in view.

• The receiver computes latitude, longitude, altitude, velocity, and precise time using satellite geometry and signal propagation characteristics.

• GNSS has become integral to navigation, geospatial mapping, land surveying, transportation logistics, scientific research, and emergency response systems.

2.2 GNSS Observables and Data Provided by Satellites

• Pseudorange – Measures the estimated distance between satellite and receiver, forming the basis for position computation.

• Doppler Shift – Estimates receiver velocity and the rate of change in satellite–receiver distance.

• Carrier Phase – Enables high-precision positioning techniques such as RTK (Real-Time Kinematic) and PPP (Precise Point Positioning).

• Signal-to-Noise Ratio (SNR) – Indicates the strength and quality of the received signal, reflecting environmental conditions and satellite geometry.

• These observables are extracted from raw satellite signals and provide fundamental data for both positioning and signal behavior analysis.

2.3 Multi-GNSS Operation and Satellite Constellations

Modern GNSS receivers are designed to operate across multiple satellite constellations simultaneously, including GPS, GLONASS, Galileo, BeiDou, and India's NavIC (IRNSS).
By combining observations from all available constellations, the receiver computes a unified position solution with improved robustness, satellite availability, and geometric dilution of precision (GDOP).
Such multi-GNSS operation is particularly advantageous in challenging environments, including urban areas, dense vegetation, and regions with limited sky visibility.

2.4 NavIC (IRNSS) within the GNSS Framework

NavIC is India's regional navigation satellite system, formally known as the Navigation with Indian Constellation (IRNSS). It is designed to provide reliable positioning, navigation, and timing services over the Indian subcontinent and surrounding regions. Unlike global GNSS constellations that primarily operate in Medium Earth Orbit (MEO), NavIC employs a unique satellite configuration that influences its visibility and signal characteristics.

• NavIC utilizes a distinctive constellation architecture consisting of Geostationary (GEO) and Geosynchronous (GSO) satellites.

• This GEO–GSO configuration results in satellite visibility patterns that differ from those of global GNSS systems.

• NavIC signals are tracked alongside GPS, GLONASS, Galileo, and BeiDou in modern multi-GNSS receivers.

• While final position solutions are computed using combined multi-GNSS data, NavIC satellites can be independently isolated and analyzed for availability, signal strength, and geometric contribution.

2.5 Importance of Satellite Observability and Signal Analysis

• GNSS performance is strongly influenced by satellite visibility, geometric configuration, elevation angles, and SNR.

• Raw satellite-level analysis provides deeper insights than processed position outputs alone.

• Signal strength and availability vary due to environmental factors (multipath, obstructions, atmospheric effects) and satellite-specific characteristics.

• Such analysis is especially important for regional systems like NavIC, where constellation geometry differs from global GNSS architectures.

• Understanding raw observables enables a realistic and transparent assessment of GNSS performance under practical operating conditions.

Chapter 3: Satellite Systems Considered in This Study

This chapter provides a brief overview of the satellite navigation systems whose signals are tracked during the experimental data collection. While position solutions are computed using a combined multi-GNSS approach, satellite-level observations are analyzed separately for each constellation.

3.1 Global Positioning System (GPS)

GPS is a global navigation satellite system operated by the United States Space Force.

It consists of approximately 31 operational satellites in Medium Earth Orbit (MEO) at an altitude of about 20,200 km.

GPS provides worldwide coverage with at least 4 satellites visible from any point on Earth at any time.

GPS observations serve as a reference baseline in this study due to its maturity and global availability.

3.2 GLONASS (Russian Federation)

GLONASS is Russia's global navigation satellite system operated by Roscosmos.

It operates using approximately 24 operational satellites in MEO at an altitude of about 19,100 km.

GLONASS satellites are distributed across three orbital planes, improving satellite geometry in multi-GNSS positioning.

GLONASS uses a different frequency division multiple access (FDMA) technique compared to GPS.

3.3 Galileo (European Union)

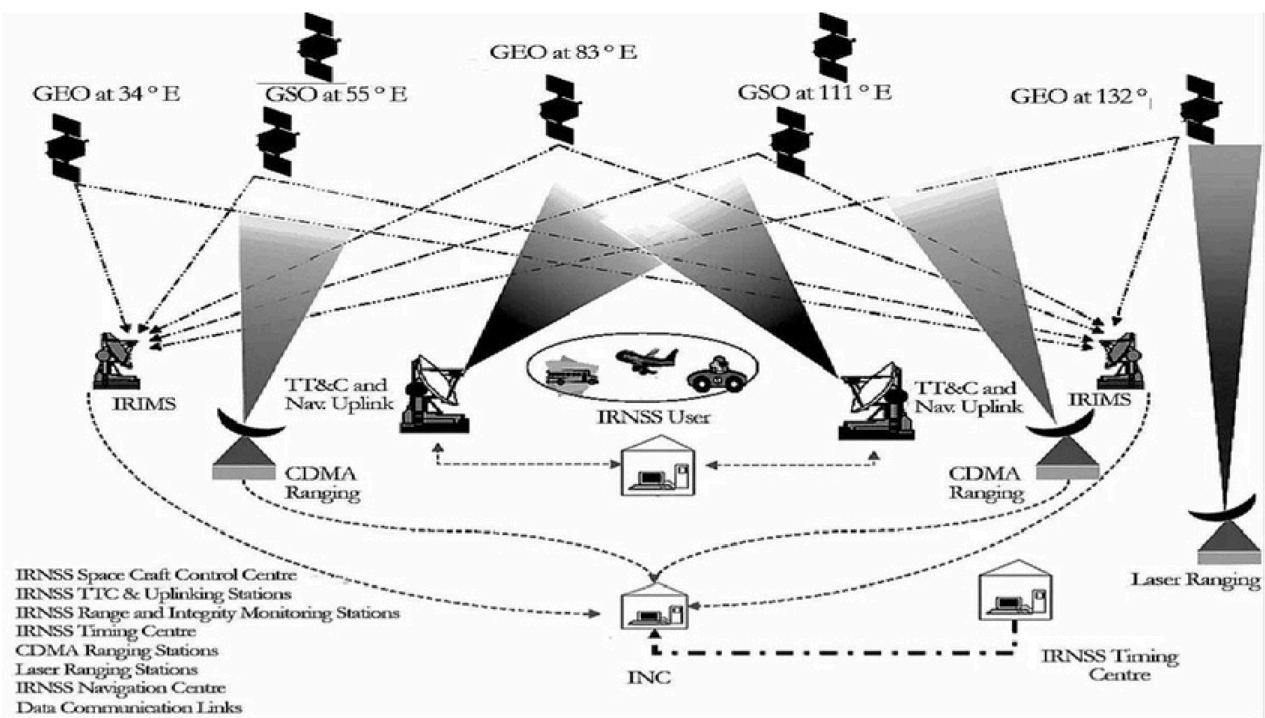
Galileo is a civilian global navigation system developed and operated by the European Union.
The constellation consists of approximately 28 operational satellites in MEO at an altitude of about 23,200 km.
Galileo provides high-quality navigation signals with enhanced accuracy and is designed specifically for civilian applications.
Galileo observations are included for multi-constellation completeness and improved positioning precision.

3.4 BeiDou (China)

BeiDou is China's global navigation satellite system operated by the China National Space Administration.
It employs a hybrid constellation with approximately 35 operational satellites, including MEO, GEO, and Inclined Geosynchronous Orbit (IGSO) satellites.
BeiDou provides global coverage with enhanced performance over the Asia-Pacific region.
BeiDou signals contribute additional satellite availability and improve positioning robustness.

3.5 NavIC / IRNSS (India)

NavIC is India's regional navigation system, designed to provide reliable navigation services over the Indian subcontinent and surrounding regions. Its primary service area covers India and an extended region of approximately 1,500 km, including nearby areas such as the Bay of Bengal, Arabian Sea, Sri Lanka, Bangladesh, Nepal, Bhutan, and parts of Southeast Asia.
The NavIC constellation comprises seven satellites, including three GEO and four GSO satellites, operating at an altitude of approximately 36,000 km. In this study, NavIC satellite observations are isolated and analyzed independently to evaluate regional GNSS availability and signal characteristics under real-world operating conditions.



Chapter 4: NavIC (IRNSS) System Description

4.1 NavIC Mission Objectives and Coverage

Navigation with Indian Constellation (NavIC), earlier known as the Indian Regional Navigation Satellite System (IRNSS), is a regional satellite-based navigation system developed and operated by the Indian Space Research Organisation (ISRO). NavIC was conceived to provide India with an independent, reliable, and assured Positioning, Navigation, and Timing (PNT) service without reliance on foreign GNSS constellations. Such autonomy is particularly important for critical applications including transportation, disaster management, and other time-sensitive services requiring service continuity.

Unlike global GNSS constellations designed for worldwide coverage, NavIC is optimized specifically for the Indian subcontinent. Its primary service area extends up to approximately 1,500 km beyond India's borders, covering regions such as the Bay of Bengal, Arabian Sea, Sri Lanka, Bangladesh, Nepal, and Bhutan. Within this region, NavIC ensures continuous satellite visibility and stable constellation geometry, allowing users to track multiple NavIC satellites consistently throughout the day. This region-focused design enables reliable performance where it is most needed, rather than distributing resources globally.

4.2 NavIC Constellation Architecture (GEO and GSO)

NavIC employs a distinctive constellation architecture that differentiates it from global GNSS systems. The constellation consists of seven operational satellites, including three satellites in Geostationary Orbit (GEO) and four satellites in Geosynchronous Orbit (GSO). This hybrid GEO–GSO configuration contrasts with systems such as GPS or Galileo, which primarily rely on Medium Earth Orbit (MEO) satellites that continuously traverse the sky.

The three GEO satellites are positioned at fixed longitudes of approximately 32.5°E, 83°E, and 131.5°E, appearing stationary to ground-based users in India. The four GSO satellites share a 24-hour orbital period but follow inclined orbits, producing a figure-eight ground track over time. This inclination improves constellation geometry and provides better elevation angle diversity. Together, the GEO and GSO satellites ensure persistent visibility over the Indian region, reducing signal outages and enhancing service stability compared to purely MEO-based constellations

4.3 NavIC Signal Structure and Frequency Bands

NavIC transmits navigation signals in two primary frequency bands: the L5 band at 1176.45 MHz and the S-band at 2492.028 MHz. The L5 band is commonly used by modern GNSS systems and offers improved resistance to ionospheric disturbances and multipath effects compared to legacy navigation frequencies. This makes it well suited for navigation in urban and semi-obstructed environments.

The use of the S-band is a unique feature of NavIC among navigation systems. Since the S-band is relatively less congested, it offers improved signal robustness and reduced interference from commercial communication systems. Each NavIC signal carries essential navigation data, including satellite ephemeris, clock correction parameters, and system timing information. NavIC provides a Standard Positioning Service (SPS) for civilian users, with an emphasis on consistent and reliable regional performance.

4.4 NavIC Integration within Multi-GNSS Receivers

Modern GNSS receivers are typically multi-constellation capable, allowing them to track signals from multiple systems such as GPS, GLONASS, Galileo, BeiDou, and NavIC simultaneously. By combining observations from all available constellations, receivers compute a unified position solution with improved availability and robustness, especially in environments where satellite visibility may be partially obstructed.

In this study, the receiver operates in a multi-GNSS mode, meaning that the reported latitude, longitude, and altitude are derived from combined observations rather than from NavIC alone. However, raw observation data enables individual NavIC satellites to be identified and analyzed separately. This allows the evaluation of NavIC-specific characteristics such as satellite visibility, elevation angles, and signal strength. Separating position computation from satellite-level analysis ensures methodological clarity and prevents over-attribution of positioning performance to NavIC alone, enabling a realistic assessment of its role within a multi-GNSS environment.

Chapter 5: Experimental Setup and Hardware Configuration

5.1 Overview of Experimental Setup

This study is based on real-world experimental data collected using a portable GNSS data acquisition system specifically assembled for field testing. Rather than relying on static installations or simulated datasets, the objective was to observe GNSS behavior as it occurs during practical activities such as walking and cycling. The experimental setup was designed with three key priorities: simplicity, portability, and data integrity, ensuring reliable operation and faithful recording of raw GNSS observations without any artificial enhancement or modification.

The core of the system consists of a NavIC-capable multi-GNSS receiver interfaced with a Raspberry Pi single-board computer. The Raspberry Pi functions as both the control unit and data logging platform, offering a compact, low-power, and flexible solution for continuous GNSS data collection. This configuration enabled extended field experiments across diverse environments without dependence on laboratory infrastructure, allowing raw satellite observations to be captured transparently under realistic operating conditions.

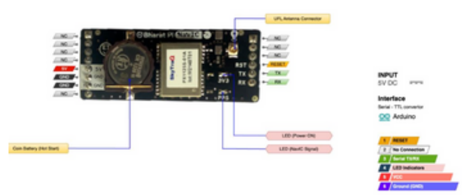
5.2 GNSS Receiver and Sensor Characteristics

A NavIC-capable multi-GNSS receiver was used in this study to track signals from multiple satellite constellations, including GPS, GLONASS, Galileo, BeiDou, and NavIC. The receiver computes latitude, longitude, altitude, velocity, and time using combined multi-GNSS observations, which improves positioning robustness and continuity, particularly in environments with partial satellite obstruction. In addition to position solutions, the receiver outputs raw satellite-level information through standard NMEA sentences, providing details such as satellite visibility, elevation, azimuth, constellation identifiers, and signal-to-noise ratio (SNR).

Although position solutions are derived from a multi-GNSS approach, NavIC satellites are clearly identified using constellation identifiers and PRN numbers and are analyzed independently in this study. This enables the evaluation of NavIC-specific satellite availability, signal strength, and visibility patterns under real-world operating conditions. Accordingly, the emphasis of this work is on NavIC satellite observability and signal behavior rather than on standalone positioning accuracy, ensuring methodological clarity and avoiding over-attribution of positioning performance to NavIC alone.

Technical Specifications

Receiver Type	NavIC L5, GAGAN/GPS L1 C/A code Phoenix engine
Accuracy	Position – 2.5m CEP Velocity – 0.1m/sec Time – 12nsec
Startup Time	~1sec hot start < 30sec cold start
Sensitivity	Better than -145 / -144dBm GPS / NavIC cold-start Better than -154 / -153dBm GPS / NavIC hot-start Better than -155 / -154dBm GPS / NavIC re-acquisition Better than -165 / -156dBm GPS / NavIC tracking
Multi-path Mitigation	Multi-path detection and suppression
A-GPS	7-day server-based AGPS Self-aided ephemeris estimation
Update Rate	1 / 2 / 4 / 5 / 8 / 10 Hz, default 1Hz
Dynamics	4G (39.2m/sec²) acceleration
Operational Limits	Altitude < 80,000m and velocity < 515m/s, not exceeding both
Serial Interface	3.3V LVTTL level UART, selectable 4800 ~ 115200 baud rate
Protocol	NMEA-0183 V3.01, SkyTraq binary, 115200 baud, 8, N, 1
Datum	Default WGS-84, User definable
Input Voltage	3.3V DC +/-10%
Current Consumption	80mA acquisition, 60mA tracking
Dimension	12.2mm W x 16.0mm L x 2.9mm H
Operating Temperature	-40°C ~ +85°C
Storage Temperature	-55°C ~ +100°C
Humidity	5% ~ 95%



Bharat Pi NavIC Pinout Diagram

5.3 Raspberry Pi–Based Data Logging and Remote Monitoring System

A Raspberry Pi single-board computer was employed as the central data logging and control unit for the experimental setup. The Raspberry Pi was selected due to its compact size, low power consumption, and built-in support for serial communication interfaces, making it well suited for portable field deployments. During the course of this research internship at the Indian Institute of Technology Jodhpur, the NavIC-capable GNSS receiver was interfaced with the Raspberry Pi using a serial communication interface (UART/USB) and deployed across multiple experimental scenarios and field conditions.

The Raspberry Pi was programmed to continuously read incoming NMEA sentences from the GNSS receiver and store them directly to local storage in real time. All data were recorded exactly as received from the sensor, without any filtering, smoothing, or post-processing at the logging stage. This ensured that the collected dataset faithfully represents true receiver-observed behavior under different operational cases, forming a reliable basis for subsequent satellite-level analysis and visualization. The raw data logged using this setup were later processed to generate trajectory plots and interactive map-based visualizations representing real-world movement and satellite observability.

To facilitate convenient operation during field experiments, the Raspberry Pi was remotely accessed from a laptop using Virtual Network Computing (VNC). This enabled real-time monitoring of receiver status, verification of continuous data logging, and system control without direct physical interaction with the hardware. Remote access proved particularly useful during mobile experiments such as walking and cycling, where stopping to manually inspect the system would have been impractical. The integration of remote monitoring improved operational flexibility and ensured uninterrupted acquisition of GNSS data throughout all experimental cases.

5.5 Field Deployment, Experimental Conditions, and Setup Summary

The experimental setup was deployed during walking and cycling activities to capture GNSS behavior under practical operating conditions. Data collection was carried out across a range of environments, including open-sky locations with minimal obstruction and semi-obstructed areas involving buildings, vegetation, and partial sky blockage. These varied conditions were intentionally selected to observe changes in satellite visibility and signal behavior under realistic field scenarios rather than controlled or idealized settings.

The portable nature of the Raspberry Pi–based system enabled continuous GNSS tracking during motion without interruption. The complete setup—including the NavIC-capable GNSS receiver, Raspberry Pi, antenna, and power supply—could be easily carried or mounted, allowing seamless data acquisition throughout the experiments. Remote monitoring via VNC further ensured stable operation and uninterrupted logging during field deployment.

Overall, the experimental configuration integrates a NavIC-capable multi-GNSS receiver with a Raspberry Pi–based portable data logging platform to enable transparent collection of raw GNSS observations under real-world conditions. By preserving unmodified receiver output and avoiding artificial enhancements, the setup provides a reliable and realistic foundation for the data processing, analysis, and performance evaluation presented in subsequent chapters.

Chapter 6: Data Collection and Methodology

6.1 Data Collection Strategy

The data for this study came from real-world field experiments conducted using the portable GNSS logging system we set up. Rather than collecting data from a fixed location, we carried the system during walking and cycling activities to capture how GNSS behaves under dynamic, everyday conditions. The experiments were deliberately conducted in different types of environments—some with clear, open skies and others with partial obstructions like buildings or trees—so we could observe how satellite visibility and signal quality change depending on the surroundings.

During each session, GNSS observations were recorded continuously to ensure we didn't miss any satellite tracking events. The key principle throughout was to capture the raw output from the receiver exactly as it came, without any processing or corrections applied in real time. This approach ensures that the data we analyze reflects what the receiver actually experienced in the field, not what it might have looked like after being cleaned up or enhanced artificially.

6.2 Raw GNSS Data Acquisition

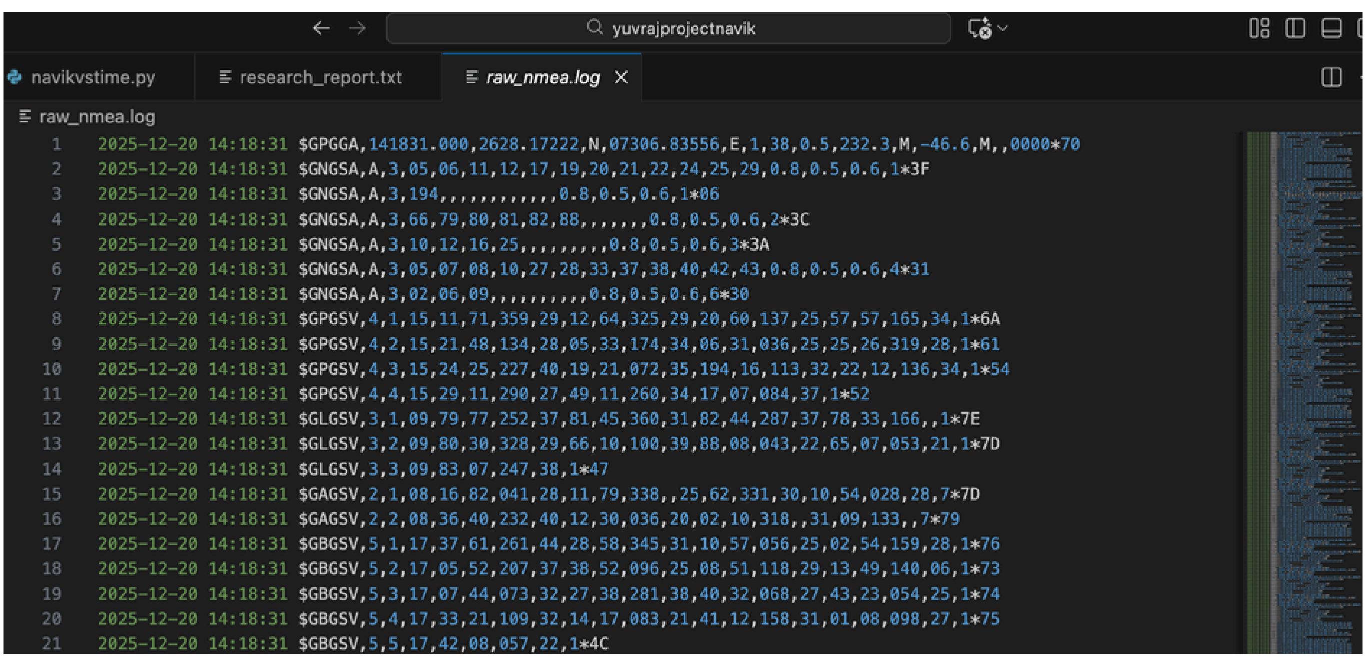
The GNSS receiver outputs standard NMEA sentences, which were logged by the Raspberry Pi in real time exactly as received. These text-based messages form the primary data source for this study and contain both position-level information (latitude, longitude, altitude) and satellite-level observations (satellite visibility and signal strength).

The main NMEA sentence types used in this study include

GGA – Position fixes and quality indicators such as fix type and HDOP

- GSV – Satellite visibility information including PRN, elevation, azimuth, and SNR
- RMC / VTG – Motion parameters such as speed and course
- ZDA (when available) – Precise timing and date information

All NMEA data were stored without any filtering, interpolation, or smoothing. Preserving the raw, unmodified receiver output ensures that the analysis reflects true GNSS behavior under real-world operating conditions, including natural variability and signal imperfections.




```
2025-12-20 14:18:31 $GPGGA,141831.000,2628.17222,N,07306.83556,E,1,38,0.5,232.3,M,-46.6,M,,0000*70
2025-12-20 14:18:31 $GNGSA,A,3,05,06,11,12,17,19,20,21,22,24,25,29,0.8,0.5,0.6,1*3F
2025-12-20 14:18:31 $GNGSA,A,3,194,,,,,,,,,,,,0.8,0.5,0.6,1*06
2025-12-20 14:18:31 $GNGSA,A,3,66,79,80,81,82,88,,,,,,,0.8,0.5,0.6,2*3C
2025-12-20 14:18:31 $GNGSA,A,3,10,12,16,25,,,,,,,,,0.8,0.5,0.6,3*3A
2025-12-20 14:18:31 $GNGSA,A,3,05,07,08,10,27,28,33,37,38,40,42,43,0.8,0.5,0.6,4*31
2025-12-20 14:18:31 $GNGSA,A,3,02,06,09,,,,,,,,,,0.8,0.5,0.6,6*30
2025-12-20 14:18:31 $GPGSV,4,1,15,11,71,359,29,12,64,325,29,20,60,137,25,57,57,165,34,1*6A
2025-12-20 14:18:31 $GPGSV,4,2,15,21,48,134,28,05,33,174,34,06,31,036,25,25,26,319,28,1*61
2025-12-20 14:18:31 $GPGSV,4,3,15,24,25,227,40,19,21,072,35,194,16,113,32,22,12,136,34,1*54
2025-12-20 14:18:31 $GPGSV,4,4,15,29,11,290,27,49,11,260,34,17,07,084,37,1*52
2025-12-20 14:18:31 $GLGSV,3,1,09,79,77,252,37,81,45,360,31,82,44,287,37,78,33,166,,1*7E
2025-12-20 14:18:31 $GLGSV,3,2,09,80,30,328,29,66,10,100,39,88,08,043,22,65,07,053,21,1*7D
2025-12-20 14:18:31 $GLGSV,3,3,09,83,07,247,38,1*47
2025-12-20 14:18:31 $GAGSV,2,1,08,16,82,041,28,11,79,338,,25,62,331,30,10,54,028,28,7*7D
2025-12-20 14:18:31 $GAGSV,2,2,08,36,40,232,40,12,30,036,20,02,10,318,,31,09,133,,7*79
2025-12-20 14:18:31 $GBGSV,5,1,17,37,61,261,44,28,58,345,31,10,57,056,25,02,54,159,28,1*76
2025-12-20 14:18:31 $GBGSV,5,2,17,05,52,207,37,38,52,096,25,08,51,118,29,13,49,140,06,1*73
2025-12-20 14:18:31 $GBGSV,5,3,17,07,44,073,32,27,38,281,38,40,32,068,27,43,23,054,25,1*74
2025-12-20 14:18:31 $GBGSV,5,4,17,33,21,109,32,14,17,083,21,41,12,158,31,01,08,098,27,1*75
2025-12-20 14:18:31 $GBGSV,5,5,17,42,08,057,22,1*4C
```

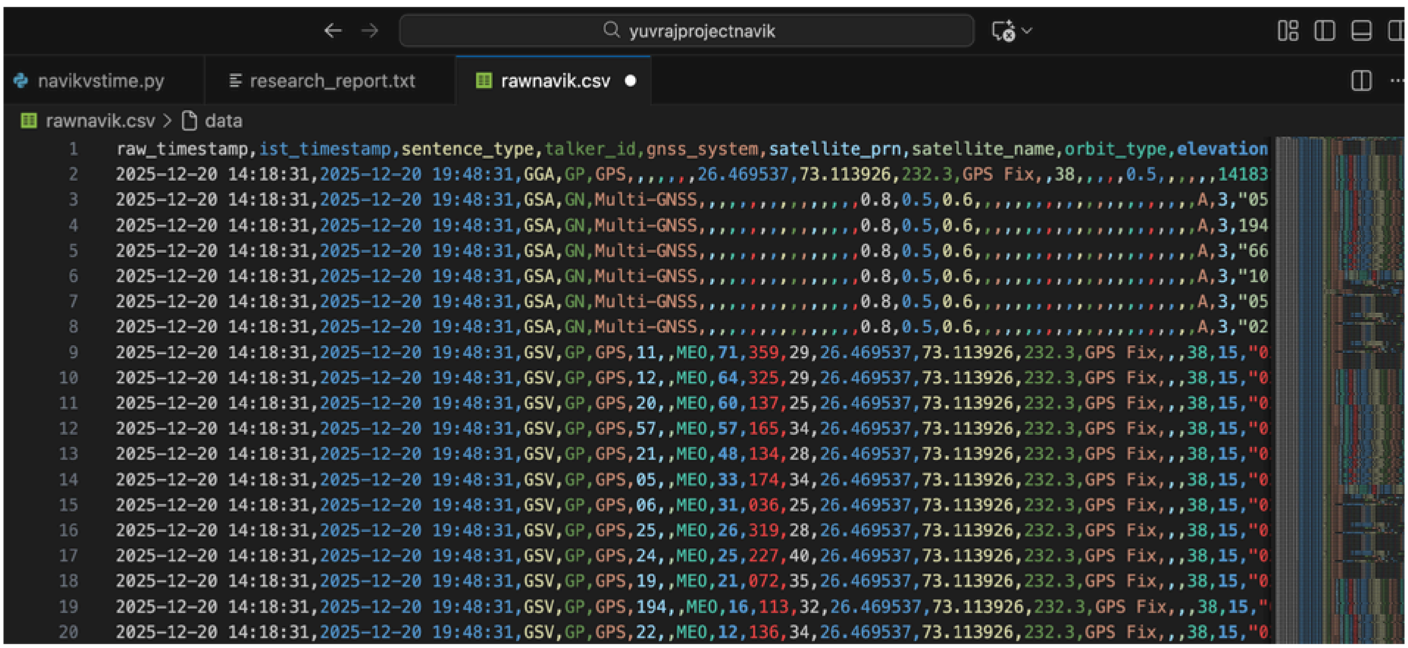
6.3 Data Preprocessing and Organization

Once the field experiments were complete, we took the raw NMEA logs and converted them into structured CSV files that are easier to work with during analysis. The data were organized into two separate datasets:

Position-level data – Contains timestamps along with latitude, longitude, and altitude values computed by the receiver

Satellite-level data – Contains information about individual satellites: which constellation they belong to, their PRN identifier, their position in the sky (elevation and azimuth), and their signal strength (SNR)

This separation is important because it maintains a clear distinction between the receiver's position solution—which uses signals from all available satellites—and the individual observations from each satellite. To analyze NavIC specifically, we filtered the satellite-level data using constellation identifiers and PRN ranges that correspond to NavIC satellites. This allowed us to isolate NavIC observations from the broader multi-GNSS dataset and study them independently.



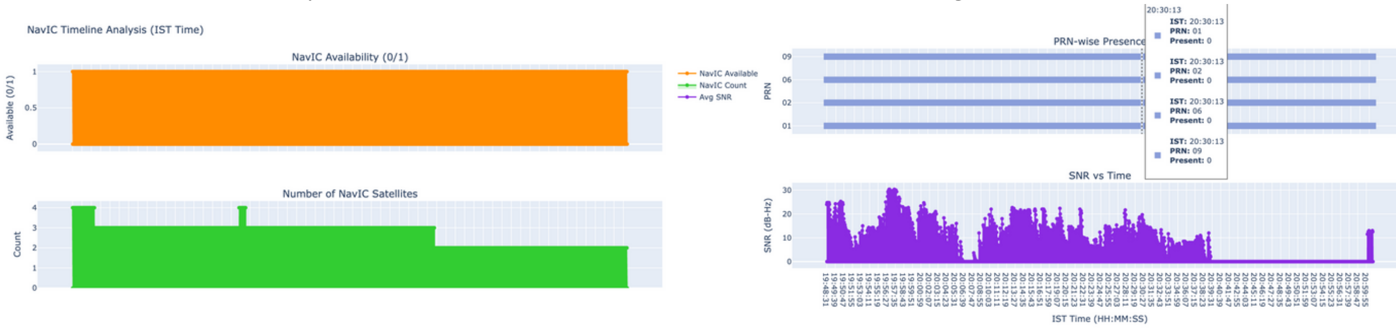

```
raw_timestamp,ist_timestamp,sentence_type,talker_id,gnss_system,satellite_prn,satellite_name,orbit_type,elevation
2025-12-20 14:18:31,2025-12-20 19:48:31,GGA,GP,GPS,,,,,,26.469537,73.113926,232.3,GPS Fix,,38,,,,0.5,,,,,14183
2025-12-20 14:18:31,2025-12-20 19:48:31,GSA,GN,Multi-GNSS,,,,,,,,,,,,,,0.8,0.5,0.6,,,,,,,,,,,,,,,,,,,,A,3,"05
2025-12-20 14:18:31,2025-12-20 19:48:31,GSA,GN,Multi-GNSS,,,,,,,,,,,,,,0.8,0.5,0.6,,,,,,,,,,,,,,,,,,,,A,3,194
2025-12-20 14:18:31,2025-12-20 19:48:31,GSA,GN,Multi-GNSS,,,,,,,,,,,,,,0.8,0.5,0.6,,,,,,,,,,,,,,,,,,,,A,3,"66
2025-12-20 14:18:31,2025-12-20 19:48:31,GSA,GN,Multi-GNSS,,,,,,,,,,,,,,0.8,0.5,0.6,,,,,,,,,,,,,,,,,,,,A,3,"10
2025-12-20 14:18:31,2025-12-20 19:48:31,GSA,GN,Multi-GNSS,,,,,,,,,,,,,,0.8,0.5,0.6,,,,,,,,,,,,,,,,,,,,A,3,"05
2025-12-20 14:18:31,2025-12-20 19:48:31,GSA,GN,Multi-GNSS,,,,,,,,,,,,,,0.8,0.5,0.6,,,,,,,,,,,,,,,,,,,,A,3,"02
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,11,,MEO,71,359,29,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,12,,MEO,64,325,29,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,20,,MEO,60,137,25,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,57,,MEO,57,165,34,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,21,,MEO,48,134,28,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,05,,MEO,33,174,34,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,06,,MEO,31,036,25,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,25,,MEO,26,319,28,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,24,,MEO,25,227,40,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,19,,MEO,21,072,35,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,194,,MEO,16,113,32,26.469537,73.113926,232.3,GPS Fix,,38,15,"
2025-12-20 14:18:31,2025-12-20 19:48:31,GSV,GP,GPS,22,,MEO,12,136,34,26.469537,73.113926,232.3,GPS Fix,,38,15,"0
```

6.4 Methodology for Satellite Availability Analysis (Timeline-Based)

To evaluate the temporal availability of NavIC satellites during the experiments, we analyzed the GSV messages recorded by the receiver, which provide time-tagged information about satellite visibility. A NavIC satellite was considered available at a given epoch if it appeared in the receiver's satellite visibility reports at that time. Using this criterion, multiple timeline-based visualizations were generated to characterize NavIC satellite availability over the full observation period.

The first visualization presents the NavIC satellite availability timeline, where the horizontal axis represents time and the vertical axis represents individual NavIC PRNs, indicating when each satellite was visible or absent. The second graph shows the temporal variation in the total count of visible NavIC satellites, highlighting changes in overall constellation availability. The third visualization focuses on PRN-wise presence, allowing identification of continuity and dropouts for individual satellites. The fourth graph depicts the signal-to-noise ratio (SNR) variation over time, providing insight into signal quality associated with observed availability patterns.

Together, these timeline-based analyses enable examination of both observability and continuity of NavIC signals under real-world conditions. Rather than focusing on positioning accuracy, this methodology emphasizes practical system behavior—specifically, how reliably NavIC satellites remain observable and how their signal strength evolves during field experiments. The combined use of availability, count, PRN-wise presence, and SNR (signal to noise ratio) timelines allows intuitive correlation between satellite visibility and environmental conditions encountered during data collection.



“The interactive visualization can be accessed via the link provided at the end of this section.”

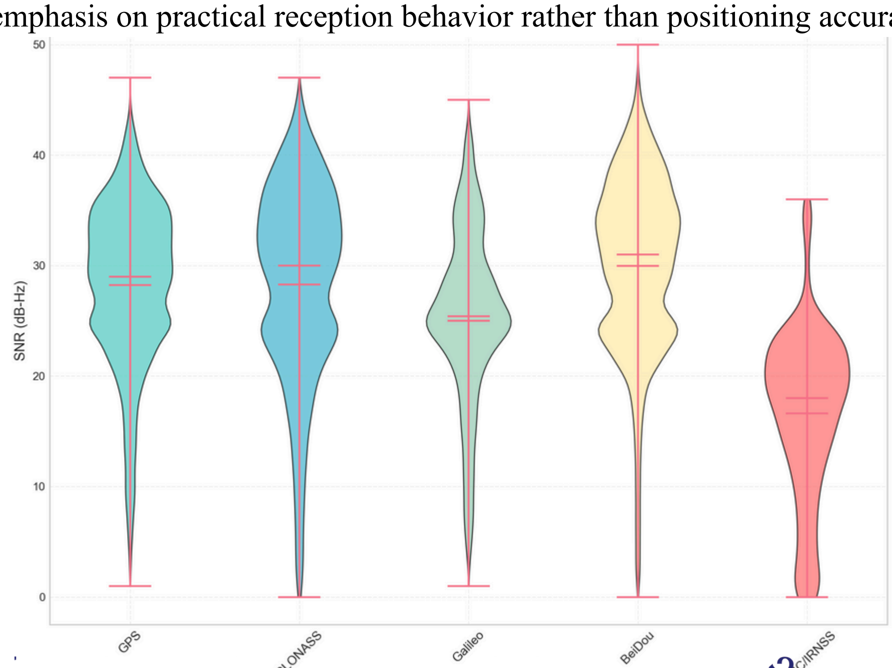
https://yuvraj24-afk.github.io/navik-gnss-visualization/navic_timeline_copy.html

6.5 Signal Strength and Observability Metrics

Signal quality was evaluated using the Signal-to-Noise Ratio (SNR) values obtained from GSV messages, which directly reflect the strength and clarity of the received signals. Higher SNR values correspond to stronger and more reliable reception, whereas lower values generally arise from low satellite elevation, antenna orientation effects, or partial obstructions in the receiver environment.

To examine overall signal behavior, SNR distributions were analyzed using violin plots for different GNSS constellations, including NavIC. These distributions summarize typical signal levels, variability, and the presence of weak-signal conditions. In comparison to global GNSS systems, NavIC shows a relatively lower median SNR and a more compact distribution, consistent with its regional coverage and stronger dependence on satellite geometry and visibility conditions.

The observed variations in SNR highlight the influence of real-world factors such as elevation angle, line-of-sight availability, and surrounding obstructions on signal observability. This distribution-based analysis complements the earlier timeline results by providing a concise statistical view of signal strength, with emphasis on practical reception behavior rather than positioning accuracy.



6.6 Position Visualization and Trajectory Mapping

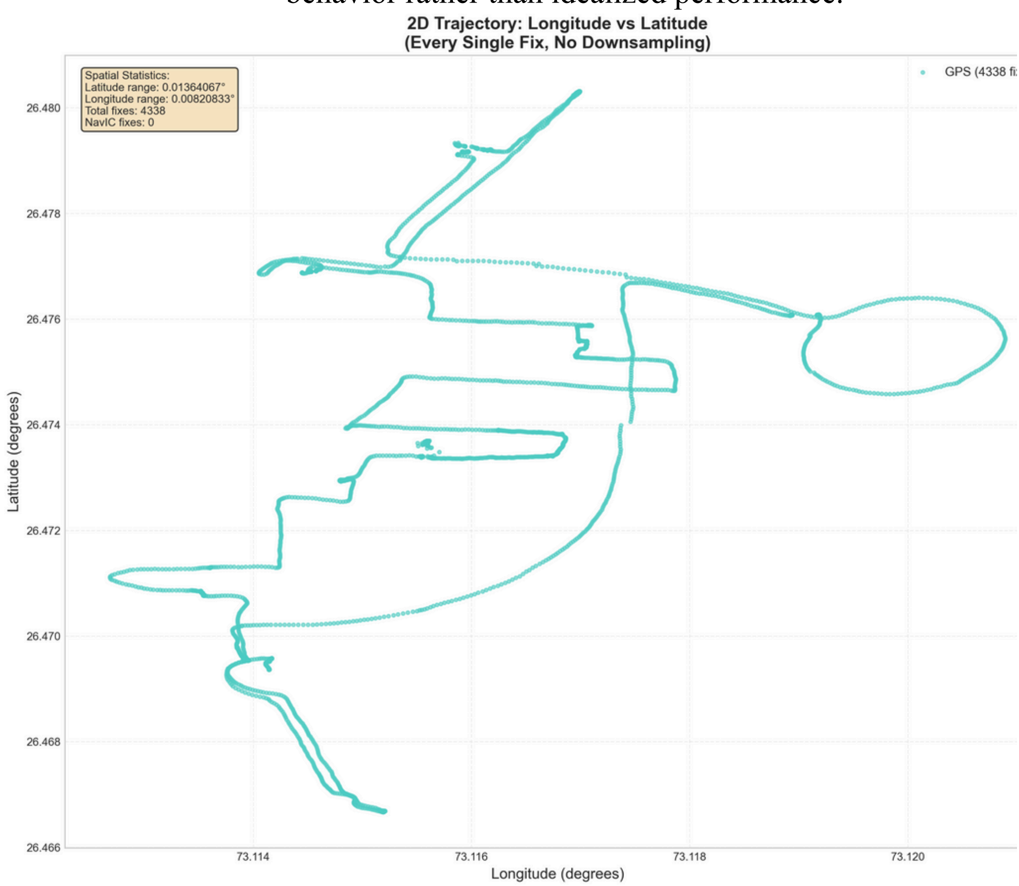
Although position solutions were computed using all available GNSS constellations, the resulting latitude, longitude, and altitude data were primarily used for visualization of receiver motion during the experiments. Two-dimensional trajectory plots based on latitude and longitude were generated to illustrate the walking and cycling paths, providing clear spatial context for where satellite observations were collected.

In addition, three-dimensional trajectory visualizations incorporating altitude were created to better represent motion and environmental variation along the routes. To enhance interpretability, interactive map-based visualizations were also developed, allowing zooming, panning, and point-wise inspection of the receiver trajectory. These visual tools help relate changes in satellite availability and signal strength to specific locations, such as areas with nearby buildings or vegetation. Links to the interactive 2D and 3D trajectory maps generated from the experimental data are provided separately.

6.7 Methodological Scope and Limitations

This methodology is designed to examine satellite observability and signal characteristics, including visibility continuity and SNR behavior of NavIC satellites under real-world conditions. It does not aim to assess standalone positioning accuracy or demonstrate NavIC-only navigation performance.

No differential corrections, filtering, or precision-enhancement techniques were applied, and the analysis was conducted using minimally processed receiver data. While position solutions were obtained using multi-GNSS observations, NavIC-specific analyses were performed independently to avoid over-interpreting its contribution. This approach ensures transparency and presents an honest representation of practical system behavior rather than idealized performance.



Interactive 2D GNSS Trajectory:

The GNSS-based latitude–longitude path can be explored via the link below(IIT JODHPUR)

https://yuvraj24-afk.github.io/navik-gnss-visualization/

Chapter 7: Results and Discussion

This chapter summarizes the results obtained from the analysis of raw GNSS data collected during field experiments, with a specific focus on NavIC satellite observability and signal behavior under real-world conditions. The objective is not to evaluate positioning accuracy, but to understand what the receiver actually observed—how often NavIC satellites were visible, how strong their signals were, and how consistently they remained available over time, based entirely on unfiltered NMEA data.

All findings presented in this chapter are fully traceable to a raw CSV dataset containing time-stamped position fixes and satellite observations. No filtering, smoothing, interpolation, or correction techniques were applied. As a result, the data preserve genuine signal fluctuations, temporary satellite outages, and abrupt changes in visibility, providing an honest representation of practical system behavior.

Raw GNSS Data (CSV): link_here

https://github.com/yuvraj24-afk/navik-gnss-visualization/blob/main/rawnavik.csv

7.1 Raw Data Integrity and Observational Validity

The analysis is based entirely on raw GNSS receiver measurements collected while traversing different environments during the experiments. The dataset directly reflects what the receiver observed and includes time-stamped position information, satellite visibility status, PRN identifiers, elevation and azimuth angles, and signal-to-noise ratio (SNR) values.

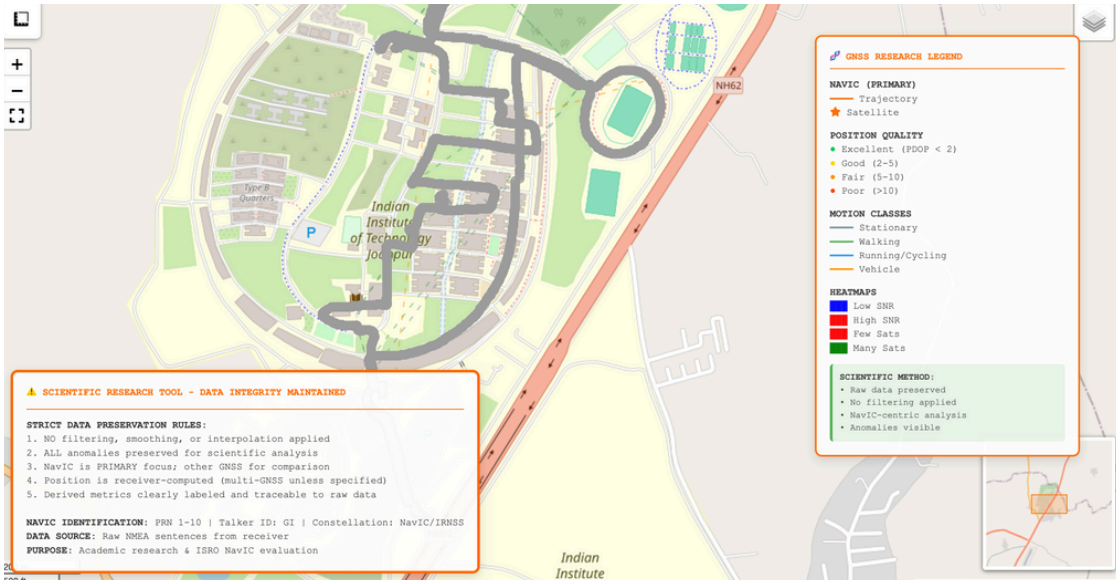
No filtering, smoothing, interpolation, or correction techniques were applied prior to analysis. Consequently, any gaps, fluctuations, or irregularities present in the data represent genuine variations in satellite geometry, line-of-sight conditions, and signal propagation effects encountered in the field, rather than artifacts introduced during data processing. This approach ensures that all subsequent analyses are grounded in realistic system behavior as observed under practical operating conditions

7.2 GNSS-Based Position Trajectories as Spatial Context

Position solutions were computed using all available GNSS constellations together, and the resulting latitude, longitude, and altitude data were used to visualize the receiver's movement during the experiments. Two-dimensional trajectory plots and an interactive map were generated to show where the data were collected, providing essential spatial context for interpreting NavIC satellite behavior.

In particular, an interactive Folium-based GNSS trajectory map was created using the raw receiver position data. The map displays the experimental paths across the study area and allows point-wise inspection of location-specific information such as time, altitude, satellite count, and signal strength. This visualization was generated directly from unfiltered GNSS measurements and serves purely as a contextual reference, without implying NavIC-only positioning capability.

By mapping the receiver trajectory onto the real geographic layout of the experiment location, the interactive map helps relate observed NavIC availability and signal variations to specific places and movement patterns encountered during data collection.



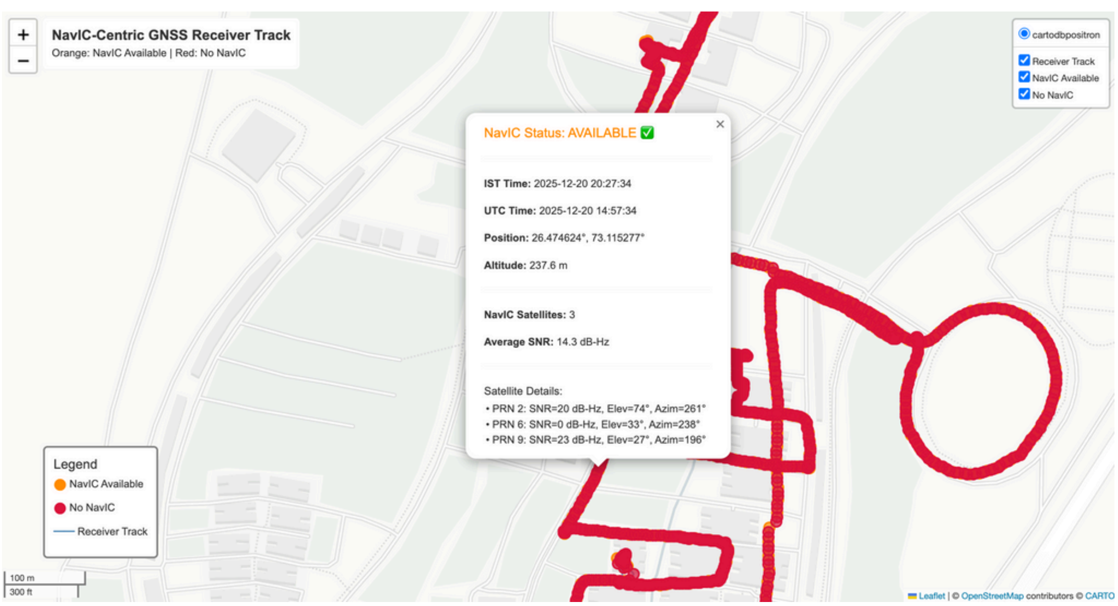
Here is the link to the NavIC Research Tool (interactive visualization)(IIT JODHPUR):

https://yuvraj24-afk.github.io/navik-gnss-visualization/navic_research_tool.html

7.3 NavIC Availability Along the Receiver Path

NavIC-specific availability maps reveal that NavIC satellites are not continuously available along the trajectory. Availability varies with location and time, with clear alternation between periods of visibility and complete unavailability, even along short routes.

Compared to global GNSS constellations such as GPS, NavIC generally shows lower satellite availability. This is expected given its regional nature and smaller constellation size. The observed transitions are primarily driven by satellite geometry and local line-of-sight obstructions rather than receiver motion alone.



Interactive NavIC–GNSS visualization generated(IIT JODHPUR) from raw receiver data is available at:

https://yuvraj24-afk.github.io/navik-gnss-visualization/navik_gnss.html

7.4 Signal Strength and Satellite-Level Characteristics

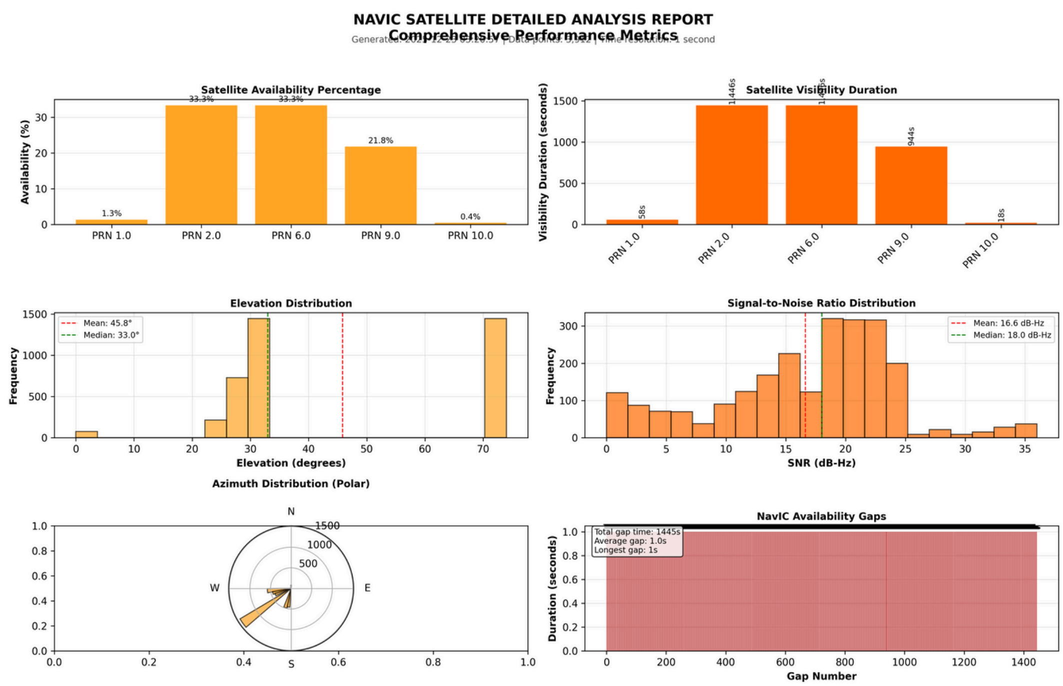
The analysis of signal strength reveals that NavIC availability during the experiments was typically supported by a limited number of satellites. As a result, signal continuity is highly sensitive to small changes in satellite geometry. The SNR distribution clearly indicates that NavIC signals are, on average, weaker and more variable than those from global GNSS constellations. This behavior reflects the combined influence of the regional constellation size, satellite sky geometry, and the local propagation environment encountered during the measurements

.

A satellite-level examination further highlights the non-uniform contribution of individual NavIC satellites. A small subset of PRNs accounts for the majority of the observed availability and total visibility duration, while other satellites appear only intermittently or for short intervals. This uneven contribution emphasizes the dependence of NavIC observability on a few dominant satellites at any given time.

The elevation and azimuth distributions show a clear relationship between satellite sky position and signal quality. Satellites observed at higher elevation angles generally exhibit stronger and more stable SNR values, whereas low-elevation satellites contribute weaker and less consistent signals. This dependence on elevation reinforces the role of geometry and line-of-sight conditions in determining NavIC signal performance.

In addition, periods of complete NavIC unavailability are evident in the availability gap analysis, even when multi-GNSS positioning continues uninterrupted using other constellations. The presence of frequent short gaps, along with occasional longer interruptions, demonstrates that NavIC observability under real-world conditions is inherently intermittent. These findings underline the importance of analyzing NavIC signal behavior independently, rather than inferring its performance solely from overall GNSS position continuity.



Chapter 8: Conclusion and Applications

This work presented a practical, field-based evaluation of NavIC (IRNSS) using raw GNSS receiver data collected during real-world experiments. Rather than pursuing claims about positioning accuracy, the study deliberately focused on satellite observability, signal strength, and availability continuity—exploring how NavIC actually performs in everyday conditions through direct, unfiltered receiver measurements.

The strength of this approach lies in its commitment to raw data integrity. Throughout the entire analysis, no filtering, smoothing, interpolation, or correction techniques were applied. The dataset therefore captures authentic signal behavior—genuine fluctuations, temporary dropouts, and availability gaps exactly as they occurred in the field. This transparency ensures that the evaluation reflects real-world system performance rather than artificially enhanced results.

The findings reveal that NavIC satellite availability is intermittent and generally lower compared to global GNSS constellations such as GPS. Availability changes notably with both location and time, shaped primarily by satellite geometry and local environmental factors including obstructions and limited sky visibility. Signal strength analysis confirms that NavIC observability often depends on just a few satellites, making system continuity vulnerable to even modest changes in geometry. These characteristics align naturally with NavIC's regional design and limited constellation size.

An important methodological principle maintained throughout this work was the clear separation between multi-GNSS position computation and NavIC-specific satellite analysis. While the receiver's position solutions remained stable by combining signals from multiple constellations, NavIC signal presence varied independently. This distinction underscores why constellation-specific evaluation matters and demonstrates that overall positioning continuity alone cannot reliably indicate individual system performance.

NavIC represents India's indigenous regional navigation capability, operated by ISRO, and currently comprises a modest constellation of geostationary (GEO) and geosynchronous (GSO) satellites: IRNSS-1B, IRNSS-1C, IRNSS-1D, IRNSS-1E, IRNSS-1F, IRNSS-1G, IRNSS-1I, and IRNSS-1J. The observability patterns documented in this study should be understood within this regional architecture rather than viewed as limitations of the analysis itself.

x

In conclusion, this study establishes a realistic and reproducible approach to evaluating NavIC observability through raw GNSS data. By maintaining strict focus on directly measurable phenomena and resisting over-interpretation, it delivers genuine insight into NavIC's real-world behavior and provides a solid foundation for future long-term, large-scale observational research.

Chapter 9: Future Scope

This work represents an initial step toward understanding how NavIC behaves under real-world conditions. The focus of this study was deliberately practical—examining satellite availability, signal strength, and visibility using raw GNSS receiver data. While the results provide valuable insights, the scope of this work is limited by time, location, and experimental scale. As a result, there are several important directions in which this study can be meaningfully extended.

One of the most important future directions is **long-term monitoring of NavIC performance**. Extending data collection over months or seasons would allow the study of repeatability in satellite visibility, long-term signal stability, and changes in availability due to evolving satellite geometry. Such extended datasets could reveal trends that are not observable in short experiments, including seasonal effects and consistency of individual satellite performance over time

.

Another major extension involves **expanding experiments across different regions of India**. NavIC performance is expected to vary significantly between dense urban areas, semi-urban regions, open rural landscapes, coastal zones, and challenging terrains such as hills or forests. Systematic measurements across these environments would help quantify the impact of obstructions, multipath, and horizon masking, leading to a more complete understanding of where NavIC performs reliably and where improvements may be required. This knowledge is especially relevant for applications related to transportation, disaster management, and regional infrastructure planning.

While this study intentionally avoided claims about standalone positioning accuracy, **future work can explore NavIC-only positioning performance** under controlled conditions. Once sufficient satellite visibility and receiver support are available, such experiments could evaluate positioning accuracy, continuity, and robustness in comparison with global GNSS systems. The emphasis should remain on transparent methodology and realistic assessment rather than optimistic performance claims.

From a **national and strategic perspective**, NavIC plays a crucial role as an independent navigation system for India.

Dependence on foreign GNSS systems can introduce vulnerability during emergencies or geopolitical uncertainties. Studies focused on satellite availability, signal continuity, and system reliability directly support the goal of national resilience in areas such as defense, disaster response, and critical infrastructure. Importantly, this type of observability-focused research can be conducted openly without involving sensitive operational details.

The methodology developed in this work can also serve as a **baseline framework for tracking NavIC's evolution,** particularly as ISRO continues to launch new satellites and enhance system capabilities. Repeating similar analyses after system upgrades would allow objective assessment of improvements in coverage, signal strength, and continuity, providing long-term, data-driven insight into NavIC's growth.

Finally, the visualization tools developed in this project point toward the possibility of **real-time GNSS monitoring platforms**. With further development, such systems could support live satellite availability tracking, automated performance analysis, receiver testing, and educational use. These platforms could improve transparency, support field diagnostics, and build broader confidence in NavIC's performance.

In summary, this work lays a foundation for continued, realistic evaluation of NavIC under real-world conditions. By extending the analysis across time, geography, and application domains, future studies can contribute not only to scientific understanding but also to the development of a robust, reliable, and independent navigation capability for India.

References

[1] Indian Space Research Organisation (ISRO), NavIC – Indian Regional Navigation Satellite System, **https://www.isro.gov.in/SatelliteNavigationServices.html (accessed Jan. 2025).**

[2] Indian Space Research Organisation (ISRO), IRNSS/NavIC System Overview, **https://www.isro.gov.in/IRNSS.html (accessed Jan. 2025).**

[3] National Marine Electronics Association, NMEA 0183 Standard, **https://www.nmea.org (accessed Jan. 2025).**

[4] E. D. Kaplan and C. J. Hegarty, Understanding GPS/GNSS: Principles and Applications, 3rd ed., Artech House, 2017.

[5] Python Software Foundation, Python Documentation, **https://docs.python.org/3/ (accessed Jan. 2025)**.

[6] Folium Developers, Folium: Python Library for Interactive Maps, **https://python-visualization.github.io/folium/ (accessed Jan. 2025).**

[7] V. Agafonkin, Leaflet: Open-Source JavaScript Library for Interactive Maps, **https://leafletjs.com/ (accessed Jan. 2025).**