NavIC
Navigation with Indian Constellation

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Abstract

We delve into the latest innovation within the spacecraft domain, our very own contender against the American GPS system, NavIC. Our exploration encompasses a comprehensive examination of satellite design, utilization, and an overview of the satellite's operational mechanics. Furthermore, we undertake the task of simulating the orbital dynamics of the satellites involved, delving into the complexities of their trajectories and its movement within the celestial realm. Through this endeavor, we aim to gain deeper insights into NavIC's capabilities and its potential to redefine the landscape of satellite navigation.

1. Introduction

NavIC, formerly known as the Indian Regional Navigation Satellite System (IRNSS), is India's regional satellite navigation system developed by the Indian Space Research Organisation (ISRO). Comprising a constellation of seven satellites, NavIC provides accurate positioning, navigation, and timing services over the Indian region and surrounding areas up to 1500 kilometers beyond its borders. Launched to reduce dependency on foreign navigation systems, NavIC offers various applications across sectors such as transportation, agriculture, disaster management, and defense. With its indigenous technology and commitment to regional self-reliance, NavIC enhances India's capabilities in satellite-based navigation and contributes to the nation's technological advancement.

1.1. Constellation Design

NavIC is designed with a 7-satellite constellation and a network of ground stations that operate around the clock. The constellation's three satellites are in geostationary orbit at 32.5°E, 83°E, and 129.5°E, respectively, and four satellites are in inclined geosynchronous orbit with equatorial crossings of 55°E and 111.75°E, respectively, with an inclination of 29° (two satellites per plane).

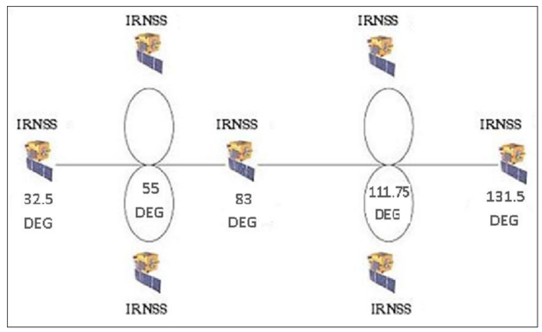

Figure 1. Satelite Cluster and Posistion

First Generation(IRNSS):
- IRNSS-1A
- IRNSS-1B
- IRNSS-1C
- IRNSS-1D
- IRNSS-1E
- IRNSS-1F
- IRNSS-1G
- IRNSS-1H(Launch Failure)
- IRNSS-1I

Each of the seven satellites in the IRNSS constellation weighed much less (around 1,425 kg at liftoff) and rode the lighter Polar Satellite Launch Vehicle (PSLV)

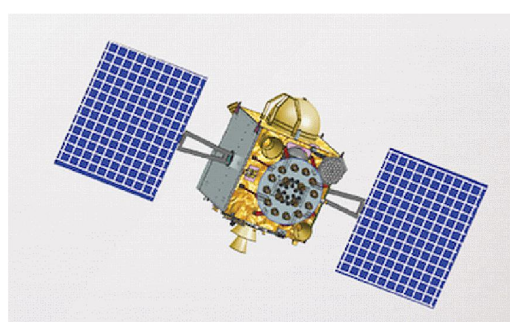

Figure 2. IRNSS Satelite

Second Generation(NavIC): The first of its kind NVS-01 is heavier and has the following specs:

- Atomic clock: The satellite will have a Rubidium atomic clock onboard, developed indigenously by the Space Application Centre Ahmedabad. Using the atomic clocks on board, a satellite-based positioning system precisely measures the time it takes for a signal to travel to and from an object.
- Frequency addition: The 2nd generation of NavIC satellites will send signals at a third frequency, L1, increasing interoperability with other satellite-based navigation systems.
- Longer life span: The 2nd-generation NavIC satellites will also have a longer mission life of more than 12 years (existing satellites - 10 years).

1.2. Network and Services

NavIC provides two services: Standard Position Service (SPS) for civilian customers and Restricted Service (RS) for strategic users. These two services are available on both L5 (1176.45 MHz) and S band (2498.028 MHz).

A new civilian signal was introduced in the L1 band(1575.42 MHz). NavIC L1 signal is also interoperable with the other GNSS signals. The L1 frequency is among the most commonly used in GPS and will increase the use of the regional navigation system in wearable devices and personal trackers that use low-power, single-frequency chips. All upcoming NavIC satellites, starting in 2023, will transmit SPS signals in the L1, L5, and S bands.

The user position precision and timing accuracy of NavIC signals are designed to be greater than 5 meters and 10 nanoseconds, respectively. The signals of the NavIC SPS are compatible with those of the other GNSS systems, such as GPS, Glonass, Galileo, and BeiDou.

The satellites continuously transmit signals containing information about their precise orbits and the current time. Receivers on the ground or in other platforms, like ships or aircraft, receive these signals and use them to calculate their own position, velocity, and time.

1.3. Ground Control

ISRO operates ground control stations to monitor the health of the satellites, update their orbits if necessary, and synchronize their clocks. These control stations ensure the accuracy and reliability of the NavIC signals.

It consists of several key components, including:

- IRSCF (IRNSS Spacecraft Control Facility): It is the facility that serves as the mission control center for the IRNSS satellites. It sends telemetry commands to the satellites, monitors their health and performance, and maneuvers them as needed.
- IRIMS (IRNSS Range and Integrity Monitoring Stations): It is a network of geographically distributed stations strategically placed across India. These stations continuously monitor the signals transmitted by the IRNSS satellites to ensure their accuracy and integrity.
- IRDCN (IRNSS Data Communication Network): This is a secure communication network that connects all the elements of the IRNSS ground segment, enabling the exchange of data and control signals between them.
- INC (ISRO Navigation Center): This center is the heart of the IRNSS system. It generates navigation data using information from the IRSS satellites and ground stations. This data is then uploaded to the satellites for transmission to user receivers.

1.4. Control Stratergy

Satellites in geosynchronous and geostationary orbits require periodic stationkeeping maneuvers to counteract perturbations such as gravitational effects from the Earth and lunar and solar influences. These maneuvers involve firing thrusters to adjust the satellite's velocity and altitude, keeping it within its designated orbital slot and ensuring it remains aligned with the Earth's rotation.

To prevent collisions with other satellites or space debris, NavIC satellites are constantly monitored for potential conjunctions with objects in their vicinity. If a collision risk is detected, corrective maneuvers can be planned and executed to ensure the satellite remains safe and operational.

The spacecraft has the capability to optimize the use of the solar panels and to support the thermal control of the satellite. The two solar panels generates 1660 Watts and powers its Electrical Power Subsystem (EPS) and also charges a 90 Amp-hour lithium-ion battery.

The spacecraft is 3-axis stabilized. Attitude control of the satellite is provided with yaw steering. The Attitude Determination and Control Subsystem (ADCS) maintain the spacecraft's orientation utilizing sun sensors, star sensors, and gyroscopes. Maneuvering is managed by reaction wheels, magnetic torquers, and 22 Newton thrusters as actuators. For larger maneuvers, the spacecraft is equipped with a 440 Newton Liquid Apogee Motor (LAM), while twelve 22 Newton thrusters handle finer adjustments. Thrust Vector Control (TVC) systems allows for precise control of thrust direction. By adjusting the orientation of the thruster exhaust, engineers can finely tune the satellite's trajectory and maintain its desired orbit.

2. Methodology

A Matlab code is attached with the report. The provided MATLAB code is designed to simulate the orbits of seven satellites around the Earth. It begins by initializing standard parameters such as, the latitudes and z-components of each satellite, as well as constants such as gravitational constant and Earth radius. These parameters are crucial for defining the initial conditions of the simulation and setting up the environment for orbit computation.

Once the parameters are initialized, the code proceeds to calculate the orbital elements for each satellite based on its position and velocity vectors. This involves computing eccentricity, inclination, right ascension of ascending node (RAAN), argument of perigee, and mean anomaly. These orbital elements are essential for determining the trajectory of each satellite and predicting its position at different points in time.

With the orbital elements calculated, the code enters a simulation loop where it iterates through time steps to update the positions of each of the satellites over time. This is achieved by solving Kepler's equations and applying the equations of motion for orbital dynamics. The positions of the satellites are continuously updated based on their orbital elements and the gravitational forces acting upon them.

As the simulation progresses, the code visualizes the orbits of the satellites in 3D space. It plots the movement of each satellite over time, around the Earth, allowing for the visualization of their trajectories and interactions with the Earth's gravitational field. Additionally, the code generates ground tracks to visualize the paths of the satellites on the Earth's surface, providing further insights into their orbital behavior.

The base for the code by taken from the github: https://github.com/deedy/Satellite-Orbit-Simulation.

This code encountered several issues and bugs, particularly in its functionality limited to low Earth orbits. To address these limitations, significant modifications were implemented, including the removal of unnecessary parts of the code and the addition of features to simulate plot five satellites at once. Among these, three were designated as geostationary, maintaining a fixed position relative to Earth's surface, while the remaining two were set to occupy the same geosynchronous orbit. These enhancements aimed to broaden the code's applicability across a wider range of orbital configurations and improve its overall performance.

3. Results

- **Geostationary Satellite**: The ground track appears as a single point on the equator. The satellite remains fixed above a specific location on Earth due to its synchronous rotation with Earth's rotation.
- **Geosynchronous Satellite**: The ground track appears as a figure-eight shaped loop, traced out over the course of its orbit. The loop's size and distortion depend on the satellite's orbital inclination and eccentricity. The satellite revisits the same ground locations every orbital period (e.g., once per sidereal day). The equatorial crossing is the point in a geosynchronous orbit where a satellite crosses the Earth's equatorial plane.

The below images shows the result from simulating NavIC in Matlab.

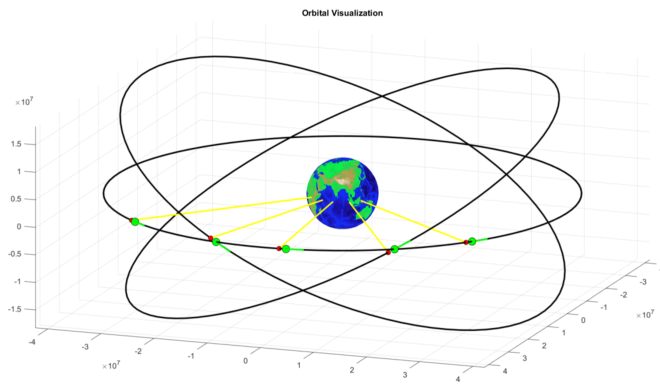

Figure 3. 3D Simulation of NavIC

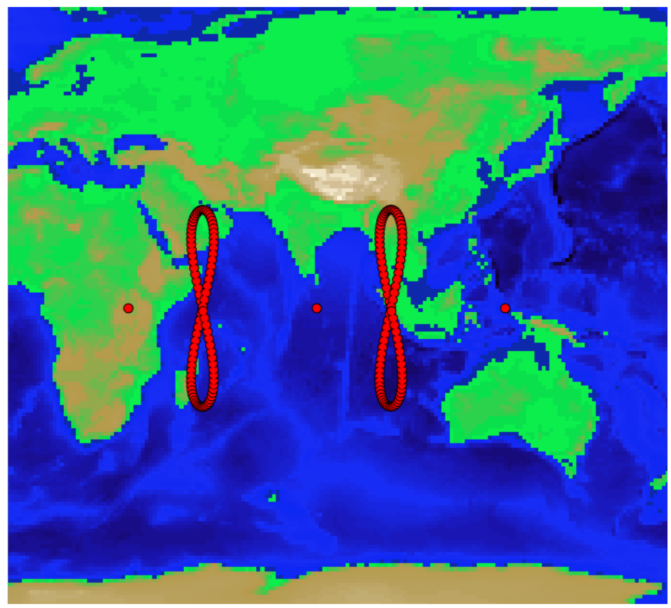

Figure 4. Ground-track of NavIC

4. Contribution

The collaborative effort was a testament to the dedication and teamwork of all involved. Devananth V, Nikhil Krishna, Avish Santhosh, and Niyas Jaman contributed to the code development, each bringing their unique skills and expertise to the table. Everyone played a role in crafting an engaging presentation, especially Ajay Shankar and Ameen Ahmed, to ensure that our work was effectively communicated. Additionally, everyone played a role in the report's creation, contributing their insights and expertise to produce a comprehensive and cohesive document.

5. References

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