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RF in loop HLS profile test station for evaluation of GNSS integrated navigation system

Anand Shankar OT*(1), Mohammed Basim (1), Biju VS(1),Vinoj VS(1), Radhakrishna Pillai C(1) and Sasikumar S(1)
(1) ISRO Inertial Systems Unit, Trivandrum, Kerala, India, 695013

Abstract

Inertial navigation systems with expensive navigation grade accelerometers and gyroscopes are typically used for navigation in high reliability applications such as launch vehicles. Usage of GNSS receivers with measurements synchronized with INS provides the scope for incorporating inexpensive control grade MEMS gyroscopes for navigation without compromising in mission accuracy. However, it calls for additional test mechanisms to ensure the performance of the integrated navigation system under different performance conditions of GNSS receiver. Design of such an RF in loop HLS (Hardware in Loop Simulation) profile test station for evaluation of the performance of the integrated navigation system is explored in detail. The system has the capability to simulate GNSS RF signal corresponding to the mission trajectory in synchronization with angular rates simulated by angular motion simulator and other sensor data through simulation interfaces. Evaluation of the integrated navigation system and aiding algorithms using GNSS outputs has successfully been carried out using the test station and expected accuracy in navigation outputs are demonstrated.

1. Introduction

Inertial navigation systems (INS) are navigation systems that use accelerometers and gyroscopes for computing the position, velocity and orientation of an object or a vehicle in which the INS is mounted. These systems are self contained and does not depend on any external factors or signals for their functioning. However, an INS should have accurate prior information about the initial position, velocity and orientation of the vehicle for functioning. Further, the linear motion and the angular motion sensed by the inertial sensors are integrated to derive the current position, velocity and orientation, a technique often termed as dead reckoning.

For inertial navigation systems to provide accurate estimates of position, velocity and orientation, it requires highly accurate sensors, since the process of computation involves integration of sensor outputs. Errors in the sensor outputs can result in unbounded error growth in the navigation solutions over time. However, attitude error caused by gyroscopes are more detrimental since it leads to an error in calculated acceleration vector, leading to further errors in position and velocity.

With advancements in sensor development and allied technologies, inertial sensors with very high degree of accuracy have been available for many decades. Availability of such sensorshave made it feasible to build and use inertial navigation systems for a variety of applications ranging from strategic and tactical application such as aircrafts, missiles, spacecrafts, launch vehicles, submarines and ships to common applications like mobile phones.

For strategic applications like launch vehicles which demands high reliability and accuracy, navigation grade sensors along with MIL grade processing electronics are conventionally used. This makes the INS for a launch vehicle extremely costly. With space sector becoming more open towards commercial ventures and space based services becoming part and parcel of our everyday life, efforts to reduce the cost of access to space is being undertaken all around the globe. Reducing the cost of navigation system of the launch vehicle is a vital step towards the realization of a low cost launch vehicle.

Such a low cost navigation system which is highly reliable has been developed for India's launch vehicle applications. The system is an integrated navigation system with inbuilt GNSS receiver. Instead of expensive and bulky navigation grade gyroscopes, the system is configured with MEMS based control grade gyroscopes. The system is designed such that the measurement instances of GNSS receiver coincides with the inertial sensor measurements. The inaccuracies that are caused by the MEMS gyroscope is compensated using attitude aiding with the help of GNSS solutions. State vector aiding with GNSS solution is carried out to improve the accuracy of the navigation solution.

2. Configuration of the integrated navigation system

The integrated navigation system consists of MEMS gyros, accelerometers, sensor electronics cards and GNSS receiver embedded navigation processor housed in a single package. MEMS IMU is configured with 6 MEMS Gyros & 6 accelerometers mounted in skewed triad hexadconfiguration with half cone angle of 54.73° and cone axis vertical. The configuration providesredundancy for all axes, capable of tolerating two sensor failures. There are two independent GNSS receiver embedded navigation processors within the system and they are configured in dual redundantconfiguration, cross-strapped to the onboard computer. Each navigation processor is interfaced with sensor dataacquisition electronics through three isolated RS422 interfaces. The navigation processor is also interfaced with RF subsystemsfor acquiring GNSS signals and performing receiver functions. Embedded GNSS receiver supports GPS L1 C/A and NavIC L5-SPS signals, and generates NavIC alone, GPS alone and Hybrid navigation solutions. Along with GNSS receiver functionalities, the processor performs acquisition of inertial sensor data from sensor electronics cards, Inertial Navigationcomputations and aided navigation computations to generate integrated navigation solution. Functionaloutputs and telemetry data are communicated to onboard computer over MIL1553B bus. Dedicated RS422 interfacesare available in the navigation processor for acquiring simulation data for the validation of NGCsystems at various test beds. The configuration of the integrated navigation system is illustrated in the figure below.

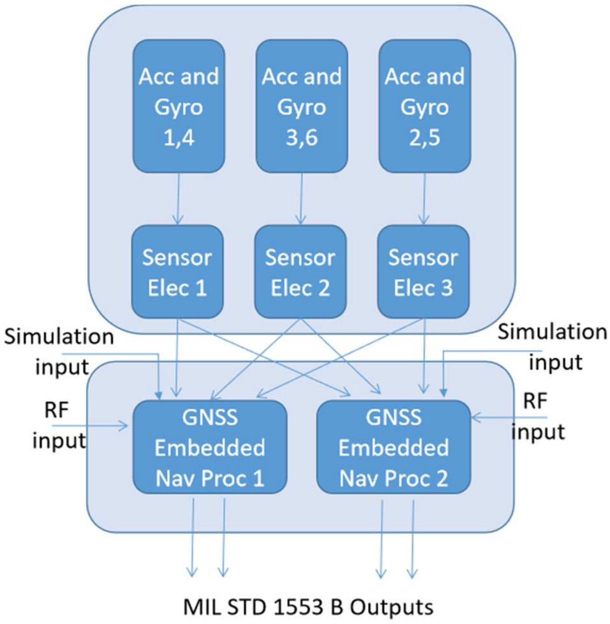

Figure 1. Configuration of integrated navigation system

3. Need for RF in loop HLS profile test

The GNSS integrated navigation system provides the desired performance of a launch vehicle INS by aiding the inertial navigation output using data from the GNSS receiver. System is designed with in-built GNSS receiver which also acts as the navigation processor for execution of Inertial Navigation and Aided Navigation software. The required mission accuracy will be achieved with attitude aiding using GNSS data, in addition to position and velocity aiding. Novel algorithms are used to estimate the error in the attitude, position and velocity of theINS using the GNSS data and correct them so that mission accuracyis achieved. The attitude aiding algorithm also depends on accelerationmeasurement. All these aspects make the performance of GNSS receiver an important factor in determining the performance of the integrated navigation system. Functioning of the GNSS receiver is dependent on external aspects as well, mainly the signals received by the antenna. There can be multiple factors affecting the performance of the GNSS receivers asgiven below:

1. Availability of signals: GNSS antennae used for the system are patch antennae. Two such antennae are mounted 180^0 opposite on the structure of the launch vehicle to ensure maximum visibility. The gain of the antennae would be maximum along its boresight and it decreases along elevation or azimuth as one moves away from the boresight. While the vehicle is in motion and during maneuvers it is possible that GNSS solution availability is interrupted for a short duration.
2. Correctness of solution: In scenarios where the number of satellites available for computation of solution is less and the geometry of satellites are poor, it can lead to high PDOP values and GNSS solution with errors greater than acceptable limits.
3. Deviations due to spoofing: Spoofing of GNSS signals can result in incorrect solutions being given by the GNSS receiver.
4. Signal jamming / interference : Intentional GNSS signal jamming or presence of an unintentional in band interference signal can result in saturation of the receiver RF front end circuitry leading to no GNSS solution from the receiver.

The above mentioned factors affecting the performance of the GNSS receiver can result in either the GNSS solution being not available or it being incorrect. The availability of GNSS solution is essential for the accurate functioning of the integrated navigation system.Different algorithms are incorporated to detect and avoid incorrect solutions and overcome the non availability of solution for short durations. The overall performance of the integrated navigation system heavily depends on when it occurs during the mission and its duration too. To study the impact of such events in the performance of the integrated navigation system at different instances during the mission, RF in loop HLS profile simulations become essential. Such tests are also essential for determining the performance of the integrated navigation system under nominal performance of the GNSS receiver for the evaluation of different aiding algorithms and estimating the accuracy that can be achieved during the mission.

4. RF in loop HLS profile test station

4.1 Requirements

The integrated navigation system has different sensors i.e, the accelerometers, the gyroscopes and the GNSS receiver. In an actual scenario of a launch vehicle flight, all the sensors will the sense the input corresponding to the actual motion of the vehicle. In case of RF in loop HLS test, the most fundamental as well as the most challenging requirement is that all the sensors get input corresponding to the simulated trajectory of the vehicle synchronously. The angular rates sensed by the gyroscopes are simulated by angular motion simulators (AMS). The integrated navigation system is mounted on AMS during RF in loop HLS profile simulation. While the system in on ground and static, the accelerometers in the system would sense earth's gravity and there is no possible means to simulate input to accelerometers according to the vehicle trajectory. Hence the sensor data corresponding to the trajectory is simulated to the navigation processor through RS 422 simulation interface. The input to the GNSS receiver is RF signals and signals corresponding to the trajectory is generated using commercially available GNSS RF signal simulator. The integrated navigation system communicates the navigation solution to the onboard computer which is the bus controller in the launch vehicle MIL 1553 bus. During the tests, a checkout system is used to simulate this role and acquire the data from the navigation system. To perform the RF in loop HLS profile simulation correctly, these different simulation systems namely the angular motion simulator, accelerometer data profile simulator, GNSS RF signal simulator and the checkout system should be synchronized.

4.2 Configuration and operation

Though it is essential to synchronize different simulation systems involved in RF in loop HLS test stations, it is a challenging task. GNSS RF signal simulator as well the checkout system simulating the role of onboard computer are both master with respect to their clocks and does not synchronize with any external systems. Hence in order to achieve synchronization while testing, a new hardware named Bus Controller and Synchronization card (BC & Sync card) is designed and developed. The overall configuration of the test station is as given in below figure.

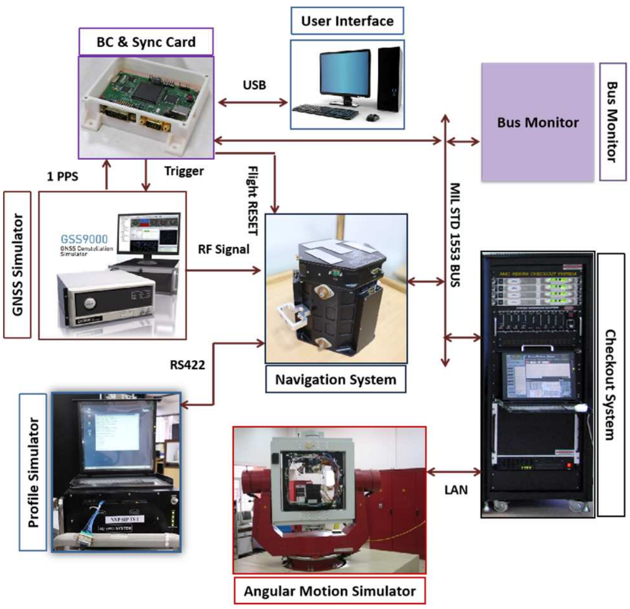

Figure 2. Overall configuration of the RF in loop HLS profile simulation test station. The image depicts different systems involved in the test along with the communication interfaces among them.

4.3 Subsystems

The subsystems involved in RF in loop HLS profile test station are as given below:

1. User Interface PC: A separate computer with graphical user interface for controlling the start and end of the simulation test.
2. BC & Sync Card: It is a custom built circuit centered on a processor and FPGA for achieving synchronization between different simulation systems.
3. GNSS RF signal simulator: The GNSS simulator used is commercially available RF signal simulator made by M/s Spirent (Model-GSS9000).
4. Profile simulator: Accelerometer profile simulation system is a custom built simulation system in RT linux platform for simulating the sensor electronics interface to the navigation processor.
5. Angular motion simulator: 3 axis angular motion simulator is used for simulating the orientation and angular rates of the launch vehicle as per trajectory.
6. Checkout system: The checkout system for the integrated navigation system is also a custom built system. It is used for powering the navigation system, acquiring data from the system and doing a variety of different operations on the navigation systems in different test conditions.
7. Bus Monitor: An in-house built generic MIL STD 1553 bus monitor is used to watch and log the transactions in the bus and ensure synchronized operation between different simulation systems.

4.4 Operation

In the launch vehicle, the onboard computer is the bus controller and master with respect to clock. In the test station, the checkout system simulates the function of the onboard computer. In the newly developed test station, instead of the checkout computer, BC and sync card acts as the bus controller in the MIL STD 1553 bus and generates the required synchronization signals (Flight reset) to be given to navigation system while synchronizing itself with the GNSS RF signal simulator.
Information corresponding to the trajectory to be simulated are to be loaded in GNSS RF signal simulator, checkout system and the accelerometer profile simulation system a-priori. The GNSS RF signal simulator is configured in triggered mode of operation. The navigation system is mounted on the angular motion simulator and the checkout system and accelerometer profile simulation system are started and made ready for response on reception of commands.
For ease of operation, a separate computer with graphical user interface is established. On start command from the user interface, the information is passed to the BC & Sync card through USB interface. The card has FPGA with bus controller core in it. On reception of the start command, a

trigger pulse is generated which is passed to the GNSS RF signal simulator. On reception of the trigger pulse, the GNSS simulator starts signal simulation from the next rising edge of its 1 PPS signal. The 1PPS signal is also given back to the BC & Sync card and on its reception the card generates and posts the bus controller commands to the MIL STD 1553 bus. The checkout system is a bus monitor in this bus and once it detects the bus controller commands, it aligns itself with the command periodicity and sends the angle data to be simulated to the angular motion simulator through LAN interface. And thus the bus controller, GNSS RF signal simulator and the angular motion simulator are synchronized. The accelerometer profile simulation system does not require separate mechanism for synchronization since the communication protocol between navigation processor and the sensor electronics involves a command response protocol and the commands for sensor data are sent by navigation processor at pre defined periodicity. Thus the accelerometer profile simulation system is also synchronized.

4.5 Test Results

The accuracy achieved by the system evaluated under nominal flight conditions are tabulated as given below:

Table 1. Orbital accuracy achieved at satellite separation by integrated navigation system during RF in loop HLS profile test

Parameter	Error
Apogee	56 m
Perigee	18 m
Inclination	-0.0004^0

Table 2. Orbital accuracy achieved at satellite separation by integrated navigation system during its first flight testing

Parameter	Error
Apogee	83m
Perigee	-16m
Inclination	-0.0006^0

5. Conclusions

The integrated navigation system with MEMS gyroscopes, navigation grade accelerometers, inbuilt GNSS receiver and attitude & state vector aiding is designed as a low cost navigation system with high reliability and accuracy. RF in loop HLS profile tests station is developed and commissioned for evaluation of the performance of such an integrated navigation system. Different flight scenarios including the nominal conditions are simulated and performance of the integrated navigation system is assessed and evaluated in detail. The test station provides a very effective mechanism for evaluating the performance of the integrated navigation system in different scenarios.

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