INS GPS integration scheme for canisterised Flight Vehicle

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ABSTRACT

Inertial Navigation System is widely used in the guided missiles for the purpose of midcourse guidance during the flight. Primarily, the grade of the inertial sensors dictates the ultimate navigation accuracy of any INS. The INS errors are not bounded and grow rapidly with time. In order to check the error growth of INS and provide an accurate navigation solution, typically a Satellite based Navigation System, say GPS, is integrated with INS by employing a data fusion filter. In order to implement this scheme, generally, the flight vehicle is equipped with an onboard GPS receiver for computing GPS navigation outputs and a GPS antenna for acquiring the GPS RF signals from the GPS constellation of satellites. In such a scheme, it is always desirable to obtain the GPS position fix much before launch of the vehicle or within few seconds after the vehicle lifts off. In case of canisterised missiles, acquiring fix is not possible because the GPS antenna is not open to sky till the flight vehicle ejects out of the launcher and canister. Generic GPS receivers require about 90 seconds, Time to First Fix, in the cold start mode. Given this scenario and the requirement of INS GPS integrated accurate navigation outputs, this paper brings out two possible implementation approaches conceived.

Keywords: Inertial Navigation System, Global Positioning System, Kalman Filter, Dynamically Tuned Gyro, Correlator

1. INTRODUCTION

1.1 Inertial Navigation System

Inertial Navigation is widely used for the guidance of aircraft, missiles, ships and land vehicles as well as a number of more novel applications, such as surveying underground pipelines etc. Originally, the INS technology used stable platform techniques, wherein the inertial sensors are mounted on a stable platform and are mechanically isolated from the rotational motion of the vehicle. Modern Inertial Navigation Systems adopt the strap-down technique, wherein the sensors are attached/strapped sown rigidly to the body of the flight vehicle. The advances in the computer technology combined with the development of suitable inertial sensors have allowed strap down systems to become a reality offering the potential benefits of lower cost, reduced size and greater reliability suitable for small guided missiles, for instance.

1.2 Need for Integrated Navigation Systems

In a practical implementation, the accuracy to which a strap-down INS operates is limited by errors typically, initial alignment errors, inertial sensor errors and computation errors. Hence the performance of an inertial navigation system is characterized by the time dependent drift in the accuracy of the position, velocity and attitude information it provides. The rate at which the navigation errors grow over long time periods of time is governed predominantly by the error sources described above. For many flight vehicles requiring a navigation capability, there are two basic but conflicting requirements to be considered by the designer, namely those of achieving high accuracy and low cost. While improved accuracy can be achieved through the use of more accurate sensors, there are limits to the performance, which can reasonably be achieved before the cost of the INS becomes prohibitively large. In such a situation, the idea of employing an additional source of navigation information, external from the inertial system, to improve the accuracy of INS, has received much attention in the recent years.

In an aided inertial system, one or more of the inertial navigation system output signals is compared with independent measurements of identical quantities derived from an external source. Corrections to the INS are then derived as functions of these measurement differences. By judicious combination of this information, it is possible to achieve more accurate navigation than would be achieved using the inertial navigation system in isolation. Integrated systems of this type usually make use of two independent sources of information with complimentary characteristics, one source providing data with good short-term accuracy and the second providing good long-term stability. In our case INS and

GPS are considered the two independent sources of information wherein INS provides low noise continuous navigation data with good short-term stability and GPS provides periodic data with good long-term stability.

1.3 Global Positioning System

GPS, formally known as, NAVSTAR, is satellite transmission based navigation system, designed to provide highly accurate, three-dimensional position and velocity data to users on or near to the Earth, providing a worldwide navigation capability. This system is available to an unlimited number of users, each equipped with an antenna and a receiver. GPS comprises a constellation of 24 satellites in near circular orbit around the Earth and a ground control system. The satellites are arranged in six orbital planes, which are inclined to each other, at an altitude of 20,200Km and orbit the Earth about every 12 hours. The spacing of the satellites is arranged so that generally at least four satellites will be in view to a user at any instant of time. Each satellite transmits two navigation signals centered at frequencies of 1.575 GHz and 1.227 GHz. Position is calculated by taking measurements of distance from the satellites. The distance measurements are made by measuring how long it takes for a radio signal to travel from each satellite to the GPS receiver. Two codes are transmitted by each satellite; a coarse/acquisition (C/A) code and a precision (P) code. As the name implies, the P code is more precise and is available to restricted users only.

Measurement errors arise from a variety of causes. The Earth’s ionosphere and troposphere cause delays in the GPS signals, which can give rise to errors in the measurement of position, although their effects can be compensated to some extent by modeling. Other sources of error are satellite and receiver clock imperfections and multi-path reception. However, GPS can enable a vehicle to establish its position anywhere in the world and at any time with an accuracy of a few tens of meters and its velocity to be better than 1m/s.

1.4 Statement of Objective

BrahMos flight vehicle is equipped with a DTG based, 4 minutes reaction time indigenous INS, for its midcourse guidance and control. The terminal guidance of the vehicle is achieved by means of an RF seeker employed within the missile. The handing over errors of the midcourse guidance scheme to terminal guidance scheme is determined by the performance of the Inertial Navigation System. Even though, extensive studies are carried out and well-defined real time thermal models are established for the sensor errors, the ultimate errors from the system are of the order of hundreds of meters over a period of 500 seconds. In order to check the time varying error growth and to achieve a very accurate solution, INS is integrated with GPS for obtaining the navigation accuracy of the order of tens of meters. The scheme has been mechanized using 17 states Kalman filter.

One of the major challenges in implementing this concept arises due to the containerization of the flight vehicle within a canister and a container. Typically, GPS receivers take approximately about 64 to 90 seconds to obtain the first fix provided the GPS antenna is open to the sky. In our case, the antenna is not open to the sky till it is ejected out of the canister, after the launch process is initiated. So, prior availability of 3D fix in the GPS receiver is not possible and it will take about 64 to 90 seconds during the flight to get 3D fix. This is not acceptable for the mission. In order to circumvent this problem, two approaches have been thought of. In the first approach GPS receivers with Faster Time To First Fix (TTFF), which typically takes about 20 to 40 seconds to obtain position Fix will be employed. The second approach employs a GPS receiver with ‘Hot Start’ feature to obtain the fix within 18 seconds, typically. The details are described in the following sections.

2. METHODOLOGY

2.1 INS-GPS Integration Scheme

From the previous section, it is clear that INS and GPS can be viewed as complementary systems. The measurements from these two systems can be integrated in an optimal way to dilute the disadvantages of either of two. This is implemented using a Kalman Filter in a feed back configuration. The Kalman Filter contains the state variables representing the INS parameters errors and the GPS receiver clock errors. The various INS error states are position, velocity, attitude, gyro bias and accelerometer biases. Thus there are 17 error states implemented in this Kalman Filter. The INS computed navigation outputs and GPS outputs corresponding to the same instant of time are input to the Kalman Filter. The filter estimates the corrections to be applied to the error parameters. The Kalman Filter is of the continuous-discrete type. The INS measurements are used to propagate the hybrid state vector continuously with very fast update cycles, say 50ms, whereas the GPS measurements are used to correct the hybrid state at discrete instants. The integration scheme remains the same for either method of employing a different configuration GPS receiver.

2.2 Generic GPS Receiver

The basic functional elements of a generic GPS receiver are the Down Converter, Correlator and Navigation processor. They are briefly described below.

The The RF front end is connected to an active antenna. The RF front end down converts the L band (1575.42Mhz) signal to an intermediate frequency (IF) and rejects the out-of-band noise and interference. It also provides sufficient chain gain to the signal prior to signal processing. The intermediate frequency (IF) signal is sampled at a suitable rate and the sampled signal is sent to the FPGA for base band correlation process.

The Signal Processor/Correlator has thousands of parallel signal processing units to acquire and track GPS signal independently. Each signal-processing unit generates local replica of C/A code and carrier signal and beats with the multi-bit incoming signals. The resultant correlation values are processed in code and carrier tracking discriminators and loop filters. These are called Delay-Lock-Loop (DLL) and Costas Loop for code and carrier tracking respectively. The output of the Signal Processor consists of correlation values, pseudo range measurements, Doppler measurements, navigation data bits, signal quality indicators etc.

The Navigation processor computes position, velocity and precise time. Navigation processor synchronizes the local clock with the GPS clock and generates a precise time and time interval (PTTI) signal. It performs the housekeeping of the navigation data bits, data word, subframe synchronization, information extraction, validation and storage. It also has an interface to the host computer. The primary function of the interface module is to transmit the PVT solution, satellite range, doppler etc. to the host computer and to receive aiding information from the host computer, if available.

As it was discussed in the section 1.4, the generic GPS receiver has to be augmented either with faster TTFF feature or with Hot Start feature in order to achieve an efficient integrated navigation solution. Both the approaches are described in the following subsections.

2.2.1. Approach #1 –Augmentation with Faster TTFF

GPS data acquisition involves search in two dimensions, chip and frequency. Typically in most of the GPS receivers this is achieved by a sequential search assuming a particular frequency and chip. This method however does not suit a high dynamics application considering that the signal is constantly shifting with the dynamics of the receiver relative to the satellite.

Fast acquisition is achieved by having massive number of correlators in the acquisition blocks to accomplish cell-by-cell search in the time-frequency domain. With this architecture, in a given instance of acquisition, multiple chips or/and multiple frequencies can be searched at once. This improves the speed of signal acquisition and also addition reduces the effect of receiver dynamics during the search process. In addition for a given duration of signal observation, signals with lower power levels can be detected.

The acquisition block consists of parallel correlator units each capable of acquiring and tracking signal independently. Each correlator unit has a carrier generator, code generator, and accumulators. A post correlation-processing block is implemented for peak detection. A correlator controller controls the acquisition channels for acquiring appropriate GPS satellites for a programmable duration.

Thus the specially designed receiver with augmented massive correlators compared with conventional GPS receivers are capable of acquiring first position fix, within a time period of typically 40 seconds at nominal signal strength.

Figure 1 shows the architecture of Fast acquisition GPS correlator.

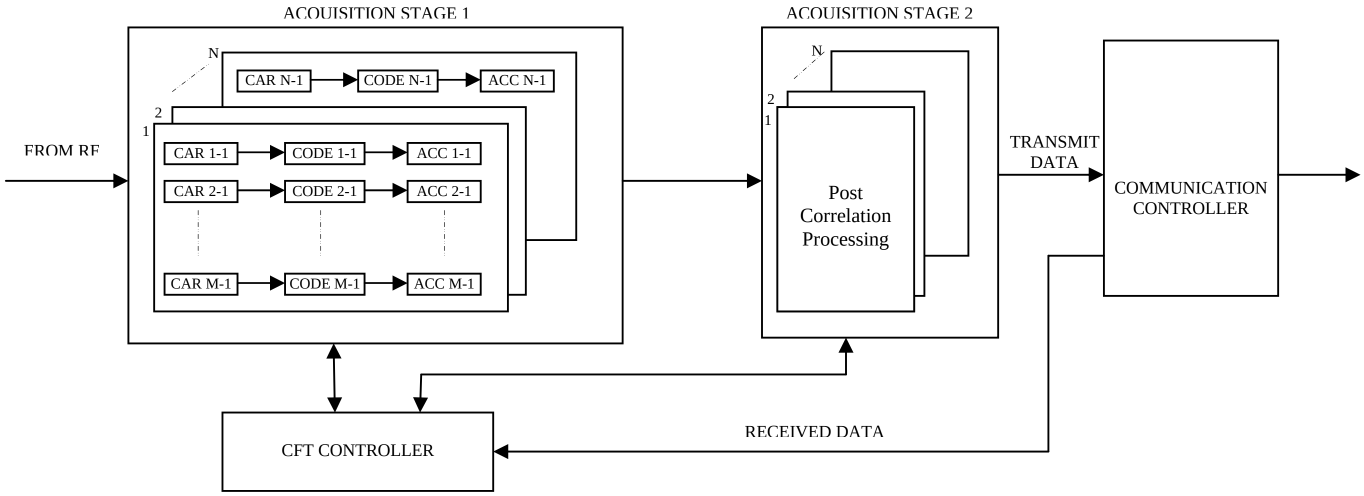

Figure 1. Architecture of Massive Correlators in Fast TTFF Receiver

2.2.2 Approach #2 – Augmentation with 'Hot Start' Feature

In a conventional GPS receiver, the Time To First Fix in cold start mode will be around 90 seconds. If the receiver has almanac, ephemeris, position and time information, the search time of 64 seconds in cold start mode will be reduced and TTFF will be reduced to 15-18 seconds. The receiver augmented with this hot start feature is capable of providing navigation outputs within 15-18 seconds. This is possible only by means of establishing a ground GPS receiver at the same location to obtain the necessary information from satellite transmissions and then uploading the Almanac, Ephemeris, Position and time to the GPS receiver fitted onboard the flight vehicle.

In BrahMos missile configuration, the onboard GPS receiver with 1553B bus interface has been integrated with the Inertial Navigation System into a single assembly. The Ground GPS receiver is interfaced with the Fire Control System on 1553B bus. In order to ensure the availability of position fix and all the ephemeris and almanac parameters in the ground GPS receiver, it is powered on at least 15 minutes prior to the launch of the flight vehicle. The information once available in the ground GPS receiver is uploaded to the onboard GPS receiver through the Fire Control System and Onboard Computer trough well established data exchange protocols.

Figure 2 depicts the scheme of uploading the required data to the onboard Hot Start Receiver from the ground GPS receiver

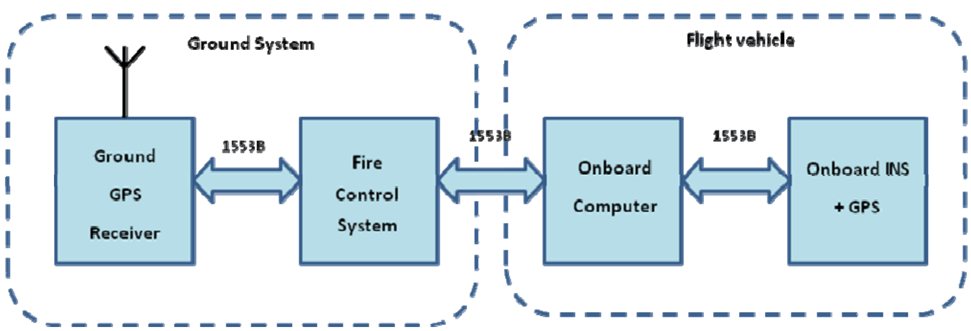

Figure 2 Scheme of uploading the Ephemeris, Almanac, Position and Time data to onboard Receiver

3. EXPERIMENTAL VALIDATION

The proposed schemes have been experimentally validated with a real INS+GPS device by carrying out real time simulations of a typical BrahMos flight trajectory. The hardware has been realized with a generic GPS receiver integrated with an INS. The complete navigation computations, data fusion and filtering techniques are all implemented to execute in real time in the navigation processor embedded within the INS. Figure 3 shows the real time flight trajectory simulation configuration using INS+GPS and GPS RF simulator.

The INS+GPS device is commanded to operate in Simulation Mode. In this mode of operation, the navigation computations do not make use of the digital data acquired from the inertial sensors. Instead, the computer utilizes the digital data sent by a real time trajectory data simulator at a desired rate over 1553B bus. The GPS RF simulator is preloaded with the trajectory information. In synchronization with the real time trajectory data simulator, the GPS RF simulator generates the RF signal corresponding to the spatial coordinate at that particular instant of time. In order to mimic the functionality of the receivers with hot start feature and massive correlator based receiver, the RF output of the RF simulator is connected to the generic GPS receiver in such a way that the GPS receiver acquires fix about 40 seconds after lift off of the flight vehicle. The navigation outputs are logged form the INS+GPS system at a predefined rate at a test station, for offline analysis of the performance of standalone INS, GPS and integrated system.

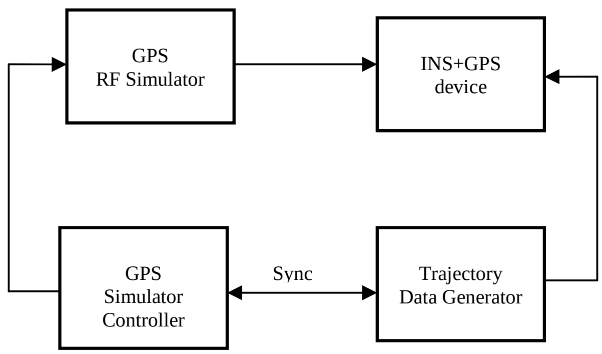

Figure 3. Real Time Flight trajectory Simulation Configuration

4. RESULTS AND CONCLUSIONS

Figure 4 (a) shows the Positions X, Y and Z as computed by the INS, GPS and INS+GPS Integrated (hybrid) modules with the inputs corresponding to a typical flight trajectory of BrahMos. Two sample test cases have been shown here. In the first case, the inertial sensors are assumed o be ideal without any errors. In the second case, 1°/Hr gyro drift has been introduced in all 3 axes and 1mg residue has been introduced in the vertical accelerometer.

Case 1: Ideal Inertial Sensors with no errors

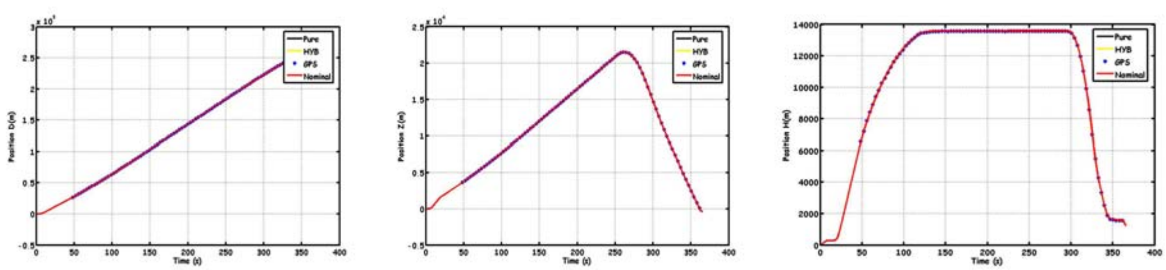

Figure 4 (a)

Case 2: Gyro drifts of 1°/Hr in all 3 axes and Vertical accelerometer residue of 1mg

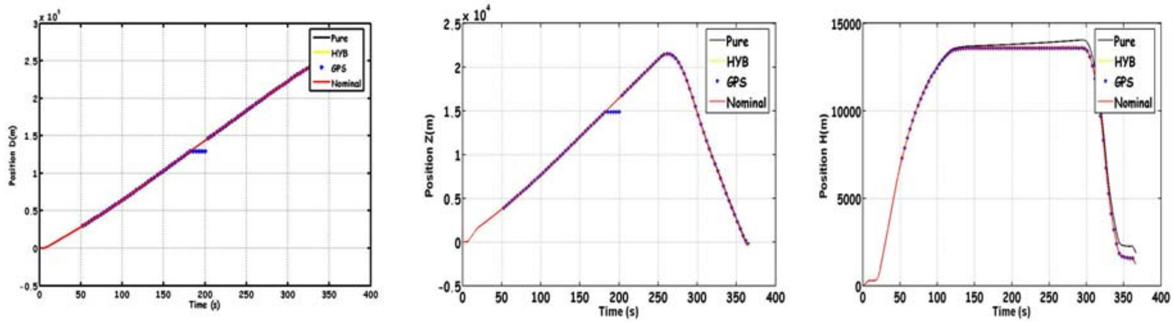

Figure 4 (b)

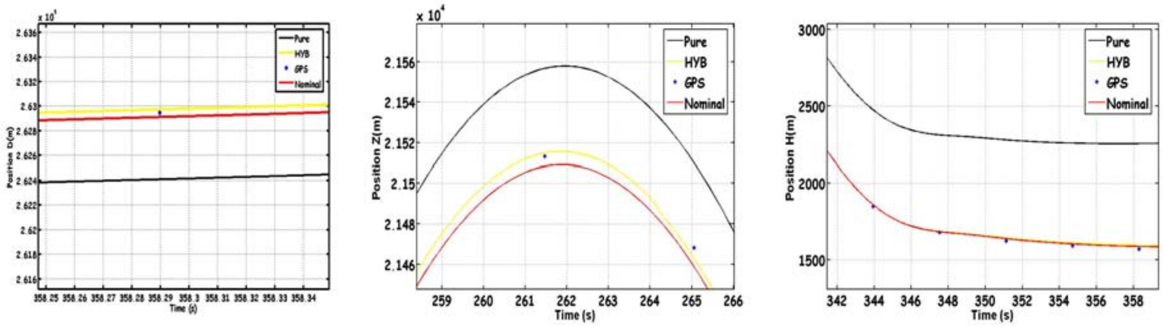

Figure 4 (c)

Figure 4. Position Coordinates (X,Y, Z) computed by Standalone INS, GPS and hybrid modules

From the test results of various simulation tests carried out in this configuration, it has been observed that the INS+GPS integrated scheme performed well, providing the desired accuracy of tens of meters in the position.

REFERENCES

1 D. H. Titterton and J. L. Weston, "Strapdown Inertial Navigation Technology"
2 Jay Farrell, Matthew Barth, "The Global Positioning System and Inertial Navigation"
3 INS-GPS Integration Scheme, Directorate of Inertial Systems, RCI