Evaluating the performance of an Integrated INS/GNSS System

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Abstract

An integrated INS/GNSS navigation system is described and tested through a land vehicle experiment. The selected route includes an underground section, where the performance of the system during a GNSS outage is evaluated. The results of different solutions are indicative of the system’s ability to apply several computational techniques.

1. Introduction

Over the last two decades GNSS (Global Navigation Satellite System) has dominated the area of positioning and navigation. By providing real time accurate information concerning position and velocity, that meets the demands of various applications, such as mobile mapping and aerial photogrammetry. GNSS has become a useful tool for scientists, researchers and engineers as well. However, despite its advantageous nature GNSS suffers from a variety of problems, like interference or multipath, that limit its accuracy.

On the other hand INS (Inertial Navigation System) is an autonomous navigation system able to provide continuous information regarding position, velocity and attitude. The achievable accuracy of the system depends greatly on the performance of its inertial sensors, which tend to deteriorate with time.

The integration of the two systems (GNSS-INS) leads to a system that keeps the advantages of both systems and rejects their limitation. Blending the GNSS and INS data and using analytical tools such as a Kalman filter for their analysis, calibration and evaluation increases the accuracy of the solution even in the presence of a GNSS outage.

This work presents the Integrated INS (Inertial Navigation System) / GNSS (Global Navigation Satellite System) that Dionysos Satellite Observatory acquired in May of 2008. Both the architecture of the System and the software, which comes with it, are demonstrated. Furthermore the performance of the system is tested in a land vehicle experiment, taking place in a rough environment regarding GPS and the results are discussed.
2. Presentation of the System

In order to develop its infrastructures, Dionysos Satellite Observatory (DSO) acquired in May 2008 an Integrated INS/GNSS System. The System is SPAN (Synchronized Position, Attitude, Navigation) of Novatel Inc. SPAN combines two different yet complimentary navigation technologies, GNSS and INS. It has a robust, tightly coupled architecture that allows the efficient blending of the raw measurements of GNSS and IMU (Inertial Measurement Unit) units and produces a reliable and accurate navigation solution even in case of a GNSS outage.

The System, which the DSO has acquired, is consisted of:
- Two GNSS receiver (master and rover)
- One IMU
- One odometer
- Radio link and other supplemental components

2.1 GNSS receivers

The System uses the receiver DL-V3, as a master station, and the receiver ProPak-V3, as a rover station in conjunction with IMU.

![Figure 1: Front face of DL-V3 (Novatel Inc.)](image1)
![Figure 2: Rear face of DL-V3 (Novatel Inc.)](image2)

The two receivers have common features, displayed in Table 1.

**Table 1: Features of GNSS receivers**

<table>
<thead>
<tr>
<th>feature</th>
<th>availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>bands</td>
<td>GPS: L1 C/A, L2C, L2 P(Y), (after L5) GLONASS: L1, L2</td>
</tr>
<tr>
<td>Measurement frequency</td>
<td>Up to 20Hz</td>
</tr>
<tr>
<td>accuracy</td>
<td>2 cm (RTK mode)</td>
</tr>
<tr>
<td>GNSS</td>
<td>GPS-GLONASS</td>
</tr>
<tr>
<td>DGPS</td>
<td>CDGPS, OmniSTAR (with subscription), WAAS, EGNOS</td>
</tr>
<tr>
<td>External chronometer</td>
<td>Yes</td>
</tr>
<tr>
<td>channels</td>
<td>72</td>
</tr>
</tbody>
</table>
Their main difference is that ProPak-V3 has embedded algorithms for the control and synchronization of the IMU and for the computation of a real time navigation solution. In addition ProPak-V3 has no internal memory and thus a laptop is required for its setup and data logging.

2.2 IMU unit

The IMU unit of DSO’s System is FSAS-EI-SN of German company iMAR. It is a tactical grade IMU, especially designed for civilian users. It is consist of three fiber optic gyros and three servo accelerometers in three orthogonal axes with a measurement rate up to 200Hz.

The technical specifications of the unit are given in Table 2.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyro rate bias</td>
<td>&lt;0.75deg/hr</td>
</tr>
<tr>
<td>Gyro rate scale factor</td>
<td>300 ppm</td>
</tr>
<tr>
<td>Angular random walk</td>
<td>0.16 deg/√hr</td>
</tr>
<tr>
<td>Gyro function limits</td>
<td>± 500 deg/sec</td>
</tr>
<tr>
<td>Accelerometer bias</td>
<td>1 mg</td>
</tr>
<tr>
<td>Accelerometer scale factor</td>
<td>400 ppm</td>
</tr>
<tr>
<td>Accelerometer function limits</td>
<td>±5 g</td>
</tr>
<tr>
<td>Dimensions</td>
<td>128×128×104 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>2.1 kg</td>
</tr>
<tr>
<td>Mean time between failure</td>
<td>35000 hr</td>
</tr>
<tr>
<td>Measurement frequency</td>
<td>Up to 200 Hz</td>
</tr>
<tr>
<td>Position accuracy</td>
<td>1.8 m rms (SPP)-0.45 m (DGPS)</td>
</tr>
<tr>
<td>Velocity accuracy</td>
<td>0.02 m/sec rms</td>
</tr>
<tr>
<td>Acceleration accuracy</td>
<td>0.03 m/sec² rms</td>
</tr>
<tr>
<td>Attitude accuracy</td>
<td>0.015° (roll-pitch)-0.041° (yaw)</td>
</tr>
</tbody>
</table>
2.3 The System’s setup and control software

CDU (Control and Display Unit) is the software that controls SPAN. Through this software users can setup, control, log data and view the real time navigation solution.

The software, through simple commands, enables the user to:

- View the behavior of the system in real time function
- Select and log both GNSS and INS data of different types
- Create numerous connections with SPAN, depending on mission’s requirements
- Set up and control the master station (DL-V3)

2.4 The post processing software

Besides the real time navigation solution of position, velocity and attitude provided by the rover receiver (on-board computation), the system has also the ability to concurrently log data for post processing, in order to produce far more accurate navigation solution.

Post-processing of the logged data is performed by Novatel’s Waypoint Inertial Explorer software package. Inertial Explorer is based on GrafNav, well known software for high precision processing of GNSS data. Also, it offers a functional interface for processing combined INS/GNSS data of various strap down systems.

Few features of the software are:

- Analysis of GNSS and INS raw measurements both in forward and reverse mode and combination of the solutions
- Implementation of an efficient smoother algorithm (RTS: Rauch-Tung-Striebel) for optimal minimization of trajectory’s inconsistencies
- Solutions based either on loosely coupled or tightly coupled methodology
- Algorithm based on Kalman filtering technique
- Readymade error models for use as initial state vectors of Kalman filtering
- Construction of various graphs suitable for helping the determination of the
accuracy of the final solution, for analyzing the data and for estimating the sensor’s biases
- Different export formats, which facilitate users and enhance the productivity
- Use of precise ephemeris
- Implementation of Precise Point Positioning technique

Overall Inertial Explorer is a powerful tool that provides a straightforward routine for the efficient post-processing of GNSS/INS data.

3. Test setup

In order to check the system’s performance, a land vehicle experiment was designed and executed. The system was mounted on a vehicle, which was driven through a carefully selected route inside the camp of NTUA (National Technical University of Athens). The total route length is 2.2km, as shown in Figure 6.

![Figure 6: The selected route in Google earth environment.](image)

3.1 Test description

The scope of the test was the evaluation of the operational function of the system when it is on the move in a “difficult” environment for GNSS and not the estimation of an accurate navigation solution. For the abovementioned reason the selected route includes a section, where the road passes under the buildings thus facing a full GNSS outage.

The IMU was placed in the back seat of the car and not in a stable base and the vector between antenna phase center and the center of the IMU unit was measured with metro meter. The master station was placed in a pillar, situated in the roof of Lampadarios building.
The test took place at Friday 20 June 2008 from 10:57 pm until 11:08 pm, while the GNSS outage lasted approximately 50 sec (from 11:01:50 pm until 11:02:40 pm). The total length of the route under the buildings (GNSS outage) is 220 m. The data rate of the IMU unit was 200 Hz, while the receivers were recording measurements every 1 sec. The elevation mask was set to 15°.

### 3.2 Test results

The results of the test are divided into three main categories:
- The real time navigation solution (on-board computation)
- The loosely coupled post processed solution
- The tightly coupled post processed solution

The following figures demonstrate the trajectories of the corresponding solutions.
Figure 11: The post processed navigation solution trajectories

The following graphs presents the accuracy of the post processed navigation solution.

Figure 12: The accuracy of loosely coupled solution
Figure 13: The accuracy of tightly coupled solution

4. Discussion of the results - Conclusions

The following remarks are extracted from the analysis of the previous graphs and Figure 8:

- The two post processed solutions have differences. Especially during the GNSS outage the tightly coupled solution differs from loosely coupled solution up to 50 meters.
- The loosely coupled solution tends to follow the GNSS-only solution, as expected.
- The tightly coupled solution presents the worst standard deviation of navigation solution, but matches more accurately the real route in the section, where the GNSS outage occurs.

The overall conclusion is that the test results confirm the basic principles of GNSS/INS navigation. The test managed to present the ability of the system to produce navigation solution even in a difficult environment, with GNSS outage and lots of electromagnetic interferences. The tightly coupled solution is preferable in cases of GNSS outages.
References


