High Precision Navigation Control with Integrated INS/GPS System

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Abstract
The paper describes the combination of a ring laser gyro inertial navigation system (INS) and Trimble SSE GPS receivers. A software package for the strapdown system was developed using common terrestrial zero velocity (ZUPT) and coordinate update (CUPT) techniques. An Integrated GPS inertial position and attitude control system (IGIPACS) is built up in different levels. The first level is a separate operation of the GPS receivers and the INS. Here the INS-system is supported by GPS positions with an update rate of at the most 2 Hz. The GPS positions are evaluated by various types of applications (rapid-static, kinematic) with cm-accuracy. The INS is used to interpolate the positions between the update points with a rate of 50 Hz. In the second level the GPS positioning is supported by the INS system during losses of lock using the Kalman filter technique (cascade integration). Within this algorithm differential GPS is applied using double difference code solutions. Numerous tests were made using a station wagon, sometimes with an array of three or four antennas, as well as an aircraft supporting the determination of a digital terrain model with laser scanner and radar altimeter. Problems and differences in terrestrial and airborne applications are outlined. The accuracy of the system, its potential and further steps are discussed.

Key words:
Inertial Navigation System,Global Positioning Syste,Kalman Flter, Strapdown System

I. Introduction

The combination of INS with its high dynamic precision and with its high accuracy is topic of many investigations,[1]. The Integrated GPS Inertial Position and Attitude Control System will be built up in modules and should finally contain four parts: The basic hardware components are ring laser gyro GPS receiver; other sensor elements may be GPS antenna arrays, radar altimeter and laser profiler; the software mainly contains the INS navigation equations, the Kalman filter algorithm and the GPS software for rapid static and for kinematic applications and additional gravity field or sensor error models may be included. Finally a telemetry unit with radio sets (modems) is necessary for transferring GPS data from the reference to the mobile station.

In March 1993 a three days flight test campaign for determining a Digital Terrain Model (DTM) was carried out in an area near Munich, Germany. The aircraft used was a Dornier DO.228 of the "Deutsche Gesellschaft fur Luftund Raumfahrttechnic" (DLR). Because of the high dynamic motion,GPS alone was not sufficient for representing the flight of trajectory. The equipment on board consisted INS, a GPS receiver Timble 4000SSE, a radar altimeter and a laser scanner. The last two sensors were constructed by the Institute of Navigation of the University of Stuttgart.The [5]. The overflow region was somewhat hilly including some water reservoirs useful for calibrating the system. There also exists a DTM derived from terrestrial data which could be used as a reference; moreover a GPS campaign was carried out by the Bavarian Survey Agency determining a set of local transformation parameters between WGS 84 and the national geodetic system. Figure 1 shows the beginning part (about 12 minutes) of the flight trajectory.

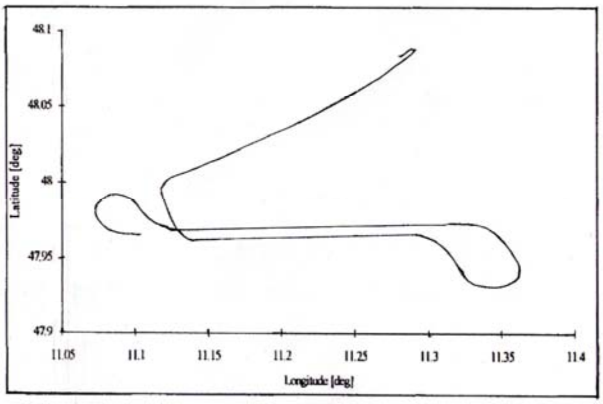

Fig. 1 – Flight trajectory (section)

II. INS/GPS Integration

Within an integrated INS/GPS-system there generally are different requirements from one system to the other one. From INS side of view GPS should be used for updating additional or complementary to other update techniques.

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From GPS side of view INS should be used during signal interrupts either to hold the position or to be reinitialize the ambiguities after re-receipt of the signal. The main tool within INS/GPS integration is a Kalman filter. The basic equations and matrices used in our software are described in detail in [3].
The INS/GPS integration is carried out in different steps, with regard to either accuracy or level of integration. One possibility is using previously computed GPS positions as updates analogues to the common terrestrial CUPT-technique. Another possibility is the combination of INS and GPS computation in one single program.

III. Update with Precise GPS Positions

The most precise way to compute GPS positions is the use of phase double differences. Receiving five or more satellites centimeter accuracy is achievable with in few minutes. Here for the purpose of initialization the program STARTS for rapid static application is used as well as the external computed coordinates are used as CUPT's in a closed loop Kalman filter with an update rate of 2 Hz after the alignment phase of the INS. The attainable accuracy of the integrates system is mainly influenced by the accuracy of the GPS computation alone. After signal interrupt or a satellite number below four no further computation is possible without any possibility to solve the ambiguities during motion ("one the fly" algorithm).
All differences shown here are differences against the pure GPS phase solution which is used as a reference.
Figure 2 shows the differences of the INS position minus the pure GPS phase solution with an update rate of 10 to improve the accuracy of management seconds. The accuracy of the GPS positions is assumed to +/- 3 cm within the Kalman filter. The left part is the end of a curve flight while the right side shows the behaviour of the following straightforward trajectory.

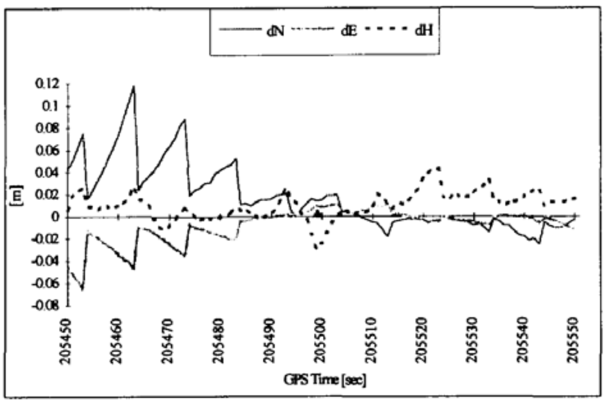

Fig. 2 – INS – position update with precise GPS positions, update rate every 10 seconds.

IV. Cascade in Tegration

Two strategies of GPS updating are included in the program: the GPS code double differences are used to remove the receiver clock errors. The observation models within the Kalman filter algorithm is in this case (compare to [1]):

$$\delta(\nabla\Delta s_j) = \left[\underline{0}, \underline{0}, \left(\frac{-(\underline{r}_j^e - \underline{r}^e)}{s_j} + \frac{(\underline{r}_f^e - \underline{r}^e)}{s_f} \right) \cdot \underline{C}_n^e, \underline{0}, \underline{0} \right] \cdot \underline{x}$$

with

$\delta(\nabla\Delta_{sj})$: code double difference for channel j
$\underline{x}$: state vector (15 states)
$\varepsilon E, \varepsilon N, \varepsilon U$: misalignment of the navigation Frame
$\delta VE, \delta VN, \delta VU$: errorstates in velocities
$\delta\lambda, \delta\ , \delta h,$: error states in longitude, latitude and height
dx, dy, dz : residual gyro drifts in the body frame
bx, by, bz : residual accelerometer biases in the body frame
sj : distance between INS and satellite (except reference satellite)
sf : distance between INS and reference satellite
$\underline{r}^e$: geocentric position vector of INS
$\underline{r}_j^e$: geocentric position vector of satellite (except reference satellite)
$\underline{r}_f^e$: geocentric position vector of reference satellite
$\underline{C}_n^e$: transformation matrix between local horizontal and geocentric system

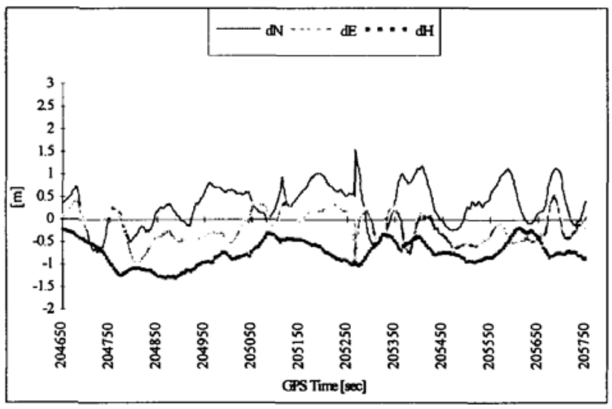

Fig. 3 – INS position update with positions derived from C/A code double differences within the cascade integration

GPS position are derived from code double differences by epochwise least square adjustment of the code double differences without any smoothing algorithm. Figures 3 using C/A code with five satellites. The GPS positions are weighted with +/- m in longitude and latitude and +/- 1.5 m in height. The code double differences are weighted with +/- 2m.

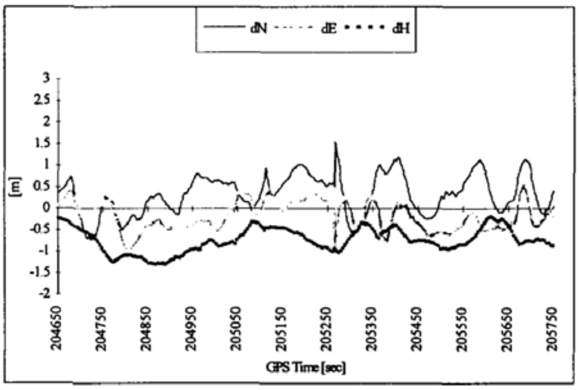

Fig.4 – INS-position updates with code double difference observations within the cascade integration

The advantage of the second method is that updating with GPS is still possible if the number of satellites fell below four. The accuracy is nearly the same using both methods. If no GPS signal is available (e.g. signal interrupt) INS has to take part of positioning alone. Figure 5 shows the position computed with the INS/GPS Kalman filter after GPS updating stopped. This total loss lock is simulated with more than one minute duration during a straightforward flight.

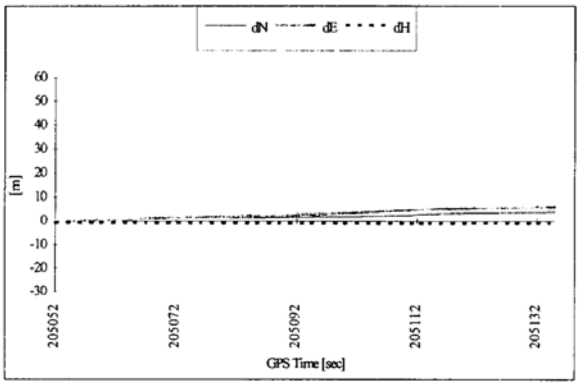

Fig.5 – INS position update with code double differences during a simulated signal interrupt of more than one minute

Figure 6 shows that behaviour of INS in standalone mode for the same period of time. Herein the starts position is shifted to the correct position for the pupose of better comparison.

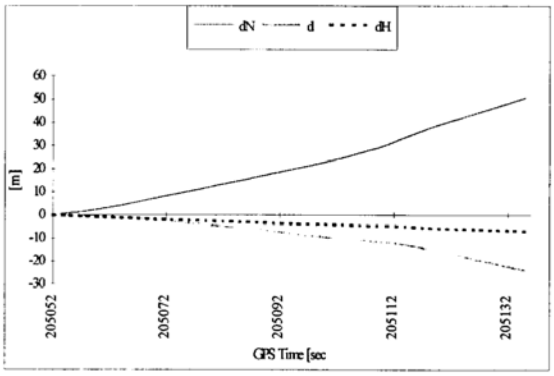

Fig.6 – INS – position in standalone mode during the simulated signal interrupts of more than one minute

With the information of GPS processed in the previous interval of the Kalman filter algorithm the INS is much better able to hold the position as in standalone mode.

V. Attitude Determination

The orientation during the flight was made only by the INS alone although it can be done also by an GPS antenna array of at minimum three antennas. Because it was impossible to install more than one antenna on the top of the aircraft during the test campaign a rectangle construction of four GPS receivers – one giving the position, three for the orientation – was installed on the roof car while the ring laser gyro. The distances between the antennas inside the rectangular array were 0.9m and 1.4 m, respectively. With the kinematic software PSEUDOKI the, position as well as the Euler angels pitch, roll and heading between a local level and an antenna fixed coordinate system were computed. Table 1 shows the standard deviations of the Euler angles of both systems during a static period of about the minutes.

	INS Standard Deviation [^{0}]	GPS Standard Deviation [^{0}]
Pitch	0.01853	0.10193
Roll	0.00912	0.17177
Azimuth	0.00572	0.04216

The GPS standard deviations agree with accuracies proposed with those values of about 0.2 degree for commercial systems [6]. The achievable accuracies of the INS system are by a factor of 10 better than those of GPS. Nevertheless GPS orientation information may be used in an integrated system. It can be used to diminish the alignment phase because after the first measurement there is a value for the heading available while the INS usually is slowly arriving its real value. Over a long period of time not only the INS position is drifting but also the gyro errors can be put back.

VI. Conclusion

The integrated system with the Ring Laser gyro and with GPS used in differential mode is working. The system can be used in land vehicle as well as aircraft application. The inclusion of the GPS phase double difference ambiguities into the Kalman filter state vector is under progress. An automatic cycle slip detection and correction algorithm as part of an integrity monitoring may also be included in the future. Especially in high dynamic motion like aircraft application the time synchronization causes a main error source. Up to now the synchronization between GPS and INS is made with a one second pulse which the GPS receiver provided and which is stored at the corresponding place within the recorded INS data stream. With a mean velocity of 75-80 m/s during the survey flight the unknown position of the GPS signal within a 0.02 second interval of the INS ARINC interface card for recording the INS data and the pps signal of the GPS receiver to PC will overcome this problem in the near future.

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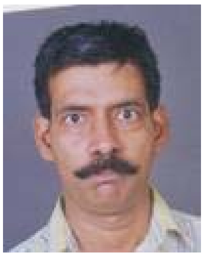

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Dr. Lal Kishore the Rector of the now autonomous Jawaharlal Nehru Technological University is an expert in the academic front. He has good administrative skills having handled various positions in the university itself. Dr.Kishore has membership in many honourable professional societies. The awards and honours received by him indicate that he is an able administrator and an academician too. He has the credit of writing many textbooks on complex subjects like Electronic Devices and Circuits, Linear I.C. Applications and Electronic Measurements. Along with this he is the recipient of many awards and honours both nationally and internationally. A few of his awards are from the Defence Engineering College, Ethiopia for distinguished service, another award from International Compendium for distinction in Academics.