Evaluating EGNOS augmentation on a military helicopter

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Biography

Major Alain Muls graduated as M.Sc. in Telecommunications and Construction from the Royal Military Academy in 1984 and obtained a Master in Computer Sciences degree in 1988 and a Ph.D. in applied sciences in 1994 at the Katholieke Universiteit Leuven. He is currently assistant Professor at the Astronomy, Geodesy and Topography Department of the Royal Military Academy. In this function he is lecturing courses on Geodesy and GPS. His main field of interest is the use of GPS for navigational purposes.

Frank Boon, M.Sc. in Aerospace Engineering, is responsible for the development of the GNSS navigation algorithms and the data analysis at Septentrio Satellite Navigation. Previously he was a Ph.D. student at Delft University of Technology, under a contract of the Dutch National Aerospace Technology, on the topic of OTF ambiguity resolution. He worked for 1.5 years at the Survey Department of the Dutch Ministry of Transport, where he evaluated GPS/INS systems applied to airborne laser surveying.

Abstract

The European Geostationary Navigation Overlay System, or EGNOS, is a satellite based augmentation system for GPS and Glonass which shall ensure the accuracy and integrity for multi-modal transport applications. The EGNOS signal is provided through an infrastructure based on space and ground segments, which are currently operational in test mode. EGNOS is the basis on which many future satellite navigation services will be developed.

The goal of EGNOS is to augment GPS and Glonass in order to provide: accuracy better than stand-alone, increased availability, guaranteed integrity and continuity of service in order to meet navigation requirements for multi-modal applications. The EGNOS Implementation Phase started in November 1998 and the EGNOS prototype (ESTB) is available since February 2000. The operational area of EGNOS is the European continent and its prime mission is to service the civil aviation community.

To evaluate the current performance of EGNOS enhanced navigation with respect to traditional GPS aiding methods such as DGPS a test flight was performed. This test flight reflected the daily operations carried out with a military helicopter. In addition to this liaison flight path a tactical flight was performed over the southern part of Belgium. Special manoeuvres were also introduced stressing the system and decreasing satellite visibility due to masking effects.

A Septentrio PolaRx-1 GPS/EGNOS/WAAS receiver operating on board allows data processing in 3 different navigation modes: GPS stand alone, differential GPS and SBAS augmented GPS. An OTF reference trajectory using a nearby static reference receiver provides assessment the quality of each navigation solution.

Contrary to the expectations from high dynamics and poor satellite visibility, the results show a high availability (98.3% tracking) of the EGNOS signal. The SBAS augmented GPS solution demonstrates better accuracies than the GPS stand alone solution, similar to the DGPS track.

Motivation

The main helicopter type used by the Belgian Army is the Italian made Agusta A109 which exists in two versions: an antitank version equipped with missile launchers and a reconnaissance and liaison version with various detection sensors. From a navigational point of view the A109 is equipped with a (Rockwell-Collins) Miniature Airborne GPS Receiver (MAGR). This is a five-channel dual frequency military receiver that selects the four best satellites to form the navigation solution while the fifth channel is constantly searching for another GPS satellite to bring into the navigation solution and lower the dilution of precision factors.

In 2007 the A109 avionics will be replaced during a midlife update program. The responsible technical officers proposed a differential GPS (DGPS) solution as the navigation system to be implemented. At the same time, there is a contract open for the acquisition of a new transportation helicopter. From a logistic and maintenance point of view it would be favourable to standardize future equipment.

Belonging to the military community, it may look awkward to be interested in and testing out a civil operated navigation system on a military helicopter. However this interest can be explained by the shift in the type of military operations that has been going on during the last decade. Using a military helicopter also gave the opportunity to stress the receiver hardware and algorithms and to evaluate the performance of an EGNOS capable receiver under severe dynamic conditions.

The main operational focus of the Belgian forces are peacekeeping missions, currently mainly in the former Yugoslavian republic. Peace-keeping operations are an United Nations Organization term which comes down to having a military presence without using force to keep the peace: it is a deterrent operation. It also means that the operational zone is large and not defined beforehand. This leads to the following tactical observation[1]: the implementation of a DGPS solution means that one or several reference stations and communication links on ground have to be operated in or near to the operational zone. These installations must be protected and maintained meaning additional people and assets have to be deployed into a possible hostile zone. Moreover a DGPS communication interface has to be installed on board the helicopter, adding weight and drawing additional power from the onboard electrical supply. Since the peace keeping operations are, by definition, without engaging into battle, the use of EGNOS for providing not only differential corrections but also integrity information of the navigation solution to the pilots becomes rational.

Septentrio Satellite Navigation of Leuven Belgium develops OEM GPS receivers targeted at high-end accuracy and integrity applications. The helicopter test flight offers an interesting opportunity to test Septentrio technology and evaluate EGNOS enhanced navigation under demanding circumstances.

Test description

The flight plan, whose trajectory is shown in figure 1, consists of a 3 parts:

- A typical liaison flight is simulated by flying in all main compass directions. This part of the flight can be seen at the right-hand side of figure1;
- A typical tactical flight was flown at high speed following some river valleys in the southern part of Belgium. The operational procedure is that the pilot steers the helicopter at a height above the valley that equals 2/3rd of the height difference between the valley and the mountaintop. This assures a protection against enemy fire by the hilltops while minimizing the risks. It was believed that this would render difficult the reception of the satellites, especially the geostationary one. This part of the flight is shown on the left-hand side of figure 1;
- Special manoeuvres stress the receiver hardware, create gravitational forces on the receiver clock crystal and affect the tracking loops.

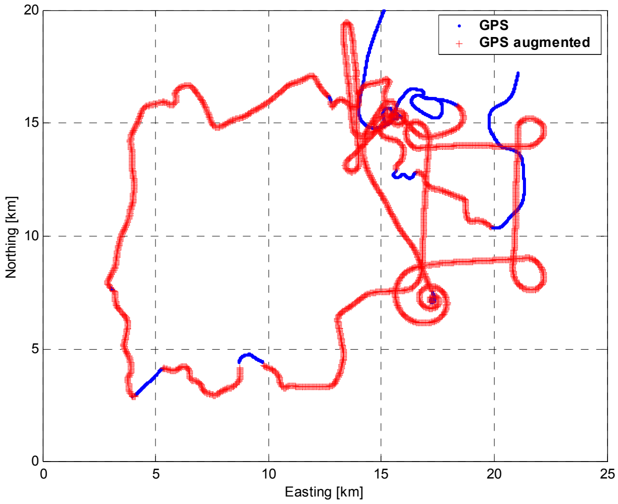

Figure 1: ground track of the test flight

The following special manoeuvres are introduced:

- several consecutive 360 degrees turns with an increasing banking angle of 10, 20, 40 up to 60 degrees resulting in a maximum increase of the gravitational acceleration to about 20 m/s^2;
- parabolic trajectories which result in periodically positive and negative accelerations in the vertical plane;
- a crab flight creates an angle between the velocity vector and the direction in which the nose is pointing. Although the helicopter pilot has the ability to compensate for these gravitational forces, we choose not to do so.

During the test flight a receiver records the data on an internal memory device. This allows us to operate the receiver in 3 different modes:

- stand-alone GPS based on the C/A code;
- differential GPS using a local reference station;
- EGNOS augmented GPS positioning.

In order to be able to compare the various navigation modes, a reference trajectory is determined by a phase based kinematic solution. Two static reference stations are installed providing the data for the differential code solution and the phase based kinematic solution. A statistical analysis assesses the accuracy and precision of the navigation solution under each specific part of the flight.

The PolaRx-1 receiver was configured as follows:

- dual-frequency mode to allow the calculation of the phase based reference trajectory;
- 10 Hz measurement rate to capture the dynamics of the flight;
- both EGNOS and WAAS tracking;

[1] The first author wants to express that this is a personal opinion and that it does not reflect the official standpoint of the Belgian government.

The PolaRx-1 demonstration receiver has the capability to track 6 satellites in dual frequency mode and 2 satellites in single frequency mode or 20 satellites in single frequency mode at a 10 Hz measurement rate. The single frequency channels can be assigned for tracking the SBAS satellites of the EGNOS or WAAS augmentation system. Figure 2 shows the PolaRx-1 installed in the Agusta 109 just behind the cockpit.

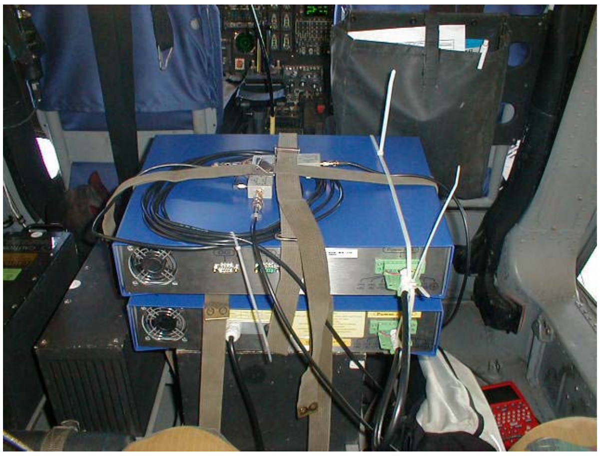

Figure 2: *set-up of the PolaRx-1 and Leica receiver*

The on board 24 VDC was converted to 220 VAC which was fed to the receiver. The MAGR antenna was replaced by an active antenna (Sensor Systems S67-1575-96) and the MAGR preamplifier was bypassed by an antenna cable that entered the cabin. A power splitter directed the signals to the PolaRx-1 receiver and a backup Leica SR530 receiver used for calculating the reference trajectory. The antenna is mounted on top of the tail of the helicopter (Figure 3) and is located above the rotor blades during a horizontal attitude of the helicopter.

Figure 3: the A109 helicopter and the tail antenna

Flight statistics

The test flight was held on August 17th 2001 between 11:07 and 12:29 GPS time resulting in somewhat more than 81 minutes of 10 Hz data (48643 observation epochs). From all observations epochs, 46789 (1854) PVT solutions are calculated using 5 (4) GPS satellites. A cut-off angle of 12 degrees is selected as dual frequency below this elevation becomes cumbersome.

During the flight PRN 120 (the EGNOS navigation payload on the InmarSat AOR-E) was tracked during 98.3% of the time. PRN 122 (the WAAS[2] navigation payload on the InmarSat AOR–W) was only available during the liaison flight paths, since its elevation angle is about 10 degrees as seen from Belgium. The tracking status can be deduced from the carrier to noise ratio as shown in Figure 4.

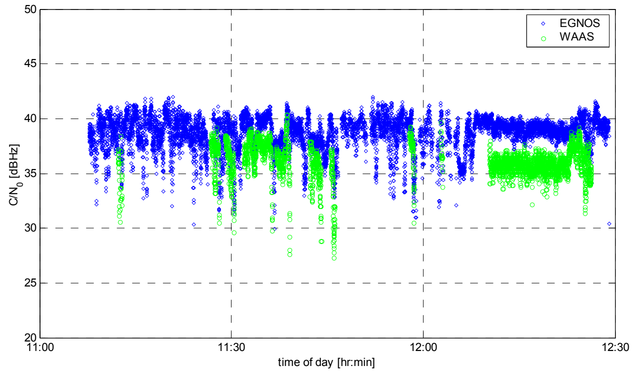

Figure 4: tracking of EGNOS and WAAS

An indication of the reliable tracking of the EGNOS satellite can also be deduced from the time delay of reception of the different SBAS messages as summarized in Table 1.

Message ID	Normal delay [s]	Maximum delay [s]	Message count
0	5	55	907
1	90	360	47
2, 3, 4	5	55	906
7	90	270	48
9, 10	90	180	51
12	225	450	19
18	15	225	60
25	5	25	408
26	15	90	223

Table 1: *SBAS message delay*

The observed normal message delay is well within the minimum operational performance standards as specified by the RTCA Inc. while a quick recovery of these messages is realized.

[2] Allthough the WAAS satellite could be tracked its performance will not be assessed in this paper.

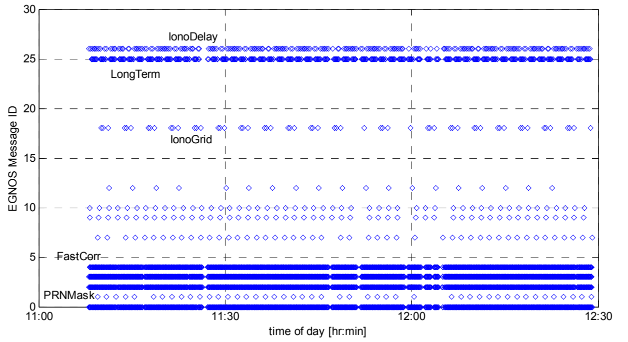

Figure 5: reception history of the SBAS messages

Figure 5 gives an overview of the reception history of the various messages. When laid out against the flight track (Figure 1) these two figures show that the loss of continuous message reception coincides with some of the special manoeuvres introduced.

The fast corrections, long-term corrections and ionospheric corrections are designed to provide the most recent information to the user. In order to guarantee integrity the user must apply models of degradation of these messages according to the phase of flight he is in. During the whole test, the more stringent degradation model for a precision approach has been applied. Figure 1 illustrates the parts of the flight that are calculated taking into account the EGNOS messages.

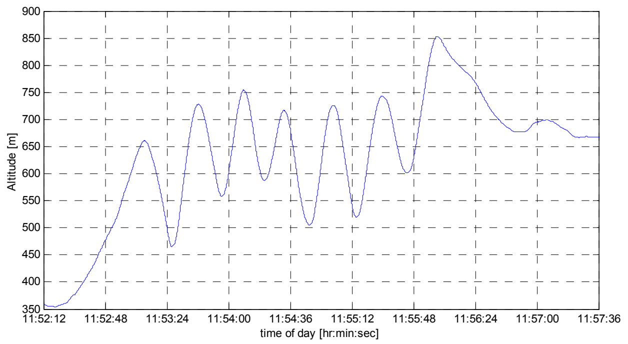

Figure 6: height variations during the parabolic manoeuvring

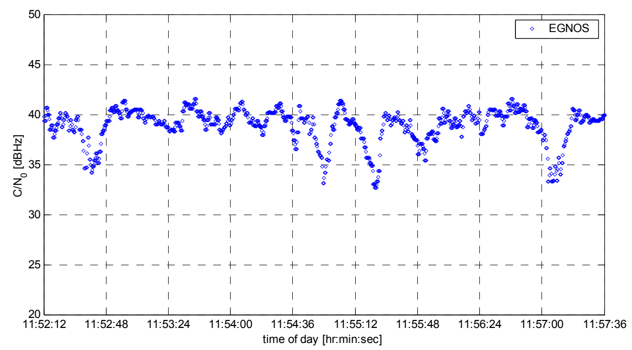

Figure 7: carrier to noise ration of the EGNOS satellite

Figure 6 depicts the height variations during the parabolic manoeuvres and illustrates the variations of the gravitational acceleration applied to the PolaRx-1 receiver. The carrier to noise ratio of the EGNOS satellite during this phase of the flight is represented by Figure 7. Both figures suggest a strong correlation between the variation of the gravitational forces and the tracking quality of the receiver. However, during this part of the flight the EGNOS signal was not lost which indicates that the loss-of-lock during the other dynamic parts is caused by masking of the signal due to high banking angles.

Preliminary results of a statistical analysis[3] of the flight is summarized in Table 2 for the height component. During the liaison flight parts, the SBAS augmented GPS solution is nearest to the reference trajectory outperforming the GPS standalone and differential solution. The latter result was not expected.

	Navigation accuracy
GPS	4 to 5 m
DGPS	2 to 3 m
EGNOS + GPS	0.8 to 1.2 m

Table 2: *statistical analysis of the flight*

After power-up of the receiver, it typically takes about 2 minutes before both sufficient long-term and fast corrections have been collected from EGNOS. This period is limited by the transmission of the PRN mask (Message ID 1) which for which satellite the receiver can expect to receive corrections. The reception of a full ionospheric grid and its delays over the grid points (Message ID 18 and 26 respectively) typically takes 5 minutes.

Conclusion

The described helicopter tests shows a promising performance of EGNOS under taxing conditions. Contrary to our expectations EGNOS was tracking throughout a significant part of the flight (98.3%). Furthermore, the accuracy of the EGNOS enhanced navigation solution compares favourably with the traditional DGPS approach, without the infrastructure overhead for the user.

Acknowledgements

We would like to express our gratitude to some people who sacrificed their time and who helped out with their expertise whenever we were facing problems. First we would like to thank both pilots, Captain ir Y. Kohnen and 1st Lieutenant ir K. Teunkens for setting up a realistic flight plan and for a safe flight. They are the technical responsible officers at their unit. All technical matters were resolved by 1st Sergeant Major M. Van Houtte of the maintenance company. Joel van Craenenbroeck from Van Hopplynus Instruments, partner of Leica Geosystems for Belgium, provided logistic support in the form of Leica SR530 receivers. He also made available the CRNet program, product of Leica Geosystems, used for the

[3] A full statistical analysis of the data is the subject of a thesis for obtaining the M.Sc. degree at the Royal Military Academy.

reference trajectory calculation. Finally, we would like to thank Lieutenant C. Garrigues for performing a more extensive statistical analysis of the flight tracks.

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