# HYBRID NAVIGATION TECHNIQUES IN AVIATION WITH USING THE GNSS

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This article shows how research for GNSS applications in civil aviation can be useful and more precious in aircraft navigation. It solves and describes metods such as hybrid navigation using GBAS, INS and GNSS. It describes how to improve integrity, acuracy and availability in navigation by using multiple GNSS and other systems.
K e y w o r d s: GPS, GNSS, GBAS, navigation, performance, equipment, accuracy, integrity

## 1 INTRODUCTION

The emergence of global navigation satellite systems, combined with the evolution of GPS, introduces new possibilities for the use of GNSS in aviation. A major gain in integrity, accuracy, and availability can be expected by using multiple GNSSes and augmented services. The path from algorithm development to the derivation of standards for use in aviation is both enduring and widely distributed among various institutional stakeholders. International and national space and aviation agencies, such as the European Space Agency (ESA) contribute to the development of new techniques.

Key elements in the current evolution of the navigation technologies employed in the project include the ground based augmentation system (GBAS), hybrid navigation using micro-electromechanical system (MEMS) inertial navigation sensors, use of Europe's Galileo system in aviation and associated safety-of-life requirements, and antenna beamforming techniques for GNSS navigation.

## 2 GBAS/INS Hybrid navigation

GBAS is designed to support precision approach operations at airports within a coverage area defined by a nominal range of 23 nautical miles. It provides desired flight path information for approaches, landings, and other maneuvers within the terminal area, as well as determining ranging source errors using multiple ground reference receivers. Information on those errors is broadcasted via VHF data broadcast (VDB) to the users in the coverage area. The GBAS ground station also monitors the integrity of the GNSS signals-in-space. High precision landing operations, such as Category II and III approaches, have very stringent integrity and continuity requirements. Without the availability of Galileo or the new GPS L5 frequency, single-frequency GNSS user equipment requires additional augmentation for GBAS equivalent approaches up to CAT IIIb (GBAS Approach Service Type D, GAST D).
*Minimum Aviation System Performance Standards (MASPS) for GPS Local Area Augmentation System Airborne* (LAAS) Equipment (RTCA Do-253C) requires several additional integrity augmentations. These augmentations include position solutions with various smoothing time constants, e.g., dual solution ionospheric gradient monitoring (DSIGM), fault detection before and during new satellite additions, satelite geometry screening, and optional on-board autonomous integrity monitoring.

A GNSS landing system (GLS) can benefit from the hybridization of GBAS with INS in two ways. First, the inertial information can be used to coast for a short time during GNSS signal outages, which may occur for some ranging sources due to shadowing by aircraft's wing or fin, or as a result of a signal-in-space being excluded from a position solution if a fault is detected. Second, the inertial information can be used to increase the ability of the system to detect and exclude ranging sources that are disturbed locally and thus cannot be detected by the GBAS ground station.

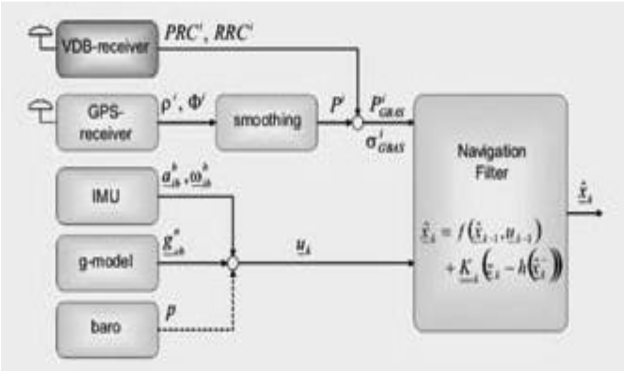

**Figure 1 GBAS/INS system layout**

Figure 1 illustrates the basic GBAS/INS system layout. A GPS receiver delivers the raw pseudoranges and carrier phases. Pseudoranges are smoothed using the carrier phase according to the *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment.*
A smoothing time constant of 100 seconds is used for GBAS Approach Service Type C (GAST C) and a time constant of 30 seconds for GAST D. A variable delay buffer (VDB) receiver delivers the message types from the GBAS ground station. The pseudorange and range rate corrections are then applied to the smoothed pseudoranges, and the GBAS corrected pseudoranges are used within the hybridization filter, which in this case is a total-state extended Kalman filter (EKF).

On the inertial side, the measured accelerations and turn rates are used together with an Earth gravity model in the propagation step of the EKF to calculate the predicted attitude, heading, velocity, and position of the vehicle. If GBAS-corrected pseudoranges are available, they are used in the correction step of the EKF in terms of a tightly coupled system.

As mentioned earlier, autonomous integrity monitoring can be used to attain the highest integrity requirements as reflected in the LAAS MASPS.

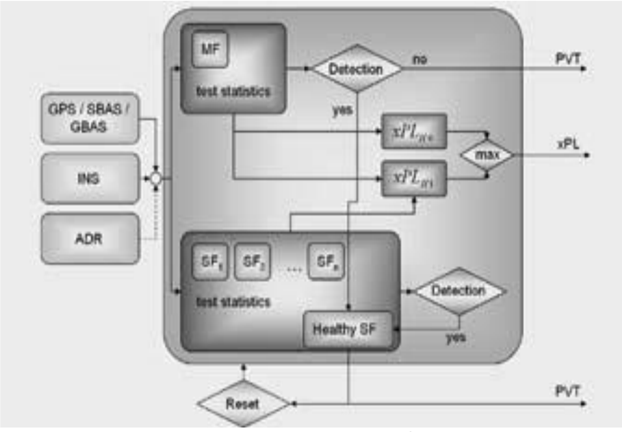


**Figure 2 GBAS/INS integrity functions**

In the present system layout, GNSS, INS, and optional barometric data from an air data reference (ADR) system are fed into the system. Depending on service availability, the GNSS data can be either solely GPS or raw data corrected by space-based augmentation system (SBAS) or GBAS differential broadcasts.

A main filter (MF) uses all (*n*) available GNSS ranging sources, while a bank of *n*-1 sub-filters ($SF_i$) operates in parallel. Each sub-filter excludes one ranging source. Fault detection is performed by monitoring either the main filter's residuals or the solution separations in the horizontal and vertical domain between the main filter and sub-filters. If a fault is detected, the healthy sub-filter – the one that is excluding the faulty ranging source – is used to reset the whole system. For the calculation of hybrid protection levels, the integrity monitor uses filter characteristics from the main and sub-filters. For the purpose of testing and evaluating the basic functions and system performance, we performed several ground and flight tests. During the flight trials,various kinds of inertial measurement units (IMUs) were used, ranging from low-cost MEMS to tactical- and navigation-grade units.

## 3 BEAMFORMING EQUIPMENT DESIGN

Because signals from the navigation satellites arrive at the user receiver with extremely low power density, GNSSbased equipment is inherently vulnerable to the radio frequency interference (RFI). Due to the spread spectrum technology used by GNSS, some RFI robustness is provided by the de-spreading processing gain. However, this can easily become inadequate in case of strong interference. Of particularly great concern is the RFI problem in GNSS applications with safety-critical aspects, such as aircraft landing with GBAS.

The main beam of the array reception pattern can be steered to a particular GNSS satelite while nulls are produced along the directions of arrival (DOAs) of interferers.

The antenna array serves as a spatial filter for the incoming signals, which can be easily combined with the receiver-based mitigation techniques inthe time-frequency processing domain. Similarly, spatial filter may also be used to minimize multipath error. The adaptation of the array weights is performed individually for each satellite signal tracked by the receiver. The weight control algorithms for each satelite channel work independently from each other and produce multiple sets of weights. Each and every set is optimized for the reception of a given satellite. In other words, each satellite signal is received through its own array reception pattern. Two low-noise amplifiers (LNAs) with total gain of 25 decibels are placed directly after each of the antenna elements in order to compensate for the losses in the cabling and to obtain an acceptable noise figure for the receiver.

## 4 BEAMFORMING TECHNIQUES

The signal-processing software running on the host PC of the PXI chassis is basically a software receiver that implements all typical GNSS signal-processing functions after the PRN code correlation. The signal processing includes signal tracking by using code and carrier loops, navigation data decoding, and position determination. For processing the signals from the antenna array, the software receiver also has blocks that implement the various algorithms used for adaptive array weight control and estimation of DOAs.

The calculated array weights are applied in each receiver channel, and the beamformer output feeds into the tracking loops.

Using digital beamforming in the software receiver allows for fast implementation of the array processing algorithms

and high flexibility. The new array receiver platform supports beamforming drawing on one of two types of aiding information:

- ✓ the satellite signal's known DOA, or
- ✓ highly correlated reference and GNSS

signals, after PRN-code correlation. In the first case, can be either calculate the DOA by using the broadcast ephemeris data of the navigation message or estimate it using a direction-estimation algorithm. The reference signal used with the second type of beamforming is a sequence of the navigation data bits estimated by the receiver-tracking block. The weight control algorithms with the first type of beamforming are usually based on the minimum variance (power minimization) criteria, while the algorithms with the second type minimize mean square error between the beamformer output and the reference signal.

The use of the beamforming of the first type requires well-calibrated amplitude and phase transfer characteristics of array elements and RF front end of the receiver hardware. This can also be shown to be a prerequisite for determining the position of the phase center of the array antenna for given array weights, for which purpose the calibration signal is used. The distribution of the signal with a calibration network is designed such that the signal appears in each array channel with almost equal phases and amplitudes. The calibration signal propagates through the entire processing chain and is individually processed in the receiver tracking part. Then can be use the phases and amplitudes of the calibration signals reported by the tracking algorithm to produce corresponding corrections for beamforming and direction estimation. This allows live calibration of the timevariant part of the receiver hardware with active elements, including amplifiers, mixers, and ADCs.

The system obtains the DOA (Deteriorate On Approach) in two steps by using the 2-D unitary ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques) technique. First, the DOAs of GPS satellites were estimated with the real-time calibration corrections but without accounting for the reception patterns of array elements.

In the next step, estimated DOAs were used to find the corresponding phase responses of the array elements and take them into account in the second DOA estimation.

| PRN | Azimuth error (deg) | | Elevation error (deg) | |
|---|---|---|---|---|
| | Bias | Std | Bias | Std |
| 9 | -1.85 | 0.40 | -2.06 | 0.26 |
| 12 | -1.95 | 1.21 | -3.05 | 0.92 |
| 15 | -3.21 | 0.40 | -3.49 | 0.39 |
| 17 | 0.66 | 0.33 | 2.17 | 0.48 |
| 18 | 0.92 | 0.40 | -2.48 | 0.79 |
| 22 | -3.68 | 0.81 | -12.98 | 1.32 |
| 26 | -9.12 | 0.54 | -2.94 | 0.86 |
| 27 | -2.20 | 0.61 | 0.67 | 0.27 |
| 28 | -1.36 | 0.47 | 1.53 | 1.22 |

Table summarizes the statistical characteristics of the DOA estimation errors from more than 350 runs during seven seconds of signal tracking. The actual satellite DOAs are computed with the ephemeris information from the GPS system almanac.

## 5 CONCLUSION

This article has shown techniques to improve the acuracy of navigation. Article described advatages of GNSS landing system (GLS) which can benefit from the hybridization with GBAS. With beamforming techniques the system can improved the transmitting mistakes of GNSS systems in aviation much better. Using digital beamforming in the software receiver allows for fast implementation of the array processing algorithms and high flexibility.

## BIBLIOGRAPHY


[1] Minimum Aviation System Performance Standards for the Local Area Augmentation System (LAAS); RTCA Do-245A; RTCA, Inc., 2004

[2] *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment*; RTCA Do-253C; RTCA Dec 2008

[3] Steen, M., and M. Becker, U. Bestmann, M. Kujawska, T. Feuerle, and P. Hecker, “Integrated GBAS/INS Navigation System – Continuity and Integrity Aspects,” Symposium Gyro Technology 2009, Karlsruhe, ISSN 1439-4502, pp. 16.1-16.15

[4] Steen, M., and P. Hecker, “GBAS/INS Navigation System: Further Developments of On-Board Integrity Monitoring,” *Proceedings of the 2010 International Technical Meeting of the Institute of Navigation*, San Diego, California USA, January 25–27, 2010, pp. 386 – 393

[5] M. V. T. Heckler, W. Elmarissi, L. A. Greda, M. Cuntz, and A. Dreher, “Narrow-band microstrip antenna array for a robust receiver for navigation applications”, 3rd European Conference on Antennas and Propagation (EuCAP 2009), Berlin, Germany, Mar. 2009, pp. 1206-1210.

[6] M. Cuntz, L. A. Greda, M. Heckler, A. Konovaltsev, M. Meurer, L. Kurz, G. Kappen, and T. G. Noll, “Architecture of a real-time safety of life receiver”, Proc. of the 2009 ION International Technical Meeting, Savannah GA, USA, Sep. 2009.

[7] A. Konovaltsev, F. Antreich, A. Hornbostel (2007), “Performance assessment of antenna array algorithms for multipath and interferers mitigation”, Proc. of 2nd Workshop on GNSS Signals & Signal Processing (GNSS SIGNALS’2007), 24-25 April 2007, Noordwijk, the Netherlands.


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