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Development of a Highly Integrated and Autonomous Position Reference and Navigation System for Flight Inspection

David Gondy
Aerodata AG
Hermann-Blenk Strasse 36
38108 Braunschweig
Germany

Dr. Harald Hoffmann
Aerodata AG
Hermann-Blenk Strasse 36
38108 Braunschweig
Germany

Yunfei Hoffmeister-Han
Aerodata AG
Hermann-Blenk Strasse 36
38108 Braunschweig
Germany

ABSTRACT

Flight Inspection has a double requirement concerning the position reference and navigation system: firstly, a very accurate positioning solution used as reference is required and secondly, attitude and heading angles are necessary for guidance and leverarm transformation, for example from the GPS antenna to the ILS antenna. The current position reference systems that offer the best accuracy and availability perform it through the combination of an INS with different sensors like P-DGPS, Laser Tracker etc.. They are very expensive if an INS sensor has to be bought and difficult to integrate if the primary avionics has to be interfaced. Furthermore, the newest developments in navigation have to be taken into account, this means the system shall also be able to perform RNAV/NPA navigation, to handle WAAS & GBAS data. At last, the guidance task and the data acquisition of the flight inspection receivers have to be performed.

A solution could be a highly integrated system using also low cost sensors, which works independently from of the primary avionics and attains a performance near or equal to current INS systems. In fact, such a system could be easily installed and is much cheaper than e.g. a current INS system. In this case, the major challenge in the development of the system is in the achievement of an INS like attitude output.

The basis approach to solve the described problem is offered by the EC- funded SHINE project. The prototype, which was developed in the frame of this project, integrates two GPS receivers, IMU, CPU board and I/O concentrator in one unit complying with the ARINC-704 standard. The main idea is to use a two- GPS antenna system with ant approximately 2 m baseline to have a position based (range, range rate) and derived attitude information (pitch, heading) calculated on the base of a phase solution. The GPS based information and the IMU output are hybridised. True air speed, barometric altitude and heading are available as inputs for the hybridisation. The advantage of the SHINE prototype is a good observability of the attitudes and the gyro bias in all flight phases where GPS is available. The estimation performance of the Kalman filter for these values is drastically increased. This improvement leads directly to a higher accuracy of the Strapdown solution also during GPS outages. Both are now possible – the use of the system as position and attitude/heading reference system for flight inspection. The system was shown to work according to specifications what was confirmed by the flight tests.

This paper presents the test results and the development approach for a low-cost integrated and autonomous multi-sensor system for aeronautical applications. The adaptation of this system to the requirements of flight inspection will be also discussed. They are related especially to the accuracy of the positioning solution, to the extension to other positioning sensors used in flight inspection, to the integration of the guidance task ion the prototype and to the integration of the data acquisition for flight inspection receivers.

INTRODUCTION AND PROBLEM DESCRIPTION

SHINE (Smart Hybrid Integrated Navigation Equipment - The SHINE project is funded by the European Community) is an airborne equipment designed for offering with lower weight and cost than current configurations all the positioning and attitude parameters required by aircraft and helicopters for highly accurate and safe navigation within the airspace. This project is realized in a close-collaboration by an international consortium consisting of:

- THALES Avionics (project leader, France),
- Aerodata AG (Germany),
- Technische Universiteit Delft (Netherlands),
- National Space Laboratory (Netherlands),
- Cranfield University (United Kingdom) and
- Eurocopter S.A.S. (France).

Similarly to navigation, flight inspection has high requirements concerning the accuracy and the safety of position and attitude parameters. To introduce the SHINE equipment in the field of flight inspection, it has especially to be adapted to the different combinations of position and attitude sensors commonly used for approach calibration. These combinations are listed in Table 1.

#	Position Sensor Combination	Attitude sensor
1.	INS + P-DGPS	INS
2.	INS + GPS + Camera + Laser Altimeter + ADC	INS
3.	INS + Laser Tracker + DGPS	INS
4.	P-DGPS	AHRS or aircraft gyrometers
5.	Theodolite	AHRS or aircraft gyrometers

Table 1: Position Sensor Combination for Approach Calibration

For the first three position reference systems that use INS as attitude sensor, the INS can be replaced by a low-cost IMU cheaper for factor ten. The problem until now was that the accuracy of attitude outputs of a combined GPS/AHRS system (typically 2°) was much worse than this of an INS (0.4° for heading, 0.1° for bank and pitch). The concept, presented in this paper, brings here a solution thanks to the use of a two-GPS antenna system with an approximately 1.5 m baseline: GPS attitude outputs (pitch, heading) enable to improve considerably the accuracy of the attitude outputs of the GPS/AHRS system and to reach an IRS-like accuracy. For the both last position reference systems, the accuracy of the position reference is degraded on a significant way by the use of low accurate AHRS or aircraft gyrometers for lever arm transformation. The developed concept would enable for these systems to improve the accuracy of the attitude angles and thus of the position reference. As a consequence, the new concept is interesting for all kinds of current flight inspection systems.

DESCRIPTION OF SHINE EQUIPMENT

System Architecture

The SHINE prototype has a standard mechanical housing for airborne applications and can be installed in a tray. Following devices are mounted in the housing (Figure 1):

- Two THALES L1 GPS receivers, based on the TOPSTAR series but adapted for the SHINE application.
- A MotionPak IMU
- One I/O board, which concentrates all inputs and performs the management of the input data.
- One CPU board (PowerPC) for the processing of the sensor inputs.

External devices (heading sensor, air data computer) can be connected via ARINC 429 protocol. The prototype provides different recording, monitoring and control capabilities via serial or Ethernet line.

The processing software can be separated into four main blocks. These are:

- Data acquisition. The software runs on the I/O board. The software provides interface drivers (RS422, ARINC etc.) and capabilities to manage the incoming data stream. This includes the time stamping of all data using an internal clock stamp and the communication with subsequent processes (data transfer, process control etc.).

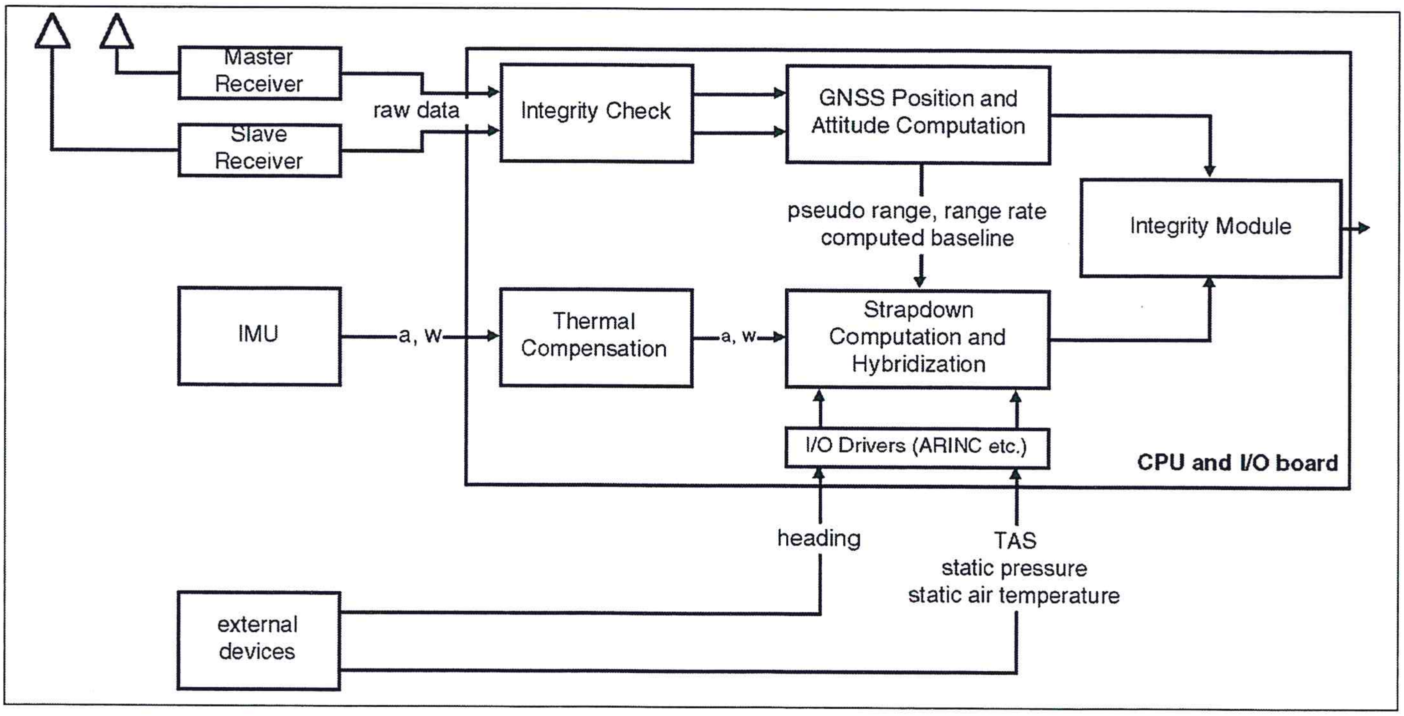

Figure 1: System architecture of the SHINE prototype

- GPS raw data processing. The processing of the GPS raw data is performed on the CPU board. The software performs following main tasks:
  - Integrity check of the incoming data via RAIM,
  - Calculation of independent solution for position and velocity,
  - Calculation of pitch and heading. Details are given in the next paragraph.

  Range information which pass through RAIM and the calculated antenna baseline are provided to the hybridisation process.
- Hybridisation. This software runs also on the CPU board and includes the Strapdown process as well as the data hybridisation via an Extended Kalman filter. An overview is given in this paper.
- Process control and monitoring. The related software includes modules like the "Integrity Module" (Figure 1), which performs an error detection based on comparison between positions/velocities computed directly from the raw data source (GPS) against the estimated position/velocity by the hybridisation process.

GNSS Attitude Computation

Basic Principle

A principle of basic geometry states that two distinct points define a unique line. If relative position of one point with respect to other is known, the orientation of the line can be determined. These points may be substituted by GNSS antennas (either sharing one local oscillator or separate ones). In such a twin-antenna setup, one antenna is designated *master* (M) and the other, *slave* (S). The separation between the phase centers of master and slave antennas is called *baseline*. The *baseline vector* is one whose magnitude is the length of baseline and which is directed from master to slave antenna.

GNSS-attitude determination uses carrier-phase measurements since only these have a level of precision required to achieve desired accuracy in attitude computations. The aim is then to determine the relative position of the slave by measuring the difference in carrier-phase between the two antennas. If multiple non-collinear antennas (two slaves or more) are used, the full 3-axis attitude of the vehicle can be estimated. The carrier-phase measurements, however, are ambiguous and in order to obtain precise attitude, resolution of the ambiguities is required. Moreover, the ambiguity resolution must be instantaneous in order to enable real-time attitude computation. As to the pseudorange measurements, they are used to aid the ambiguity resolution process. Once the ambiguities have been resolved, the relative position (baseline vector) coordinates are estimated and the heading and pitch angles computed. This technique (see Figure 2) of computing attitude angles is called *baseline vector-based (or relative position) attitude determination*.

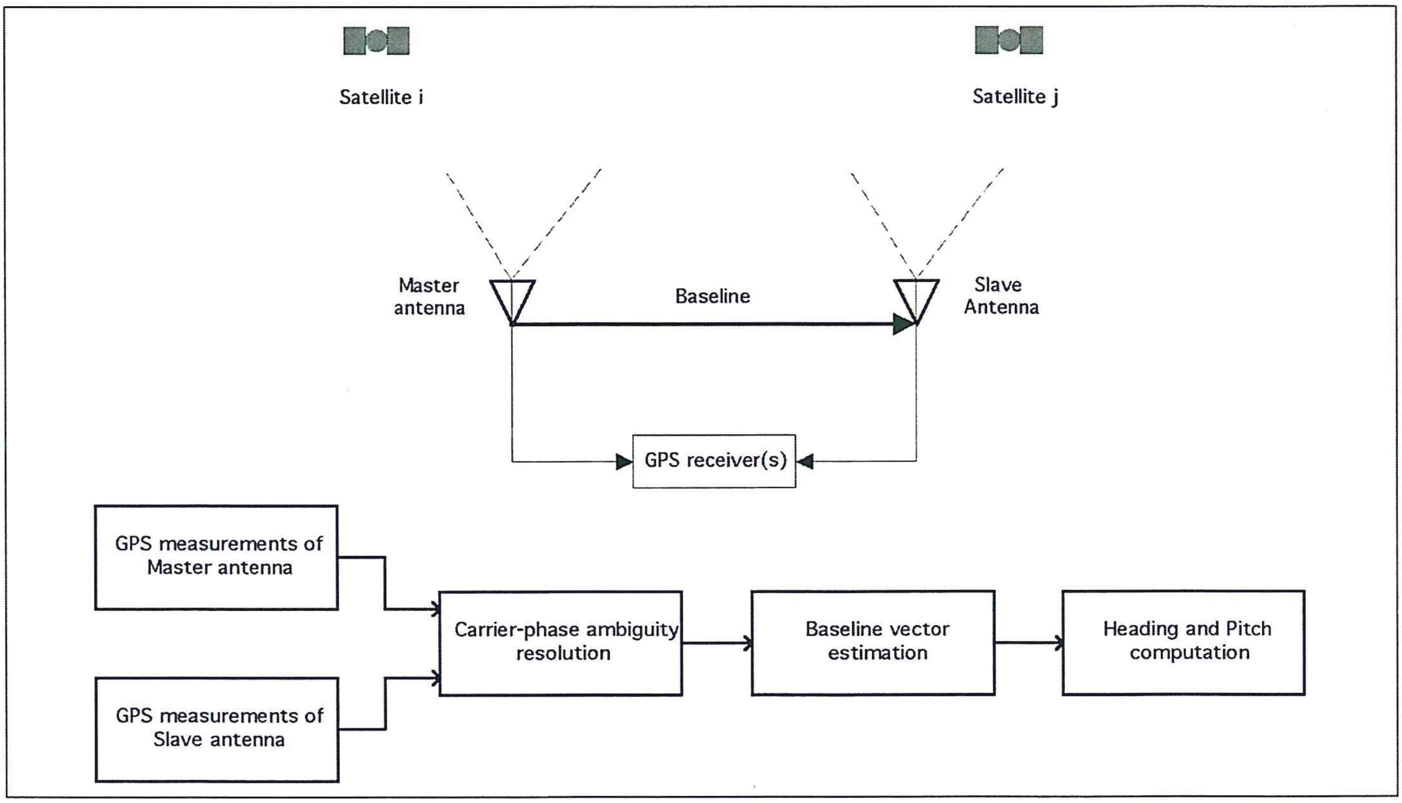

Figure 2: Synopsis of baseline vector-based heading determination

Technical Implementation

An overview of the technical implementation of the GNSS attitude software is given on Figure 3

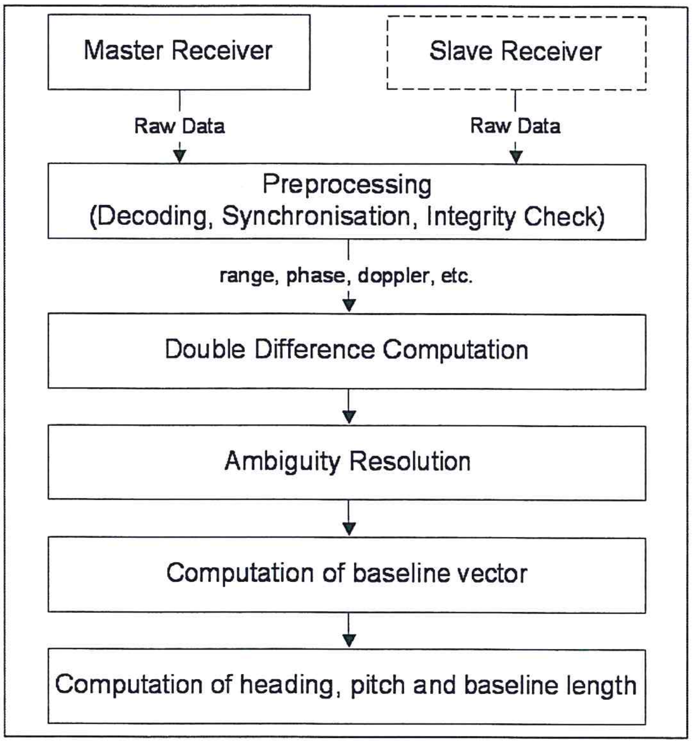

Figure 3: Structure of the GNSS attitude software

The computational steps can be described as follows:

Double Difference Computation
Before they can be used in attitude computations, the carrier-phase measurements must be made free of the various error terms. That is why the phase differences are applied. A *single phase difference* between measurements of two antennas enables to eliminate the satellite clock errors, the tropospheric and ionospheric delays in the cases where the baseline does not exceed several meters. Only the receiver clock errors and the line-bias due to electrical path differences between signals from the two antennas remain after the single phase difference. These errors are eliminated by the appliance of the *double phase difference* formed by the difference of single differences between two distinct satellites.

Overview of carrier-phase ambiguity resolution

The difficulty in using directly the carrier-phase double differences for baseline vector estimation is that their integer ambiguities are unknown. These ambiguities must be estimated at initialisation and whenever phase lock is lost simultaneously on several satellites. However, they may also be estimated every epoch, this being the case for the SHINE software. The process of ambiguity estimation is also referred to as search or resolution. An overview is given on Figure 4.

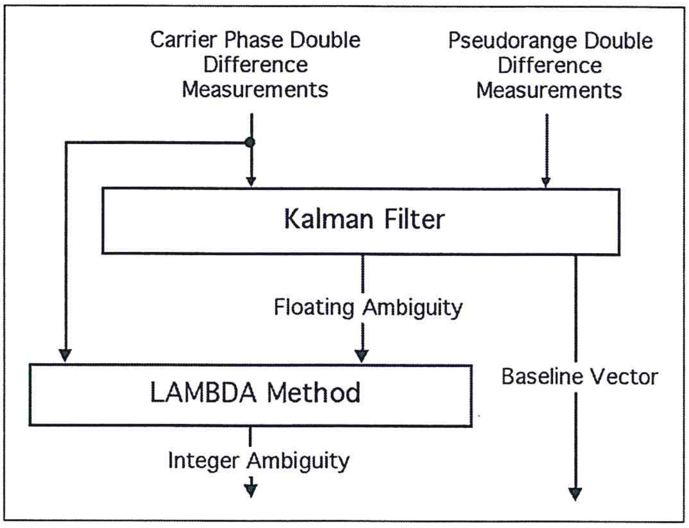

Figure 4: Overview of ambiguity estimation process

Floating-point ambiguity estimation
A search algorithm estimates in a first step the floating-point or real values of the ambiguities. A Kalman filter is used to perform this step. This estimate is based on the double difference carrier-phase and pseudorange measurements and the carrier-phase and pseudorange variance matrices. The floating-point ambiguity estimates, being outputs of the Kalman filter, are updated ever epoch. Along with the ambiguities, the float solution also estimates the baseline vector. However, this estimate is not accurate enough to be used in attitude computations. For a 2 meters baseline, the standard deviation of the float-solution-computed baseline length is about 0.5 meters, obviously not accurate enough for attitude computations.

Integer ambiguity estimation
In this second step, based on the floating-point estimates and their covariance matrix, the most likely set of integer ambiguities is searched. There are several mathematical methods to search integer ambiguities. One such method is LAMBDA, which will be used in the SHINE context. This algorithm is mainly based on the methods presented by Teunissen et al. [3][4][5] and Jonge et al. [2]. For SHINE prototype, the integer ambiguities are searched every epoch regardless of whether or not they were found in previous epoch. The resolved double difference integer ambiguities are then used to estimate the baseline vector.

Computation of baseline vector

The baseline vector is computed via a least square system in WGS-84 coordinates. It is then transformed in local geodetic reference frame. The origin of the local geodetic frame is selected such that it coincides with the phase-center of master antenna.

Computation of heading, pitch and baseline length

Using the local geodetic coordinates as computed above, the heading (ψ), pitch (θ), and baseline length (L) are determined as follows:

$$\psi = \sin^{-1}\left(\frac{\text{äEast}}{\sqrt{\text{äNorth}^2 + \text{äEast}^2}}\right) \quad [\text{rad}]$$

$$\theta = \tan^{-1}\left(\frac{\text{äUp}}{\sqrt{\text{äNorth}^2 + \text{äEast}^2}}\right) \quad [\text{rad}]$$

$$L = \sqrt{\text{äNorth}^2 + \text{äEast}^2 + \text{äUp}^2} \quad [\text{m}]$$

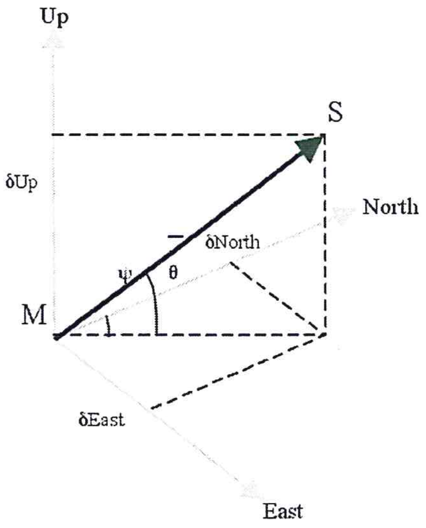

Figure 5: Baseline vector orientation with respect to local geodetic frame

Baseline verification check

The integrity of GNSS attitudes solution may be verified through the baseline test wherein the computed baseline is compared with the pre-measured known length. If the difference exceeds a pre-determined threshold, the solution is declared invalid, in which case ambiguities have to be estimated anew if required.

The selection of threshold is crucial as it determines the validity of the attitude solution. Clearly, it should be as small as possible so that no erroneous solution is output. However, if a too small value is selected, there is a risk that a solution is rejected even when the accuracy was enough. Generally, it can be kept within 5σ value of the relative position accuracy.

Attitude accuracy as a function of baseline length

The accuracy of GNSS-derived attitude angles has an inverse relationship with baseline length, i.e. larger baselines yield more accurate angles. This relationship can be approximated by the following equations:

$$\textbf{heading accuracy} \approx \frac{\text{relative horizontal position accuracy}}{\text{baseline length}}$$

$$\textbf{pitch accuracy} \approx \frac{\text{relative vertical position accuracy}}{\text{baseline length}}$$

In general, the accuracy of pitch will be worse than that of heading.

Another factor important in real-time GNSS attitudes applications, is the computational time required to resolve integer ambiguities. For a given computational power, the ambiguity resolution time may have a direct relationship with baseline length. However, this effect is negligible over a range of several tens of meters of baseline. Assuming that the integer ambiguities have successfully been resolved, the performance of GNSS attitudes determination depends only on the accuracy of carrier-phase measurements. The variance of double difference carrier-phase measurements is 4 times the variance of carrier-phase measurements. The baseline vector estimation in turn is based on the double difference carrier-phase model. For
Carrier-phase standard deviation (σ_φ) = 3mm (1 sigma)
Baseline length (L) = 1.5 m
HDOP = 1.5
VDOP = 2.0
the expected theoretical baseline accuracy is (2σ, 95 %):

$$\sqrt{\text{ó}_{\text{äNorth}}^2 + \text{ó}_{\text{äEast}}^2} = 2 \cdot \text{ó}_\varphi \cdot \text{HDOP} = \mathbf{9\ mm}$$

$$\text{ó}_{\text{äUp}} = 2 \cdot \text{ó}_\varphi \cdot \text{VDOP} = \mathbf{12\ mm}$$

and the corresponding attitude accuracy is therefore (2σ, 95 %)

_ψ = 0.34 deg for heading.

_θ = 0.46 deg for pitch.

Hybridization Concept

As presented in Figure 6 for a GPS/INS hybridisation, a total state Kalman filter was selected as basis architecture for the sensor data fusion. In contrast to the classical error state architecture (e.g. Titterton et al. [6]), the total state Kalman filter estimates directly the navigation parameters (position, velocity, attitude) as a share of the filter state vector elements. It is also possible to integrate the Strapdown algorithm in the prediction branch of the Kalman filter.

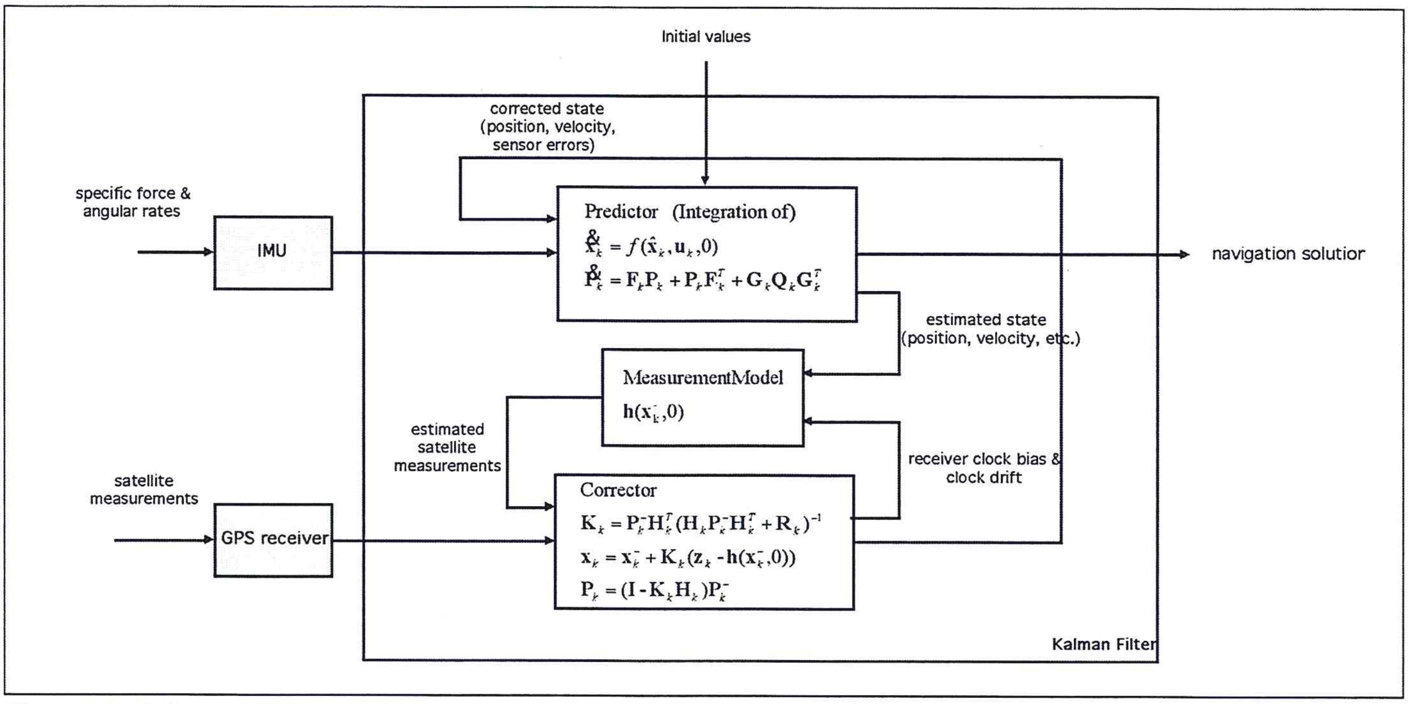

Figure 6: Kalman Filter architecture. K denotes the discrete time index.

Further the total state approach employs the GPS mechanization (Measurement Model) directly. The use of linearized models of the INS and the GPS errors is also not necessary. According to Wagner [7] the selected total state approach leads to an extended Kalman filter [1].

Figure 6 displays the basic equations of an extended Kalman filter. For the SHINE application the state vector **x** includes eight sub-vectors of altogether 22 elements (Equation 1).

$$\mathbf{x} = \begin{bmatrix} \text{position} & x_1 \ldots x_3 \\ \text{velocity} & x_4 \ldots x_6 \\ \text{attitude} & x_7 \ldots x_{10} \\ \text{GPS receiver clock (bias, drift)} & x_{11}, x_{12} \\ \text{accelerometer bias} & x_{13} \ldots x_{15} \\ \text{gyro bias} & x_{16} \ldots x_{18} \\ \text{gyro scale factor error} & x_{19} \ldots x_{21} \\ \text{static pressure} & x_{22} \end{bmatrix} = \begin{bmatrix} \mathbf{x}_p \\ \mathbf{x}_v \\ \mathbf{x}_q \\ \mathbf{x}_c \\ \mathbf{x}_a \\ \mathbf{x}_\omega \\ \mathbf{x}_S \\ \mathbf{x}_P \end{bmatrix}$$

Equation 1: State vector.

The sub-vectors $\mathbf{x}_p$ and $\mathbf{x}_v$ are formulated in the ECEF frame. The attitude representation uses four quaternions ($\mathbf{x}_q$), which refer to the ECEF frame too. The navigation filter also includes descriptions of the dominant inertial instrument errors. For the given IMU, accelerometer and gyro bias as well as the gyro scale factor error were taken in the state vector. The errors are referred to the aircraft fixed frame. The receiver clock errors are formulated by clock bias and clock drift. With respect to the board autonomous measurements given by an air-data computer, the static pressure was formulated as last element of the state vector. This allows an altitude aiding directly based on the static pressure measurement.

FLIGHT TEST RESULTS

Test Environment

The SHINE test campaign has been performed in the period from November 5th through November 13th, 2003 at Amsterdam Airport Schiphol with NLR's Swearingen Metro II research aircraft. The following equipment has been mounted onboard the aircraft.

- SHINE NCU with two laptops for, respectively, control and data collection.
- Motion Pack IMU of Aerodata
- Air Data Computer
- NLR data collection system
- Honeywell IRS HG1050 for attitude reference
- NLR Trimble L1/L2 GPS receiver for position reference

The ADC provides true air-speed, static air temperature and static pressure measurements to the prototype. The true heading output of the IRS was used as heading sensor input for the SHINE prototype during the flight test. Furthermore, two GPS antennas were mounted along the x-axis of the aircraft with a fixed baseline of about 1,461 m. The test campaign consisted of three ground tests and four flight tests.

Performance of Attitude determination

Requirements

For the attitude output the requirements were derived from the TSO-C4c and TSO-C6d/C7d. However, the target performance should be better than described in these documents so that more severe requirements for the prototype were defined. See the table below for details.

Parameter	**Minimum requirements**	**Target requirements**
Pitch accuracy	0.5° (95%) / 1° (max)	0.1° (95%) / 0.5° (max)
Heading accuracy	1° (95%) / 2° (max)	0.4° (95%) / 1° (max)

Table 2: Attitude requirements for a 2 m antenna baseline

Results

The last flight test made of several ILS approaches with low-level go-arounds and touch-and-go's will be chosen to show the performance of the attitude determination since it is at the nearest from the flight inspection conditions.

Typical results concerning the heading accuracy are given on Figure 7. The heading output of the IRS platform was used as reference.

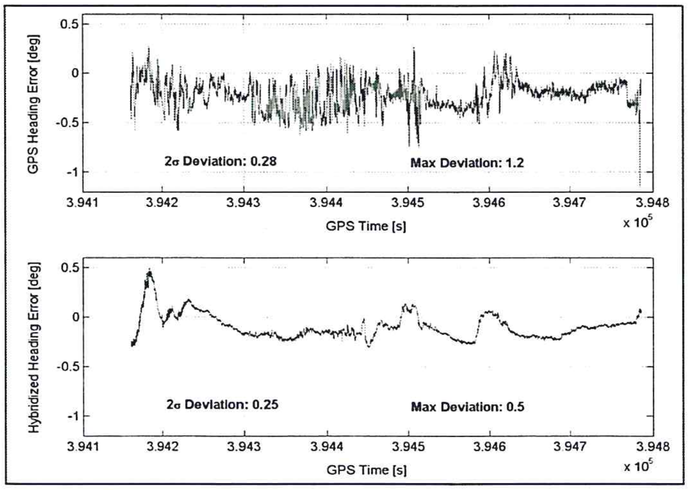

Figure 7: Heading Accuracy

The 95 % accuracy (0.28 deg) for the GPS heading is in line with the expected accuracy (0.34 deg). The hybridisation enables to improve slightly the 95 % accuracy (0.25 deg) but also significantly the maximum deviation (0.5 deg instead of 1.2 deg for GPS Heading). Target requirements and as a consequence minimum requirements are largely reached.

Typical results concerning the pitch accuracy are given on Figure 8. The pitch output of the IRS platform was used as reference.

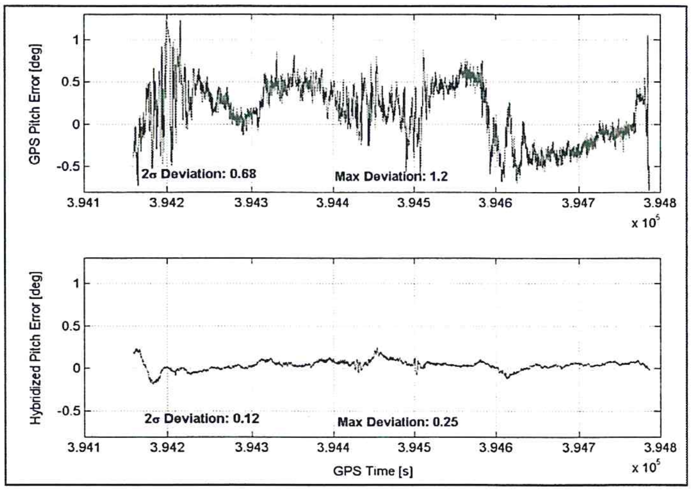

Figure 8: Pitch Accuracy

The 95 % accuracy (0.68 deg) for the GPS pitch is worse than the expected accuracy (0.46 deg). The hybridisation enables to improve largely the 95 % accuracy (0.12 deg) but also significantly the maximum deviation (0.25 deg instead of 1.2 deg for GPS Heading). Target requirements are very near to be reached. Minimum requirements for current prototype are largely reached.

Performance of Position Determination

Requirements

Minimum performance requirements were defined for the prototype during the design phase to assess the results of the later tests. The requirements for the localization performance are related to TSO 115b and the ICAO Amendment to Annex 10.

Concerning flight inspection, stand-alone GPS is used typically for en-route calibration. The document 8071 of the annex 10 requires horizontally an accuracy of 80 m and vertically of 100 m. These requirements are higher than those defined for the SHINE prototype. They will be taken into account to evaluate the results.

Results

The accuracy of the position reference is of special importance by GPS outage where the specified maximum error is likely to be exceeded. GPS outages lead particularly to high errors during turn phases that occur for en-route calibration for example during orbit flights. Figure 9 shows a typical behaviour of the hybridised position during a 360 degrees turn.

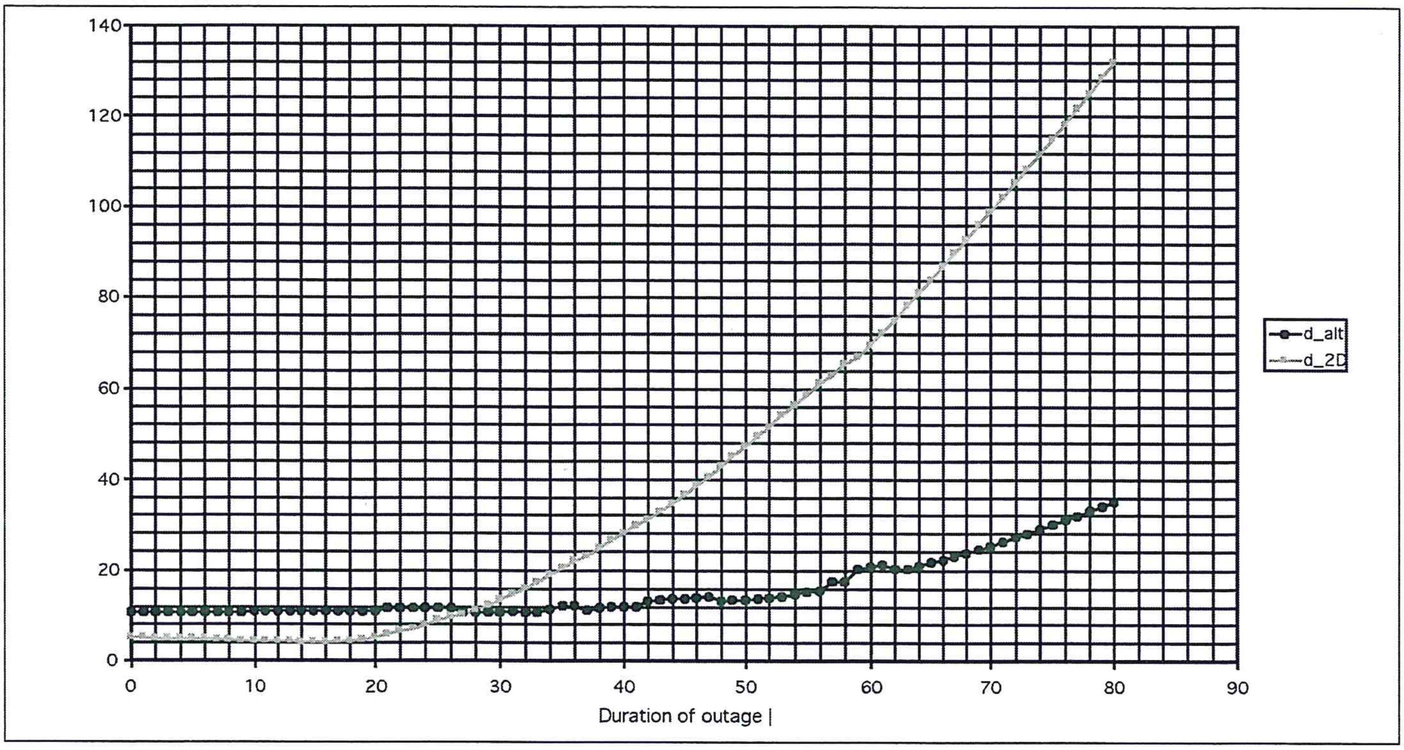

Figure 9: Behaviour of the hybridised position during a GPS outage

Only the board autonomous sensors (IMU, ADC, heading sensor) are used during the GPS outage. The specified horizontal accuracy of 80 m is reached horizontally after 65 seconds. After 80 seconds, the vertical error remains always largely under the specified accuracy of 100 m. It means the hybridisation algorithm can bypass GPS outages until typically one minute for en-route calibration.

ADAPTATION OF THE SHINE PROTOTYPE TO THE FIS REQUIREMENTS

Accuracy of the positioning solution

The SHINE prototype has basically a standard GPS accuracy that is enough for en-route calibration but not for approach calibration. For this, it has to be able to provide carrier-phase positioning. Well, as we have seen on page 4, the SHINE prototype has already a module for the carrier-phase ambiguity resolution used currently for attitude computation. The same module can also be used for carrier-phase positioning. It stands for the core of the current computation process and also the most critical part: if the found ambiguity is false, then attitudes are not available (error is detected by the baseline check) or the computed position has several tenths of centimetres errors.

For carrier phase positioning, a DGPS reference receiver on ground has to be used additionally and the L1 receivers used for SHINE have to be replaced by L1/L2 receivers. For carrier phase positioning, the ambiguity resolution process is repeated twice once for widelane frequency (L1+L2) and once for L1 alone. The GNSS attitude computation process is modified as indicated on Figure 10 (dashed lines indicate the modified steps).

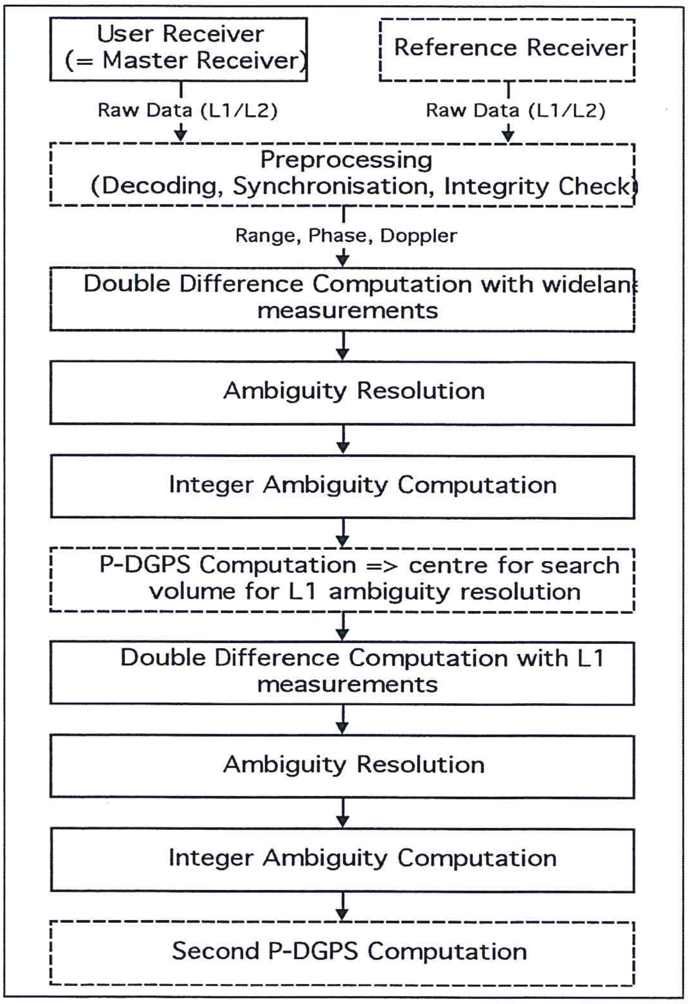

Figure 10: Carrier phase positioning computation process

Moreover, this new ambiguity core process presents some advantages in comparison to P-DGPS systems currently in use for flight inspection. The integer ambiguities are estimated at every epoch: this has following advantages:

- Errors can be detected earlier so that the integrity is improved. It should then be possible to reduce the time until the release of the phase solution.
- A backward branch and the associated check that compares ambiguities between forward and backward branches to improve the integrity become superfluous. The only interest of a backward branch would remain in the improvement of the availability. By suppressing the backward branch, it would be possible to gain computation time after the end of the calibration.

Different checks such as FDE enable also to reinforce the integrity so as a consequence to reduce more the release time of the phase solution.

Other adaptations

The other adaptations are related to the following domains:

- Extension to other positioning sensors used in flight inspection,
- Integration of the guidance task,
- Integration of the data acquisition for flight inspection receivers.

On the base of the existing know-how at Aerodata, no technical problems are expected for these tasks.

SUMMARY AND FUTURE ISSUES

The basis concept of the SHINE prototype was introduced. Especially, the GNSS attitude computation process was described in detail. Test results concerning attitude computation and behaviour during GPS outages were compiled in this paper. At last, adaptations of the SHINE prototype to the requirements of flight inspection were discussed mainly for the GNSS attitude computation process.

It turns out that the SHINE prototype, which uses low-cost sensors, reaches a good attitude performance based on a GPS attitude aiding of an IMU sensor. This ensures further a sufficient availability of accurate attitudes for shorter GPS outages. The position accuracy is comparable with the currently available single GPS accuracy. In the case of a longer GPS outage reduced capabilities can be maintained using board autonomous sensors. This is also one result of the flight tests. From the discussion to the adaptation of the SHINE concept to flight inspection, it turns out that no major difficulties have to expected and the new ambiguity resolution core has interesting properties for flight inspection.

A non-discussed item is related to the integrity requirements of flight inspection concerning the ambiguity resolution. The highest the integrity requirements are, the longest is the release time for the P-DGPS solution and the worse is the availability of the phase solution. The right compromise has to be found between integrity and availability. Here, the new ambiguity core gives new margins in the search of this compromise.

At last, the SHINE architecture represents the ideal architecture to benefit from the future GNSS improvements such as GBAS, Galileo and GNSS-2.

REFERENCES

[1] Gelb (1989), *Applied Optimal Estimation*. 11th printing, The M.I.T. Press, Cambridge MA, London.

[2] Jonge de P.J., C.C.J.M. Tiberius, and P.J.G. Teunissen (1996) *Computational aspects of the LAMBDA method for GPS ambiguity resolution*. Proceedings of ION GPS-96, 9th International Technical Meeting of the Satellite Division of the Institute of Navigation, Kansas City, Missouri, Sept. 17-20, pp. 935-944

[3] Teunissen et al. (1994), *On the spectrum of the GPS DD-ambiguities*. In: Proceedings of ION GPS-94, 7th International Technical Meeting of the Satellite Division of the Institute of Navigation, (Salt Lake City, UT, September 20-23, 1994), pp. 115-124.

[4] Teunissen, P.J.G. (1995), *The least-squares ambiguity decorrelation adjustment: a method for fast GPS integer ambiguity estimation*. Journal of Geodesy, Vol. 70, No. 1-2, pp. 65-82.

[5] Teunissen et al. (1996), *The volume of the GPS ambiguity search space and its relevance for integer ambiguity resolution*. Proceedings of ION GPS-96, 9th International Technical Meeting of the Satellite Division of the Institute of Navigation, Kansas City, Missouri, Sept. 17-20, 1996) pp. 889-898.

[6] Titterton et al. (1997), *Strapdown Inertial Navigation Technology*. IEE Radar, Sonar, Navigation and Avionics, No 5, The Institution of Electrical Engineers.

[7] Wagner et. al. (2001), *Integrating Satellite and Inertial Navigation, Conventional and New Fusion Approaches*. In: Preprints of the 15th IFAC Symposium on Automatic Control in Aerospace (Bologna, September 2-7, 2001). Pp. 241-246. IFAC, Bologna

ABOUT THE AUTHORS

David Gondy received his diploma degree in 2000 at the E.N.A.C. in Toulouse, a French engineering school for civil aviation, with main emphasis on electronics and signal processing. He got also an advanced degree in 2000 in telecommunication and network. He has been working for four years at Aerodata AG in Braunschweig, Germany as a development engineer on positioning software for Flight Inspection and Navigation Systems.

Harald Hoffmann received his diploma degree in Electrical Engineering from the Technical University of Cottbus in 1993 and Ph.D. in Electrical Engineering from the same University in 1999. Currently he works as program manager for different projects in the field of the navigation system development at Aerodata AG in Braunschweig, Germany. His interests are focused on INS/GPS integration and Kalman filtering.

Yunfei Hoffmeister-Han received his diploma degree in Electrical Engineering from the Technical University of Braunschweig in 1988. Since 1992, he has been working at Aerodata AG in Braunschweig, Germany and has been involved in numerous research program in the field of satellite navigation. His work is focused on the development of algorithm and software for satellite based navigation for applications in avionics.