14ème/th SIIV IFIS
Toulouse-France 12-16 Juin/June 2006

MOVING PLATFORM CALIBRATION

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ABSTRACT

When discussing flight inspection it is readily assumed, that the navigational aid (NAVAid) under calibration is stationary.
There is however a small percentage of NAVAids, which need to be inspected while the mounting platform is in motion: Those on ships.
Military vessels such as aircraft carriers have a number of navigational aids to provide guidance to aircraft. The guidance signals of those NAVAids often are linked to the ship's attitude and heading reference system. As such a NavAid is closely coupled to the ship, it needs to be inspected while the ship is in motion. Most accurate flight checking of such aids becomes an interesting and challenging task as its position constantly changes.
This paper shows how a moving platform inspection was realised through modification of an existing flight inspection system. The key element is a highly accurate position determination of the moving NavAid, which allows calibration in real-time.
The 'Moving Platform System' is explained in detail documenting the experience gained, while the system was used to calibrate a ship's TACAN. The system's use is not limited to this particular application. An outlook to further utilisation is given, further development and other possible applications are discussed.

INTRODUCTION

The signals of a ship's NAVAid (TACAN or other) are closely coupled to the ship's movement (i.e. ship's heading to TACAN heading). A flight inspection of this ship-based facilities must be performed when the platform is in motion. As the NAVAid's position can not be read from a facility database as usual, it has to be determined and updated in real time. This position has to be delivered to the flight inspection system (FIS).
Additionally, it is necessary to know heading and attitude angle information to determine lever arm corrections, since the reference position is non-equal to the position of the inspected facility. Thus, a multiple GPS antenna concept may be chosen or an Inertial Measurement Unit (IMU) may be integrated to provide information on movements of the ship's body coordinate system.
The newly developed 'Moving Platform System' consists of a ship-based position reference station, called Ground Mobile Positioning Unit (GMPU) and a software adaptation of the FIS software. This GMPU is a modular system, which can be customized for the position reference accuracy range from single GPS to P-DGPS. DGPS can be achieved by using the satellite-based OmniSTAR DGPS service (i.e. OmniSTAR VBS 1 m CEP or OmniSTAR HP 0.1 m CEP). An integrated IMU provides attitude angle data for calculating lever arm corrections.
All measured position and attitude angle data are transmitted to the airborne FIS for integration into the FI positioning routines. Therefore, the position of the NAVAid is not read as a static value from a database, but it is constantly updated via radio data link.
The position reference of the flight inspection (FI) aircraft is using Differential GPS (DGPS) or Phase-Differential GPS (P-DGPS).

PRINCIPLE OF OPERATION

Flight inspection of land-based NAVAids uses fixed antenna positions as references for the measured signals. These antenna positions are stored in the FI software database. The FI software calculates the vector parameters distance and azimuth between the FI aircraft and the land-based aerial in real time and compares these parameters with the measurements derived from the aerial's received signal.

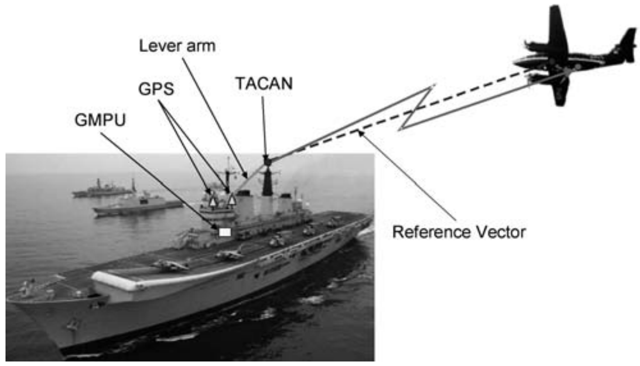

Figure 1: Principle of Operation

NAVAid aerials on ships move with the ship. Thus, a fixed database entry for the position is not given. The FI software was adapted to use reference positions of the aerial given by the GMPU transmitted via radio data link. These positions are sent approximately once per second to calculate reference azimuth and reference distance.

GMPU Data Processing

The GMPU receives GPS signals on both L1 and L2 frequencies. DGPS corrections are received from the OmniSTAR HP service. Angular rotations and acceleration data are given by an IMU.
The GMPU combines the GPS raw data from one of two GPS antennas and the OmniSTAR HP DGPS service to an accurate position solution in the WGS 84 coordinate system. With use of the second GPS antenna the heading of the base vector between the both antennas is provided. Assumed the antennas are parallel to the ship's main axis, the heading of the ship is derived.
From the IMU angular rotations and acceleration along its axis are used to calculate roll, pitch and yaw angles. The IMU feeds its data directly into one of the both GPS receivers.
All calculations are performed by an on-board personal computer (PC) with inbuilt software.
The output of the PC software is an ASCII data string, which gives the following information:

- Solution time
- Latitude
- Longitude
- Solution quality factor
- Number of satellites
- Position dilution of precision (PDOP)
- Ellipsoidal height
- Age of differential solution
- Roll value
- Pitch value
- Heading value
- Estimated roll standard deviation
- Estimated pitch standard deviation
- Estimated heading standard deviation

All data contained in the ASCII-data string are stored on a 40 GB hard disk inside the GMPU and are transmitted via radio data link to the FI aircraft.

FIS Data Processing

The FI aircraft receives GPS signals on both L1 and L2 frequencies. DGPS corrections are received from the OmniSTAR VBS service. Roll, pitch and yaw attitude data are given by the FIS Inertial Navigation System (INS) unit. Additional, radar altimeter data, barometric altitude and INS position data are provided by the FIS for the position calculation of the FI aircraft.
When installed in an aircraft, the TACAN receiver provides distance, bearing, velocity, time to station and audio identification information indicating the location of a complementary surface station with respect to the aircraft.

Figure 2: FI TACAN Receiver and Control Unit

For an accurate inspection of (Enroute) ground facilities it is very important to know the exact position of the FI aircraft in space. The position of the aircraft is the reference to which the facility data is compared in order to evaluate its performance.
In the Aerodata FIS the aircraft position is determined in real time by the navigation software which is part of the FIS software package. This software integrates the inputs of different navigational sensors (i.g. Barometric Pressure Sensor, DMEs, GPS, INS or Gyros) and uses them to calculate a highly sophisticated navigation solution. Since this unique navigation solution is independent from receiver manufactures algorithms and corrections, it is more reliable as receiver manufacturer given solutions.
The FI operator can decide what sensors shall be used for the navigation calculation by setting a 'Navigation Mode'. All available navigation sensors are automatically provided by the FIS to be chosen for the best results.
From the received data string of the GMPU and the lever arm information the position of the TACAN antenna is derived. With this,
• range across ground
• slant range
• azimuth bearing
• elevation angle
of the FI aircraft to the TACAN antenna is calculated as reference for the measured TACAN values.
From the TACAN the following FI relevant signals are available:
• Azimuth
• Status of azimuth data (flag)
• Distance
• Status of distance data (flag)
• Identification tone
• Reply rate
• Percent Main Reference Group (MRG)
• Video composite
• 15 Hz modulation
• 135 Hz modulation
• AGC
• Antenna speed
• Phase coherency
• Squitter rate
• MRG size
• Auxiliary Reference Group (ARG) size
• ARG count
The FI software determines omni bearing, current to/from flag and deviation corresponding to the actual performed FI procedure. The applicable parameters are checked for tolerances.
From the reference azimuth and reference distance, TACAN azimuth error and TACAN distance error are calculated.

Flight Procedures

The FI software provides the following flight profiles for TACAN calibration:
• Radials (inbound / outbound)
• Orbits (clockwise / counter clockwise)
• Dual radials

GROUND MOBILE POSITIONING UNIT

The GMPU is designed in a rugged housing for harsh environmental conditions. The protection of the GMPU equipment is sufficient to withstand damages from dust or entry of water where applicable. It can easily be carried by a single person.

Figure 3: AD-GMPU Enclosure

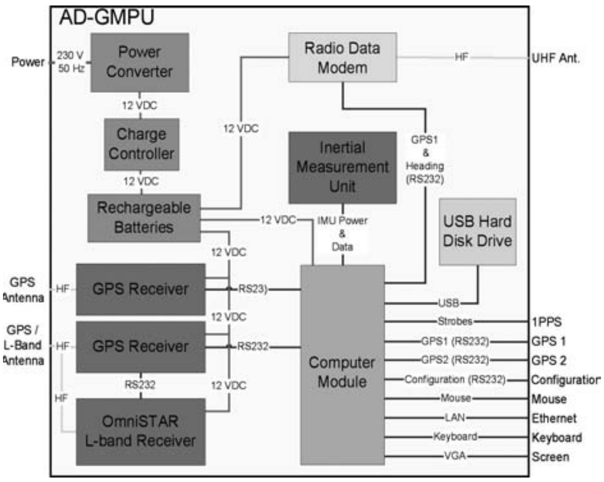

Figure 4: AD-GMPU Hardware Overview

The GMPU operates from an external electrical power supply in the range of 85 to 264 V/47-65 (440) Hz. In case of power failure it is driven by 12 VDC batteries for a minimum operation time of 2 hours.
The GMPU equipment is designed for storage at a wide temperature range, and to operate under the following ambient temperature conditions:
• 0° to +50°C (operating)
• 0° to +80°C (storage)
All external cable connections from antennas or from/to external devices are fixed on military type connectors. The GMPU provides the following interfaces:
• PS/2 keyboard and mouse
• VGA screen
• User configurable RS-232 serial data port
• GPS signal and OmniSTAR L-Band antenna input
UHF radio signal outputThe main devices of the GMPU are described in more detail in the following.

Computer Module

A dedicated computer module is used for real-time data evaluation and position and attitude angle calculation.
The computer module features an on-board Pentium personal computer (PC) processor that allows the computer module to be a versatile and powerful navigation product in a rugged enclosure. The PC enables custom made applications to be installed and run via a Windows?-based operating systems. The PC can run software to control multi-GPS-antenna arrays and/or IMU data for positioning and attitude determination.

Figure 5: Computer Module

Two NovAtel OEM4-G2 GPS cards are installed to provide GPS-data for position and heading calculation. These cards are capable for DGPS using the OmniSTAR space based DGPS service, which is supported via a L-band receiver card.
The unit can be configured with six RS-232 ports for external devices. PS/2 and VGA ports act as user interface to standard keyboards and displays. Up to 8 GB removable compact flash card memory is used for data storage. The compact flash uses a full, single slot PCMCIA interface allowing the use of an external CD-ROM, a SCSI drive or other PCMCIA devices.
The enclosure is compact at 250 ? 244 ? 52 mm? in dimension and 2.41 kg in weight. The unit is EMC tested to military standard.

GPS Receiver Card

The OEM4-G2 is a high-performance GPS receiver capable to receive and track the L1 C/A Code, L1 and L2 carrier phase, and L2 P Code (or encrypted Y Code) of up to 12 GPS satellites in parallel.
It has RS-232, RS-422 and USB standard interfaces and is programmable for user's customization. The data rate is up to 20 Hz for raw data and position output.

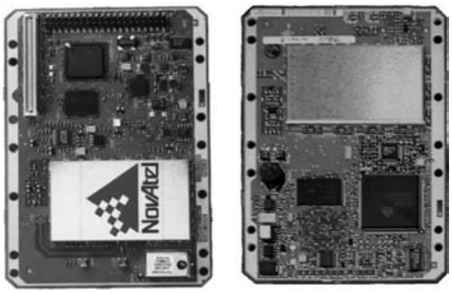

Figure 6: OEM4-G2 (Top / Bottom)

L-Band Receiver Card

The CPUPak-4 also includes a card which receives L-Band signals for differential corrections for DGPS.

Inertial Measurement Unit

The Inertial Measurement Unit (IMU) is housed in the IMU enclosure that provides a steady power supply to the IMU, which decodes and times the IMU output data. The IMU itself consists of three accelerometers and three gyroscopes (gyros) so that accelerations along specific axis and angular rotations can be measured.

Figure 7: IMU-G2

The three gyros are based on ring laser gyro (RLG) technology. A 100 Hz raw data and solution output is provided. All data are GPS time referenced. The interface is RS-232 or RS-422 compatible.
A single cable connection is necessary to the NovAtel GPS receiver for power and communication interface. The enclosure is compact at 160 X 160 X 100 mm^3 in dimension and 3.4 kg in weight.
The IMU-G2 provides an attitude accuracy for
- Pitch: 0.015°,
- Roll: 0.015° and
- Azimuth:0.05°.

Radio Data Modem

The radio data modem transfers digital data between physical locations where wire connections are impractical or too expensive. It incorporates an intelligent packet controller, a fast, frequency synthesized data radio, and supporting I/O and indicators.

Figure 8: Radio Data Modem

The radio data modem communicates with local equipment via an RS-232 data port. A second serial port is used to output special messages or as an addressable serial bus to add-on modules. 1200 to 19200 baud is available on the link side (over the air). The available frequency range is 108   512 MHz and 806 – 960 MHz.
Two radio data modems radio data modems are needed to make up point to point connections. The power level of the transmitter is 5 W. It is possible to reach distances up to 20 miles depending on topographical conditions and antenna locations.

Power Converter

The power converter includes high efficiency, reliability, low output voltage noise, and excellent dynamic response to load/line changes due to individual regulation of each output.

Figure 9: Power Converter

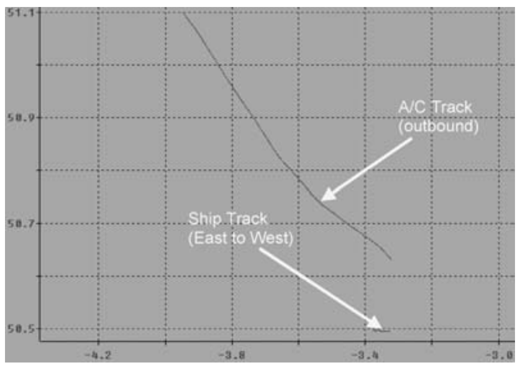

Figure 10: Ground Track of Ship and FI Aircraft

The input voltage range is 85 V to 264 V at 47 65 (440) Hz.
It is has a rugged electrical and mechanical design for operating in a wide temperature range.

EXAMPLE

A test flight with a prototype version of the GMPU without OmniSTAR HP DGPS corrections and IMU attitude data showed first results.
On figure 10 the track of the ship and the FI aircraft are shown as well as the TACAN azimuth error and TACAN distance error for a calibration performed on October 7th, 2005.
The FI aircraft was flying outbound from the TACAN antenna, which moved from east to west.
The pilot was supported from the FIS by flight guidance shown on the pilot's Electronic Flight Instrument System (EFIS) display.

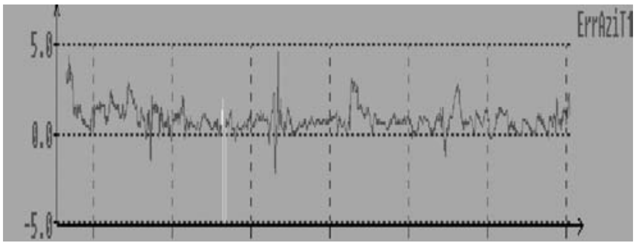

Figure 11: Azimuth Error (Detail)

This test flight shows reliable results, since the TACAN azimuth error, shown in detail in figure 11, is in general below 3.0 degrees. The distance error is smaller than 0.15 NM (see figure 12).

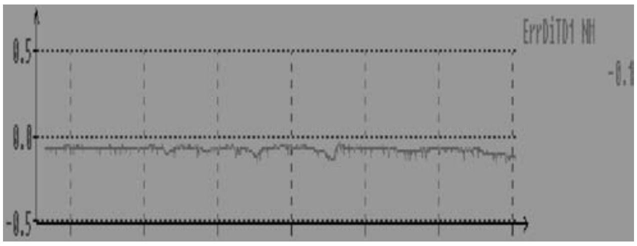

Figure 12: Distance Error (Detail)

FUTURE PAR SOFTWARE ENHANCEMENT

Flight inspection of Precision Approach Radar (PAR) facilities can be performed by PAR calibration software installed on an Aerodata FIS.
In a PAR approach the aircraft is guided by the PAR radar controller towards the touchdown point on the runway. The PAR controller continuously observes the aircraft position on the radar screens and reports to the aircraft via radiotelephony link whether the aircraft is 'On Course', 'On Glide Path' or 'On Course and On Glide Path'. In addition, he reports, when the aircraft has reached the next half-mile-interval of the distance to the touchdown point.

The FI-operator on board the FI aircraft must confirm each report with a keystroke on the corresponding function key. By doing this the aircraft position information relative to the PAR facility is sampled. An estimation about the positioning error of the radar can be made.
In addition to the PAR approach, calibration procedures for determining the radar coverage are available.
During the calibration flight PAR parameters are recorded and processed in real-time. At the end of each calibration flight a post processing is started and a mean value calculation of calibration parameters is made. At any time PAR characteristics are available in graphic or alphanumeric form.
Possible flight profiles for PAR calibration are:

- Approaches
- Orbits around the airfield
- Level Runs: Approaching the runway and flying over in constant altitude

On ships like aircraft carriers the PAR calibration is a somewhat different new task. Since the 'runway' is in motion and the aircraft to land flies towards a deck that moves along, up and down more parameters like the ship's attitude and its moving position must be concerned.
This is done in calculating the lever arm between PAR antenna and GPS position reference for every epoch of observation.
The FI software will supply:

- PAR WGS84 position
- PAR distance
- PAR reference distance
- PAR distance error
- PAR azimuth
- PAR reference azimuth
- PAR azimuth error
- PAR elevation
- PAR reference elevation

CONCLUSION

Calibration of moving platform NAVAid facilities like TACAN are now available with the known FIS software features. No hardware changes on the airborne side have to be carried out.
A single man portable, rugged Ground Mobile Positioning Unit (GMPU) provides the FI aircraft with all relevant information to acquire reference values for the flight inspection. Necessary GPS- and UHF-antenna installation may be permanent on the ship.
First tests show reliable results for TACAN azimuth error and TACAN distance error.
An enhancement to PAR inspection capability is planned for the year 2006.

REFERENCES

[1] DYBEK, J. (2005), "Specification of Moving Platform Calibration Hardware and Software", SPEC-FIS-746, Aerodata AG, Braunschweig, Germany