PRESENT ACHIEVEMENTS OF THE EXPERIMENTAL NAVIGATION SYSTEM TAG

M. Wis, L. Samsó, E. Aigner, I. Colomina
Institute of Geomatics
Campus de Castelldefels
Av. Del Canal Olímpic, s/n
E-08860 Castelldefels, Spain
http://www.ideg.es

Keywords: GPS/INS, IMU, Hardware, Software, Experimental, Real-time, Navigation, Acquisition

ABSTRACT

The Institute of Geomatics (IG) operates the experimental hardware TAG (Trajectory, Attitude and Gravimetry) for GNSS/IMU data acquisition, developed during several projects in the field of inertial navigation in photogrammetry and remote sensing, sensor orientation and geodesy. The hardware basically consists of commercially available devices. The IG has a set of inertial measurement units (IMU) available that cover the whole range of the quality and price spectrum, in order to be able to give answer to the wide demand in the field of inertial navigation research and development. The software is the result of IG development work and ensures time synchronization of the measurements obtained, data capturing for post-processing and operation in real-time mode. The system is open to extension with new sensors and to modification to new applications. This paper gives a summary of the TAG elements and their architecture, of the system's functionalities and potential, of some of the experiments in which it was involved, and it will give some results of a real time experiment conducted**.**

1 INTRODUCTION

The Institute of Geomatics (IG) is a public consortium between the Generalitat de Catalunya (the autonomous government of Catalonia, Spain) and the UPC (University of Technology of Catalonia). It started its research, development and educational activities in 1999. The IG, among other investigations, does research and advanced experimental development in the area of sensor integration (e.g. INS/GNSS) for kinematic positioning, trajectory and attitude determination and gravity measurement.

The research and development activities include amongst others:

- test, evaluation and integration of instruments (IMU inertial measurement units, GPS receivers and others like odometers and barometers or innovative redundant instrument configurations),
- development of algorithms and software to handle and analyse the data, computing modes and paradigms,
- feasibility studies and methodology tests for practical applications of the technology.

For such activities it is necessary to have full access to hardware and software that allows rapid implementation and testing of new ideas or new instruments. Therefore, the IG has over the last few years built up the TAG system (Trajectory, Attitude and Gravimetry), a data acquisition system to conduct applied research, testing sensors and for conducting experimental observation campaigns in various environments. The platform has a pure scientific / experimental character, is open to extensions on the hardware and software level and is under permanent development.

The development is request driven, i.e. it takes place in close collaboration with other research organizations and private companies. By means of the system and its instruments, the IG tries to give answers to actual demands and requests coming from geodesy, navigation, photogrammetry, remote sensing and others related to geomatics.

In this paper we want to give an update on the experimental INS/GNSS works at the Institute of Geomatics with the TAG system, present its actual configuration options and describe a few experiments and exemplary results.

2 ACTUAL REQUIREMENTS ON THE SYSTEM

Most frequent demands are:

- Determination of parameters for direct georeferencing,
- precise trajectory determination for airborne remote sensing and land vehicles for fast and/or mobile mapping,
- gravimetry measurements for geoide determination.

The areas of actual demand mentioned above imply some particular fields of actuation, which include:

- high precision and accuracy in trajectory determination in post-processing
- real time position and attitude determination
- use of low cost instruments
- use of specially designed instruments
- use of particular configurations
- performance analysis

In the context of such a wide range of possible applications, all work on and with the TAG underlies the general implicit requirements of generality, adaptability and portability (compare Colomina et al. 1992). Generality here is understood as the capacity to master the wide range of potential applications for the TAG and a broad range of IMU / GNSS sensors. Adaptability is the capacity of the system to incorporate new sensors and methodologies. Portability means the power to run the system on different platforms and in different environments with minor or no changes.

The development policy for the TAG system described in [Colomina et al. 2002] and [Wis et al. 2003] seemed to be successful so far. The system was extended to various instruments and applications. It was used in several distinct experiments and studies on the topics mentioned above. The actual potential of TAG will be described in the following sections.

3 TAG FUNCTIONALITIES

3.1 General Architecture

The system is composed of a series of hardware (HW) and software (SW) modules (see figure 1):

a) The Control Unit (CU).

The CU, which is in charge of acquiring, processing and storing the navigation data, is based on a commercially available industrial computer with a Pentium 4 at 2.4 GHz CPU and 1 Gb of RAM inside a 4U height 19 inch rack. The CU is subdivided in a series of modules:

- **GCU** GNSS receivers Control Unit.
- **ICU** IMU control unit.
- **TSU** Time Synchronization Unit.
- **OIU** Operation Interface Unit.
- **RNU** Real Time Navigation Unit.

High development efforts could be avoided by relying on a series of HW components based on Comercial-Off the Shelf (COTS) devices, which guarantee the desired functionality.

b) The Power Unit (PU)

The function of the PU is to supply the control unit and the sensors with the power they need for operation.

The PU is subdivided into the following modules:

- **BPU** Basic Power Unit**.**
- **UPU** Uninterruptible Power Unit.

c) The sensors.

TAG is capable of capturing data from various types of external sensors. This includes for example GNSS antennas, inertial measurement units (IMU), digital cameras, odometers or digital compasses and barometers. It is one of the key design issues of TAG to be open to multiple sensor use and to extensions with new types of sensors.

While the HW components basically consist of COTS devices, the software for TAG is the development work of the Institute of Geomatics. The challenge here is that the system can be operated in various modes and for quite distinct purposes with multiples sensores and sometimes in real time. Figure 2 gives an overview on the SW configuration. The details of the elements will be described further on.

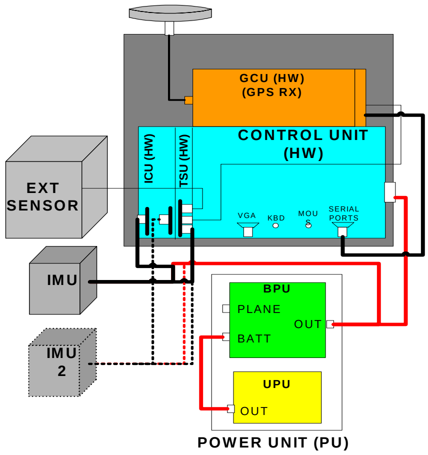

Fig.1- HW configuration diagram

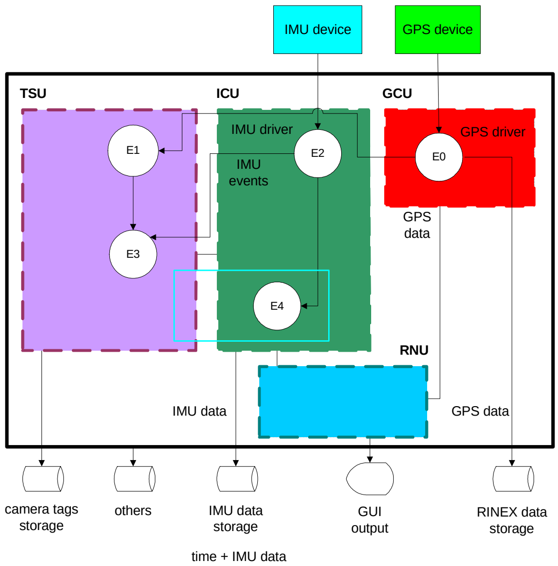

Fig.2 - SW configuration diagram

3.2 GNSS/INS data capturing

The GNSS receiver Control Unit (GCU) consists of the GNSS receiver and a controlling SW.

The implemented HW device is a geodetic GPS receiver (Novatel Millenium OEM-3, 12 L1/L2 channels) integrated within the CU rack. The interface is composed of the data ports (RS-232) and some trigger signals.

The GCU SW is in charge of capturing all the data generated by the receiver: GPS reference time, satellites phase and code signals and ephemeredes (RINEX) and position messages (NMEA).

The function of the IMU Control Unit (ICU) is the reception of the data generated by the IMU through a specific interface. Given the large number of IMUs with different characteristics this unit should be adapted on the SW level to the specific interface of the IMU/s that is/are being used in a defined configuration.

The ICU HW is composed of specialized communications cards that receive the measurements from the inertial sensors. Currently, TAG is able to communicate with sensors that use the following protocols:

- HDLC/RS-485 (2 ports available)
- RS-232 (8 ports)
- Ethernet (1 port)
- CAN-BUS (2 ports)

These ports can be used not only for reading the IMU measurements but also for transmitting data to an external device, for example a Flight Management System (FMS) or for receiving information from other kind of sensors, as for example an odometer.

3.3 Synchronization

The Time Synchronization Unit (TSU) module is the clock of the system. It is a specific HW that is configured with the GPS time when the system is booted. The function of the TSU is to register the time when an event has happened in the system. Events are for example the measurement of a data by a sensor. This card has a stable clock in order to deliver an accurate time reference. However, in order to correct the clock drift with the even more accurate GPS time, the device has a Pulse Per Second (PPS) input channel. With the PPS signal, coming from the receiver, the time precision can be set to microsecond accuracy. The TSU also has some trigger output channels that are used for some sensors to mark the moment when they have to take a measurement or for any special signalization. The current TSU HW used in the TAG is a Brandywine PCI-Sincclock-32.

3.4 Real time navigation system

There is a large number of definitions for a real time system. It could be said that a real time system is able to respond in a timely predictable way to asynchronous events coming from outside.

Another classification inside the frame of a real time system according to their properties is, to simplify, between 'hard' real time systems (*strict time constraints*) and 'soft' real time systems (*non-strict time constraints*). An example of a 'hard' real time system could be a flight control system and an example of 'soft' real time system a data adquisition system. The TAG will be discused in terms of 'soft' real time systems.

An important issue is the operating system used. There are different types of operating systems: *on-line OS, batch OS* and *real time OS* (RTOS). The best option depends on the requirements of the application being developed.
Some of the desirable characteristics of a RTOS are: preemption, concurrency, syncronization tools, privacity, efficiency,etc.Examples of commonly used OS's for real time applications in the industry are: Windows NT, Linux RT, QNX, RT, etc. The TAG currently works with a *batch OS* : Windows NT.

Windows NT is widely applied, although it was created as a general purpose operating system . It can not be considered as a 'hard' real time system, but, as it meets some of the characteristics previously mentioned, it can be seen as a 'soft' real time system Thus, for small and non complex real time applications, Windows NT can be used. To improve the performance of the system, a real time kernel (RTK) can be introduced within this OS.

The integration of Linux RT is the next goal in the SW configuration. It is expected that the real time core will give an improved solution for the navigation and a more stable behaviour of the whole system.

The Real time Navigation Unit (RNU), that integrates an INS/GPS navigator SW, is able to process the raw navigation data acquired from the GCU and the ICU and to provide a trajectory (positions and velocities) and attitude angles.

After the habitual synchronization step, the application begins registering events in terms of time from the sensors.

The program has a multithreading performance, allowing several threads to work concurrently.

3.5 Control and Interfacing

The Operation Interface Unit (OIU) is the coordinator of the components described above. It is in charge of reading the data generated by the sensors through the GCU and the ICU and read the time through the TSU, write the acquired data to output files, and interact with the user by means a FUI (file user interface) or/and a GUI (Graphic User Interface).

3.6 Power supply

The power unit (PU) was made to measure for the CU.

One part of the PU, the BPU, is composed of two aeronautical power sources that generate all the voltages needed by the CU and the sensors. This unit is able to switch automatically between the main power and a system of reserve batteries in case main power fails or is needed to be isolated from the system.

The other part, the UPU, is a system of reserve batteries to support to the BPU when the main power is disconnected. It gives up to 15 minutes of autonomy to the system. It is composed of a 24V pack of 4Ah Ni-Cd batteries and the charge circuit and it is intended to work in aeronautical environments.

3.7 Sensors

TAG is capable of operating with various sensors at the same time (e.g. GPS receiver + multiples IMUs). The IG has available a pool of sensors, in particular IMUs of distinct quality and properties, the data of which is captured by TAG.

This year the IG will have 4 IMUs with distinct properties available. The objective is to have a wide range of sensors at disposition to meet the different requirements of the applied research in this field. So, this collection of IMUs will enable the use of the TAG in configuration well adapted to the actual requirements of the planned work.

The properties of the IMUs are summarized in table 1

Before using the IMU data, it is necessary to calibrate it [Salychev, 1998]. The calibration reduces the uncertainty of the observations of the sensor, which usually depends on its quality.

So, apart from HW/SW configuration a great effort has to be put into the understanding of the sensors and their calibration, before good results can be obtained.

Mark	Systron Donner	iMAR Navigation	Northrop Grumman	iMAR Navigation
Model	Motion Pak II	iVRU-SSK	LN-200	iNAV-FJI-IDEG-001
Gyro				
Bias	5 º/sec	<3 º/sec	1 º/hr	0.003 º/hr
SF (ppm)	60000	<10000	100	< 30
Noise (º/√hr)-RW	12	<3	0.07	< 0.001
Accel				
Bias (μg)	200000	<200000	300	< 5
SF (ppm)	50000	<50000	300	< 60
Noise (μg/√Hz)	700	<800	50	8
Interface	RS232	CAN-BUS	HDLC	Ethernet
Data Rate (Hz)	32	200	400	1500
Synchro signals	NO	YES	YES	YES
Size (cm)	12.8 x 11.2 x 11.6	8 x 8 x 12	8.9 ∅ x 8.5	20 x 20 x 20
Weight (kg)	1.2	< 1	0.8	5.5
Performance				
P,R (deg – RMS)	<0.5(*)	<0.1(*)	0.02	<0.01(*)
H (deg – RMS)	<1(*)	<0.5(*)	0.01	<0.01(*)
Cost (€)	2000	10000	20000	>100000
(*) These figures are estimations.				

Tab.1 – Properties of the four IMUs of the IG

In the following the IG IMUs are listed:

3.7.1 Systronner Donner MPK2

This inertial low cost measurement unit contains six "solid-state" micro electro mechanical system (MEMS) sensors. It has 3 micromachined quartz angular rate sensors (QRS) and 3 silicon (Si) accelerometers.

3.7.2 iMAR Navigation iVRU-SSK.

This is also a low cost unit that fills the gap between the MPK2 and the LN200. It is intended to be used for real time applications and stabilization, but it is also being considered to be used for direct georeferencing. Its sensors are also based on MEMS technology. The IG has collaborated with the manufacturer, iMAR Navigation, in its design. So, the instrument reflects the experiences made at both entities.

3.7.3 Northrop Grumman LN-200

This tactical grade inertial measurememt unit has ortogonally mounted 3 fiber optic FO gyros and 3 silicon (Si) accelerometers.

The device is commonly used in photogrametry applications, remote sensing surveys and frequently is one of the components in commercial navigation systems.

3.7.4 iMAR Navigation iNAV-FJI-IDEG-001.

This navigation grade IMU is the top device of the IG. The sensor is composed of high quality fibre optic (FO) gyros and quartz flexure (QFLEX) accelerometers. Its features will make this instrument a reference device for all purposes. Thanks to the collaboration with the manufacturer in its design, it is made to measure after IG specifications.

3.8 Next development steps

As was mentioned before, the TAG is a system that is continuously evolving. So, new developments that are based on the TAG are being prepared:

- The integration of a solid – state and ruggedized hard disk that will make the system suitable for utilization in harsh environments.
- The development of a “mini – TAG” to reduce the current size and weight of the system.
- The migration to LINUX OS with RT core for enhanced real-time capacities.

4 EXPERIMENTS AND RESULTS

The TAG has been used in a series of experiments and tests. By april 2004, the TAG has accumulated 18 flight-hours and numerous car and laboratory tests. In the following, a small summary of those experiments is given.

4.1 SR-IMU experiment.

One of these experiments is related with the current research on skewed redundant IMUs (SR-IMU), that the IG is carrying out [Colomina et. Al, 2003 and Colomina et al. 2004]. The TAG was used to acquire the LN-200 raw data in a flight combined with another LN-200 in a non orthogonal configuration as if they were a redundant IMU. The results of this flight showed that the measurement made by the 2 IMUs were consistent and are good enough to use them in further research for the SR-IMUs.

Fig.3 – TAG installation for skewed redundant configuration.

4.2 Van test.

Recently a test of the performance of the real time mode of TAG for a land vehicle was conducted. The test consisted of a route of about 1h near the city of Castelldefels (Barcelona - Spain). The trajectory was calculated in real time processing and raw data was stored for post-processing. The trajectory can be seen in the figures 6 and 7. Figure 7 is a zoom of figure 6 in which it can be seen the difference between the real time solution and the post-processed solution.

The TAG system and the batteries (Fig.4) were installed at the boot of the vehicle. All the devices were carefully fixed to its surface.

The IMU_Bench platform with the LN-200 mounted on it, was placed at the back of the driver seat on the floor and properly fixed (Fig.5).

Fig.4 - TAG and batteries supply installation for van experiment.

Fig.5 – LN-200 IMU mounted on to the IMU-Bench prototype.

4.2.1 Data Analysis

Once the route was finished and the data collected, the RINEX and raw IMU measurements were processed in order to compare them with the real time solution that was also stored in the TAG. Some of the results of the comparisons can be seen in figures 6, 7, 8 and 9.

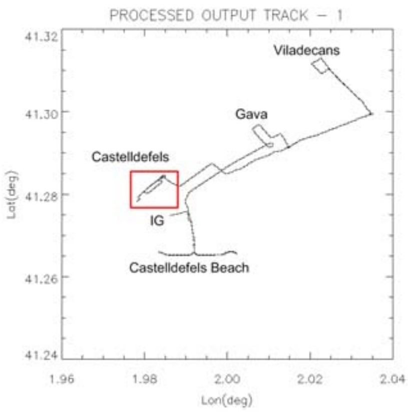

Fig.6 – Route run by the car in the experiment

The comparison of the trajectories shows that the difference in position between the two navigation solutions may vary to a maximum of about 15 meters (Fig.7). This is due to different quality of the GPS positions used in real time and in post-processing. The measurements took place in urban and sub-urban areas, where the conditions for GPS positioning are not optimal (satellite visibility, multipath). It is assumed, that the post-processing solution for the GPS trajectory is more precise. So, given that the GPS trajectory is an important part of the navigation processing, the cause of difference in position is known.

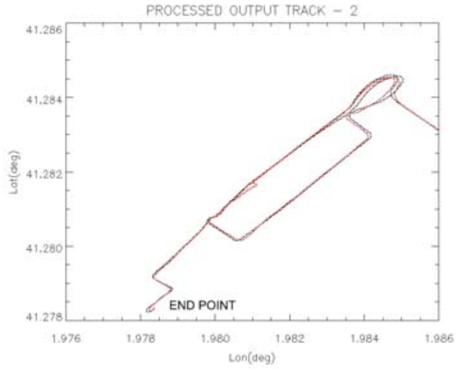

Fig.7- Zoom of experiment route. In Red it is marked the real time solution, for comparison purposes.

For the attitude angles the performance in part is good. The maximum difference between the real time and the post-processed pitch and roll is about 0.2 degrees (Fig.9). The heading varies about 1 degree, which is again due to the imprecision of the real time GPS trajectory when working in urban environments. That trajectory is internally used by the navigator for self-calibrating of the heading gyro.

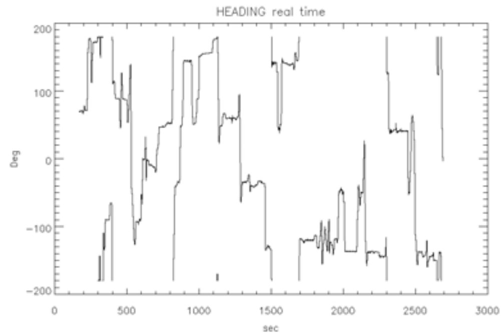

Fig.8 - Real time solution of heading angle.

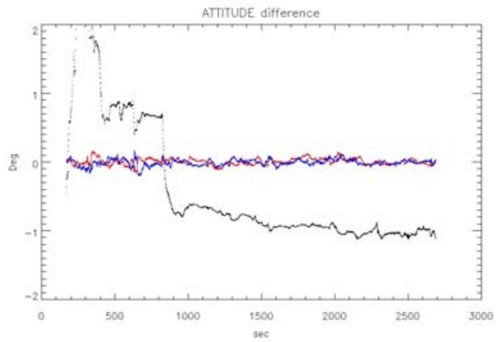

Fig.9 - Comparison of attitude angles between real time solution and post-processed solution. The black line is heading, the red one is pitch and the blue one is roll.

Only a short analysis of the results could be carried out for this paper. We will conduct a more detailed analysis in the close future.

4.4 Future experiments

In addtion to this, TAG is also being used in GeoPIE project, where it is helping to develop the navigation model of a remote sensor. In this case, two flights have been carried out with the

TAG and the LN-200 to evaluate the performance of this device. The data of the April 2004 flight is under evaluation. First preliminary results might be presented in the close future.

As for the future experiments in which the system is going to be used, two of them are remarkable. The first one will use the LN-200 for evaluating strapdown gravimetry methodology for computing a geoid model of Bolivia. For this project, the TAG will be used in a gravimetric measurement flight in Bolivia. The feasibility study will reveal the system's capacity to deliver gravimetric information in airborne platforms.

As good understanding of the IMUs is a key to good performance of inertial navigation, the IG is about to carry out a new experiment (GP-IMU-Bench) using TAG for capturing the raw data of all 4 IG IMUs (LN-200, Motion Pak 2, iVRU-SSK and iNAV-FJI) in the same flight. The aim of this project is to have a dataset that allows to compare the performance of all IG IMUs under the same conditions and then use the results to support the other projects in which the TAG is being used.

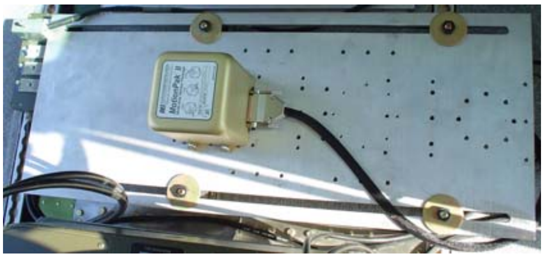

Fig.10 - Motion Pak 2 on IMU-Bench.

It is intended to extend the field of actuation for the TAG system to the following fields in future experiments / projects:

- land vehicles
- robust / absolute navigation with high end IMU
- further work with low cost instruments
- further work with object oriented real-time algorithms.

5 CONCLUSIONS

With the TAG system the IG has a flexible and extensible system available for applied research purposes in inertial navigation. Given the numerous sensors of various kind and quality that can be connected to the system, it can be used in a wide range of experiments and research. The system's applications can, for instance, be found in direct georeferencing of remote sensors, precise navigation, stabilization, strapdown gravimetry, real time solutions, etc. The system consists mainly of COTS HW components and own software developments for the drivers, the specific applications and the real time engine. While it proved its capacities in various experiments, further development and extensions for applied research and development purposes are planned in the close future.

REFERENCES

Bailey, D.L., Buhr,R.J.A.,1998. Introduction to Real-Time Systems:From Design to Networking with C/C++, Upper Saddle river,NJ: Prentice Hall.

Colomina, I., Navarro, J., Térmens, A., 1992. GeoTeX: a general point determination system. *In: International Archives of Photogrammetry and Remote Sensing*, Vol. 29-B3, ISPRS, pp. 656-664.

Colomina, I., Creixell, F., 2002. A general INS/GPS system for remote sensing and geodesy. ISPRS Commission I Midterm Symposium, Denver.

Colomina I., Giménez, M., Wis, M., Rosales, P., 2003. What can a skewed redundant IMU configuration do for photogrammetry? *ISPRS Workshop WG I/5: Theory, Technology and realities of inertial / GPS sensor orientation*. Castelldefels. Spain.

Colomina.I., Rosales, J.J., Gimenez,M.., Wis,M., Gómez,A., Miguelsanz, P., 2004, Redundant IMUs for precise trajectory determination. *ISPRS congress 2004*. Istanbul. Turkey

Fisher P., 1998.A comparison of approaches. Real-Time Magazine 1998.

Kornecki J.A.,Zalewski J.,2000. Real-Time Software Development - concepts,design,implementation. *The 22nd International Canference on software engineering ICSE*,Limerick (Irland),June 5-6,2000.

Petovello,M.G,Cannon,M.E,Lachapelle,G.,Wang,J.,Wilson,C.H .K.,Salychev,S.O.,Voronov,V.V., 2001. Development and Testing of a Real-Time GPS/INS Reference System for Autonomous Automobile Navigation. *Proceedings of ION GPS-01*, Salt Lake City, UT,September 11-14,2001.

Salychev, O., 1998. Inertial Sensors in Navigation and Geophysics. Baumann MSTO Pres, Moscow, 1998.

Schnider S., 1998. Concurrent and Real-time Systems. New York:John Wiley & Sons.

Wis, M., Colomina, I., 2003. TAG (Trajectory, attitude and gravimetry). El sistema de captura de datos de navegación delInstitut de Geomática. *5th Geomatic Week*. Barcelona. Spain.

ACKNOWLEDGEMENTS

The TAG experimental system has been continously developed since 1999 as an internal development project with the support of a number of European (European Regional Development Fund) and Catalan (DURSI) research funding organizations.

The research reported in this paper has been as well partially supported by the Spanish Ministry of Science and Technology, through the OTEA-**g** project of the the Spanish National Space Research Programme (reference: ESP2002-03687).

The IG does not intend to compete with existing or future commercial inertial/GNSS systems with the developments described in this paper.