THE GEOMATICS INSTITUTE: RESEARCH AND TEACHING AT THE SERVICE OF SOCIETY

Ismael Colomina*, Magda Martí, Edgar Aigner*** and Michele Crosetto*****

The Geomatics Institute is a public consortium formed by the Technical University of Catalonia (UPC) and the Generalitat of Catalonia. It was created by Decree 256/1997 of the Generalitat of Catalonia of 30 September 1997, and became operative in 1999. Geomatics is the science and technology that studies geographically referenced information. The Institute has two operating units (research and teaching) and two small support units (FORMA and TI), whose work is coordinated by the management team. This article describes the general organisation of the Institute and its most important lines of research, exemplified through two specific projects.

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* Ismael Colomina is the Director of the Geomatics Institute (Mediterranean Technology Park - E-08860 Castelldefels). The Geomatics Institute is a public consortium formed by the Technical University of Catalonia (UPC) and the Generalitat of Catalonia.
** Magda Martí is the Manager of the Geomatics Institute.
*** Edgar Aigner and Michele Crosetto are researchers at the Geomatics Institute.

1. Introduction

Geomatics is the science and technology that studies geographically referenced information. Geomatics deals with the gathering, storage, organisation, modelling, analysis, dissemination, management and use of spatial information. It includes traditional disciplines such as cartography, geodesy, topography, photogrammetry and navigation, in addition to modern disciplines that have emerged in the last third of the 20th century such as remote sensing, geographic information systems and satellite navigation.

The geomatic disciplines can be divided into three main areas: geodesy and navigation, photogrammetry and remote sensing, and cartographic modelling and representation. Geodesy studies the figure of the earth and its gravitational field. Among other functions, geodesy tells us where we are in relation to the space-time framework defined by the earth and its gravitational field. Modern geodesy is very precise and – among other applications – it is a tool of geophysics and navigation. Modern navigation, in turn, tells us where we are with great precision, reliability and speed, so it has become an essential tool in transport and in many other applications. Photogrammetry and remote sensing allow us to observe the earth with different criteria and at different scales. They are the fundamental tools of fields such as cartography, territorial management and environmental management. Cartographic modelling and representation allow us to create, view and use models of the earth's surface and the natural or artificial objects that it contains.

The above definition, information and classification are probably too general. What in fact does a research centre like the Geomatics Institute do? This article attempts to explain this and to introduce the readers to the fascinating world of geomatics and the research that is done at the Institute. To give a brief idea, it could be useful to describe briefly the last two projects that were undertaken by the Institute. Both Galahad and IADIRA, are projects that fall within the European Union's Sixth Framework Programme for Research and Technological Development.

The Galahad project (Advanced Remote Monitoring Techniques for Glaciers, Avalanches and Landslides Hazard Mitigation) is a STREP (Specific Targeted Research Proposal) of the European Union's Sixth Framework Programme for Research and Technological Development. It is dedicated to the development of two terrestrial remote sensing techniques, interferometric lidar and radar, applied to risks related to avalanches, landslides and glacier movements. Five research centres and companies of Italy, Austria, Switzerland and Spain participate in this project. The Geomatics Institute will contribute to the development of new tools for analysing terrestrial interferometric data and the integration of the data acquired by interferometric lidar and radar, and will be responsible for analysing the quality of the data and validating the two techniques.

The IADIRA (Inertial Aiding – Deeply Integrated Receiver Architecture) project, commissioned by the Galileo Joint Undertaking to the company Deimos Engenharia (Portugal) and to the Institute, will investigate concepts and develop technology for the future receivers of the Galileo system. In this case, the work of the Institute's researchers will consist in selecting and integrating sensors, carrying out the mathematical modelling for them and developing the algorithms.

Geomatics is now an expanding sector and it is going through a golden age due to an accumulation of internal and external circumstances.

In the last two decades geomatics has accumulated technological knowledge and developed components for the modelling and integration of instruments. The result of this process is a complex discipline that brings together multidisciplinary working groups dealing with a wide variety of activities. Geomaticians can develop hardware and software systems, mathematical models, algorithms and production procedures. They can also, of course, produce spatial information, carry out data engineering, etc.

2. The evolution of geomatics: between technology and the market

Geomatics is now an expanding sector and its evolution is dominated by the trends of technology and the market. In fact, it is going through a golden age due to an accumulation of internal and external circumstances.

Firstly, it is subject to major technological trends, such as the rapid development of information technologies and the consequences that this has on the cost, dimensions, capacity and speed of processing and gathering data; the availability of cheap and precise Global Positioning System (GPS) units; the development of the technology of sensors and data merging; the growing ease of access to aerial and spatial imagery; and the development of information management systems, in particular Geographic Information Systems (GIS). This has made it possible to develop new geomatic technologies: Earth observation with high-resolution optical and radar sensors from aeroplanes and satellites, precise navigation and geodesy by satellite, and the increasing capacity to build geographic models on different scales.

Secondly, there is a great demand in society and in the business world for geomatic information and services for applications of territorial, environmental and transport management and planning. For the geomaticians of the European Union, the current period is particularly positive because of the development and forthcoming deployment of the system of navigation and time by Galileo satellites.

Three main sectors make up the geomatics market: Earth observation, cartography and geographic information systems, and satellite navigation systems. With regard to the economic aspect (market volume and growth), geomatics is considered to be part of the information technology (IT) sector, with similar figures of growth and trends to the rest of the sector. In Europe, the geomatics market represents 2.4% of the general IT market. It should be remembered that IT is the main agent of economic growth in the European Union, that in 1998 it had a total market estimated at 148,000 million euros and a growth of 15%, and that during the period 1996-1997 it was the sector in which most jobs were created (3%).

The major trends of the geomatics market are the growing use of geographic information and the need for this information in a wide variety of management systems, the importance of the governmental sector as the main client for geomatic services, the new opportunities arising from environmental applications and navigation, the effect of the great cost of feeding in the basic information (gathering information and keeping it up-to-date), and the rapid growth of geomatic needs in Eastern Europe, Asia and Latin America.

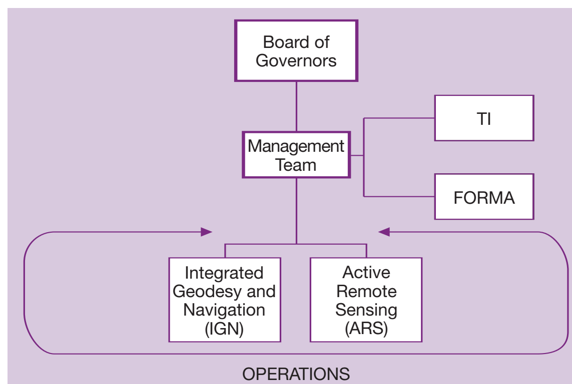
From a combination of data from different sources, it is estimated that in Europe geomatics will have a market of 71,500 million euros in the decade 1998-2007, distributed approximately between Earth observation (7%), cartography and geographic information systems (35%), and satellite navigation (58%). The satellite navigation market stands out with an average growth of 25% in the last four years. Ten years from now, in 2015, it is expected to have a turnover of 140,000 million euros, compared with 15,000 million euros in 2001.

3. The Geomatics Institute

the Geomatics Institute is a non-profit public consortium set up by the Technical University of Catalonia (UPC) and the Generalitat of Catalonia through the Department of Regional Policy and Public Works (DPTOP) and the Ministry of Universities, Research and the Information Society (DURSI). The Institute was created by a Decree of the Generalitat of Catalonia[1] and it became operative in 1999.

The Institute has two operating units (research and teaching) and two small support units (FORMA and TI). The work of all these units is coordinated by the management team (MT). The Board of Governors (BG) is the highest decision-making body of the Institute and has the highest powers of governance and administration of the consortium. The relations and dependences of these units are shown in Figure 1.

Figure 1
Administrative chart of the Geomatics Institute



The Board of Governors is composed of the Chairperson, the Minister of Regional Policy and Public Works, who delegates to the Secretary for Regional Planning; the Vice-Chairperson, the Rector of the Technical University of Catalonia; and six members, two appointed by the Ministry of Regional Policy and Public Works, two appointed by the Ministry of Universities, Research and the Information Society and two appointed by the Technical University of Catalonia.

[1] Decree 256/1997 of 30 September 1997, on the constitution of the Geomatics Institute.

The Management Team is composed of the Director, the Assistant Directors and the Heads or Coordinators of the operating units. The director, appointed by the Board of Governors at the proposal of the Chairperson, is responsible for carrying out and enforcing the agreements of the Board of Governors, proposes the policies aimed at achieving the objectives of the consortium and administers the heritage and the assets of the Institute, among other functions.

The aim of the Geomatics Institute is to carry out high-quality scientific and technological research and to foster industrial activities that involve the geomatic sciences.

The units of Integrated Geodesy and Navigation (IGN) and Active Remote Sensing (ARS) do the research and part of the teaching of the Institute. The IGN unit works in the areas of dynamic positioning geodesy (determining trajectories with inertial sensors and the GPS), physical geodesy (airborne gravimetry) and the modelling of Earth observation sensor systems (through the calibration and orientation of multi-sensor systems). The ARS unit works in two sectors of remote sensing. The first includes the processing and analysis of data from Differential Interferometric Synthetic Aperture Radar (DInSAR), mostly captured by satellite. This unit develops new calculation and analysis tools for estimating deformations and making digital terrain models. The second sector of activity is digital photogrammetry for thematic applications, such as monitoring the quality of seawater, forestry applications and precision agriculture.

The organisation of the Geomatics Institute is based on flexibility and efficacy. The focus is on the research and teaching projects and the people who carry them out. The rest of the Institute works for them with the aim of maintaining structural costs at a low level.

The Institute is located in the Mediterranean Technology Park (Castelldefels), a multidisciplinary park that – in its first stage – contains university centres, public research centres and companies with a high technology content. It occupies the ground floor of a building with a floor area of 3,500 square metres. The Institute has laboratories, classrooms and a conference room for ninety persons.

4. Research at the Geomatics Institute

In accordance with the Decree by which it was created, the aim of the Geomatics Institute is to carry out high-quality scientific and technological research and to foster industrial activities that involve the geomatic sciences. The Institute therefore carries out research oriented towards geomatic technologies and applications in close cooperation with the public administrations and companies.

In the medium and long term, the research capacity of the Institute will include geomatics in general, placing emphasis on achieving excellence in some of the its areas. At present, as can be deduced from the name of the research departments, the Institute concentrates on aspects of geodesy, navigation and remote sensing.

The research carried out by the IGN unit includes elements of geodesy, navigation and remote sensing for the positioning, navigation and orientation of sensors. It works with inertial navigation, satellite navigation and sensor modelling technologies.

The ARS unit specialises in Earth observation by means of active sensors, i.e. sensors that emit signals and record their reflection by the Earth (or by other objects). The ARS unit has specialised in Synthetic Aperture Radar (SAR), and in particular in Differential Interferometric SAR (DInSAR).

As the best way to illustrate these activities is to explain projects that involve them, we have chosen one example per unit. For the IGN unit we will present the TERRA project, which studied the feasibility of a new technology for establishing a reference framework of altitudes for Bolívia. For the ARS unit we will describe the ARGOS project, which studied and used advanced DInSAR techniques to manage the risks related to terrain deformations and subsidence.

4.1. The TERRA project: a framework of reference of altitudes for Bolivia

On 21 September 2004, an aeroplane of the air force of the Republic of Bolivia flew from the airport of El Alto in La Paz to the airport of Rurenabaque, a small city in Amazonia. The plane was carrying an unusual cargo and crew. Two of the crew members were researchers of the Geomatics Institute. Their mission – a geodesic experiment – was to measure the gravity along the trajectory of the plane that was flying over the Andes and Amazonia. The plane's cargo was not arms but scientific instruments: an experimental system of inertial sensors and high-precision GPS receivers. The system, called *trajectory-altitude-gravity* (TAG), was the result of years of work of careful design and integration in the laboratories of the Institute. While the plane was flying and the TAG was collecting data, units of the Military Geographic Institute (IGM) of the Republic of Bolivia recorded signals from the GPS system for integration and subsequent processing with the data from the airborne unit. The plane had previously undergone the delicate operation of installing a GPS antenna in a pressurised cabin.

In the TERRA project, the Geomatics Institute intended to break with the idea that geoids were always expensive by using the kinematic measurement of gravity with airborne inertial analytical systems as an alternative to static terrestrial measurement.

The mission of the flight from La Paz to Rurenabaque, and of two other flights of similar characteristics in other areas, was to obtain the data for the experimental part of the TERRA project. One of the objectives of this project was to analyse from a plane the feasibility of measuring gravity in movement using the sensors of an inertial navigation system. If the experiment and the study confirmed this, the technology could be applied to the whole of Bolivia, and with the measures of gravity thus obtained one could calculate, i.e. establish, a reference framework of altitudes, or a vertical reference framework, for the whole territory. In turn, this reference framework and the use of the GPS system would allow the centimetre-level georeferencing of objects in the whole territory of Bolivia.

The TERRA project was promoted by the Geomatics Institute; in a second stage, the Institute was awarded the project in a public competition limited to Spanish organisations. The project was funded by means of a donation by Spain to Bolivia from the Feasibility Study Fund (FEV) within the Development Aid Fund (FAD).

The TERRA project is a good example of what can be achieved by geomatic research and production, and what can be demanded of it. In order to carry out a project of the characteristics of TERRA, in addition to resolving technical and scientific problems, one must deal with the administrative, legal and logistic problems of operating at an international level. We will now study the content of this project in detail.

The readers of this article may be wondering why a geomatics research centre made a feasibility study like this in a developing country? Should not feasibility studies in these countries deal with infrastructures? This is a good question, but the answer is obvious because three-dimensional positioning systems are infrastructures of modern societies and have a high/very high return factor, as communications networks. In fact, geodesic infrastructures – and in particular positioning infrastructures – have existed for centuries, but the arrival of GPS has brought them to the forefront. What previously took days is now instantaneous with GPS navigation satellites, or rather it is partially instantaneous, because the elevations and altitudes of GPS are geometric and not, for example, orthometric.[2]

Vertical analytical reference frameworks – commonly known as geoid models or simply geoids – are a key element in a modern positioning or geodesic system. With an analytical reference framework, the instantaneity of GPS positioning can be maintained because one merely needs to transform coordinates through the numerical algorithms of geodesy.[3] The combination of GPS technology and the geoid is excellent in almost all senses. It is estimated that a hybrid, three-dimensional geometric and physical reference framework that can be established through the use of GPS and the geoid can reduce the costs of cartographic projects by 30% and that of civil engineering projects by up to 2%.

It is true that there are global geoid models for the whole earth, but they do not have sufficient precision, resolution or homogeneity for a three-dimensional geodesic infrastructure. The problem is to calculate local geoid models with high precision and resolution. And all of this loses its validity if the cost of creating the geoid model is greater than the benefits of its use. This was the case until only a few years ago, when the only technically feasible method for establishing the geoid model was that based on terrestrial gravimetry, which cannot be used in large areas or ones with a complex relief. To obtain reasonable precisions with this methodology, one must measure gravity values in a network of points that cover the territory with a density of no less than one

[2] Orthometric elevations refer to the average sea level. They are useful for the great majority of applications, such as building canals, ports and roads.
[3] There are other types of reference framework, such as levelling networks formed by land signals. Nevertheless, a geoid model fits into a computer file and is processed using a formula, whereas the same cannot be said of a levelling network.

point every 5 or 10 km. Due to the size of Bolivia, this means between 10,000 and 40,000 points, many of which would be located in zones of very difficult access (the Andes mountains, the Amazon jungle). It is therefore obviously an unfeasible undertaking.

In this project, the Geomatics Institute intended to break with the idea that geoids were always expensive by using the kinematic measurement of gravity with airborne inertial analytical systems as an alternative to static terrestrial measurement. The observation of gravity from planes solves the problems of terrestrial observation. However, because it was a new technology and the area to be covered was large and had great variations in relief (from the Andes to Amazonia), it was necessary to make a feasibility study before using the technology on a large scale in a national project.

The TERRA project thus consisted in the analysis of the airborne inertial gravimetry in comparison with conventional gravimetric methods as an alternative measuring technology for a possible future project to determine the geoid of Bolivia. From the technical viewpoint, the project involved four challenges: the analysis of the current reality and the future geodesic needs of Bolivia (a task of specification), the correct numerical simulation of the establishment of the geoid (a task of modelling, software development and analysis), the carrying out of an experiment in difficult conditions with an experimental system (a task of systems development and field work), and the analysis of the data gathered (a task of analysis and empirical data modelling).

The work of specification led to a characterisation of the geoid model based on its spectral density, as in shown in Figure 2.

The modelling and simulation work considered the different likely configurations of a general campaign for obtaining data in Bolivia. The effect of

Figure 2
Precision requirements of different applications of the geoid model

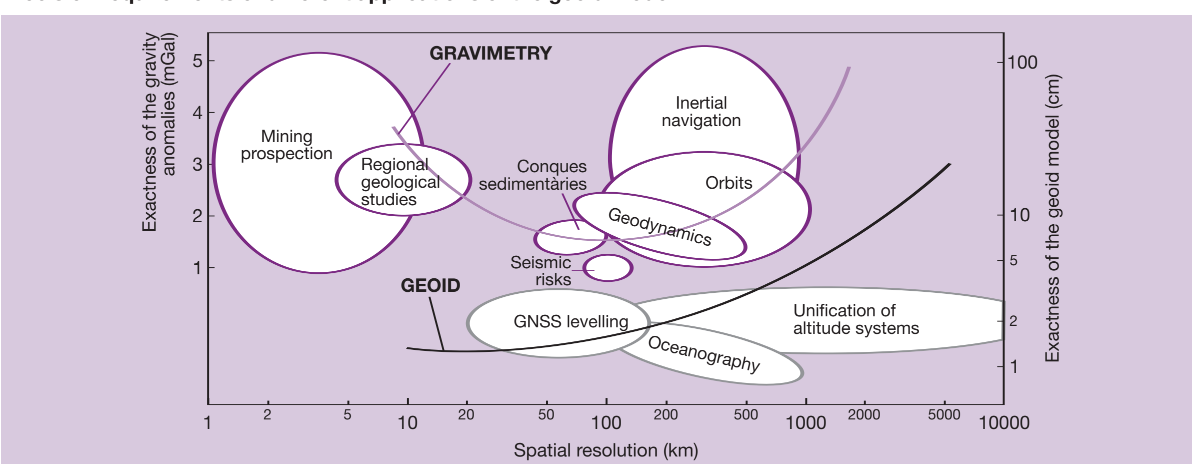
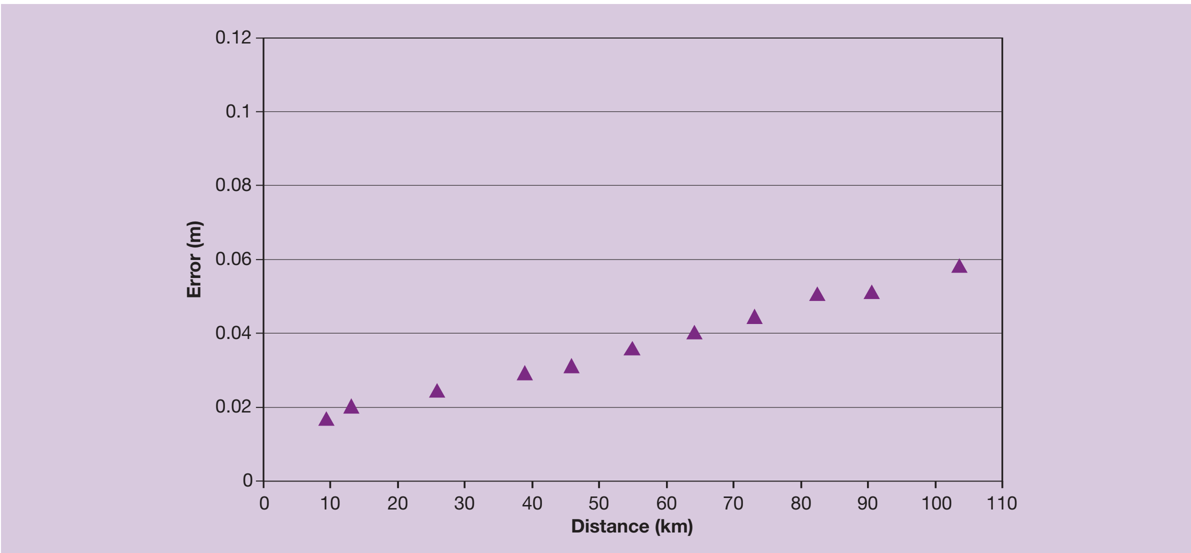


Figure 3
Simulation of the error of the geoid model according to the distance



variables such as the flight altitude, the density of flight lines and the precision of the instruments were carefully analysed. Figure 3 shows the results of one of the many configurations analysed in which, in the case considered, the specifications of Figure 2 are fulfilled.

In the near future, the result of the work carried out in the project will make it possible to set up, with a good chance of success, a measuring and calculating project to establish a geoid model of Bolivia. In view of its scope and characteristics, this future project will have to be carried out by a company or institution. This is a good example of the way in which a research centre can open paths of action.

4.2. The ARGOS project: innovative remote sensing applications for the management of natural resources

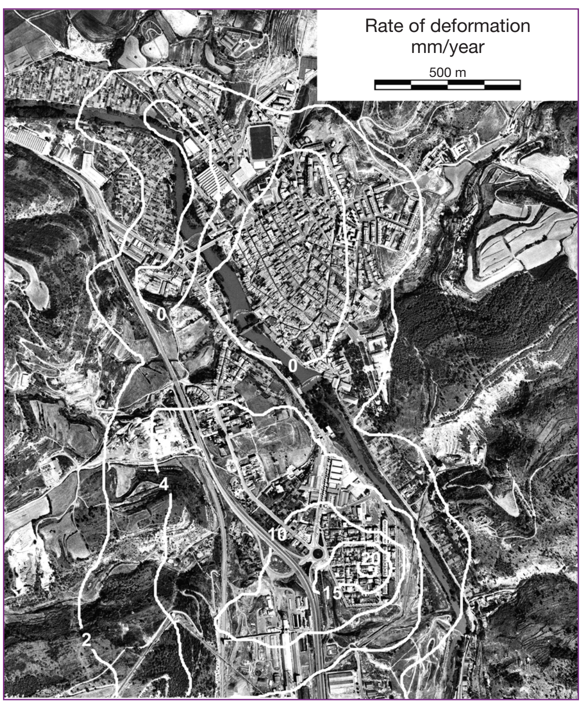
The ARGOS project[4] is a good example of an application of the technique of remote sensing developed at the Geomatics Institute. ARGOS has been a project of cooperation, research and technology development[5] in the framework of the Working Community of the Pyrenees financed by the DURSI during the period 2003-2004. The project was based on the use of SAR techniques to manage the risks related to terrain deformations and subsidence.

The chosen study area was the county of El Bages, which includes several areas affected by

[4] The full name of the project is Innovative Remote Sensing Applications for the Management of Natural Resources.
[5] Reference ITT-CTP2002-2.

phenomena of subsidence. Particular attention was paid to the area of Sallent, where these phenomena, which are monitored regularly with geodesic measurements, have an important effect on the lives of its inhabitants. The aim of this study was to provide another tool for monitoring the deformations, and to evaluate the operational capacities of interferometric techniques proposed for precisely monitoring these phenomena.

Figure 4
Average rate of vertical deformation of the land in the area of Sallent (Bages), estimated with the DInSAR technique over a period of five years.



The ARGOS project made it possible to consider two different scenarios of application of DInSAR: the detection of unknown phenomena of subsidence (or ones that are only partially known) and the measurement of known phenomena of subsidence that need a quantitative assessment, such as the subsidence of the neighbourhood of Sallent station.

Many tasks of development and research have been carried out in the framework of this project, and their efficacy has been demonstrated in the town of Sallent. Part of this town, which is located over a former potassium mine, is subject to subsidence, mostly caused by the filtration of water into the layers of the soil. Since 1997 the subsidence has been monitored regularly with an exact levelling network. This area has already been studied with DInSAR. In the ARGOS project the subsidence of Sallent, which affects approximately 1 square kilometre of the town, was used to make a quantitative analysis of the deformations based on DInSAR.

The Geomatics Institute has quadrupled in six years its volume of activity with a level of self-funding of 60-70%. In the course of this period, it has become internationally known.

Two sets of SAR data, ascending and descending, were used in order to obtain two independent estimates of the same field of deformation. The two data sets, which cover the same period, from 1995 to 2000, were processed independently, and two estimates of the rate of subsidence were obtained and compared. Figure 4 shows the result obtained with the average rate of subsidence of the land during the period observed (1995-2000). In order to assist the interpretation of this result, the rate field was superimposed on an orthophotograph at a scale of 1:5,000 generated by the Cartographic Institute of Catalonia. The quantitative comparison of the results indicates a good consistence of the two estimates, thus confirming the capacity of DInSAR for quantitative determination of the magnitude of deformation phenomena.

5. Conclusion: Where is the Geomatics Institute going

The Geomatics Institute is six years old. The comparison between the data of the early years and those of the last few years shows that the Institute has quadrupled its volume of activity with a level of self-funding of 60-70%. In the course of this period, the Institute has become an internationally known centre that is recognised for its work in its geomatic specialities. The research staff of the Institute are strongly involved in international working groups as their members or chairs. Examples of this are Comission 1 (Sensors, Primary Data Acquisition and Georeferencing) of European Data Research (EuroSDR) and Working Group 1.3 (Multi-platform Sensing and Sensor Networks) of the International Society for Photogrammetry and Remote Sensing, chaired and co-chaired respectively by members of the Institute. Also, members of the Institute are on editorial boards of journals such as *GPS World* and participate in reviews of articles of indexed journals.

In six years, thirty-five research contracts have been obtained for a value of 2.5 million euros. Of these thirty-five contracts, eighteen were established with international partners in Europe and America. Since 2000, the Institute has participated uninterruptedly in the European Union's Framework Programme for Research and Technological Development. Sixty percent of the research has been carried out in cooperation with industry, and the Institute is seen by geomatics companies as a reliable complementary partner.

In recent years, the Institute has led the process of growth of the biannual international congress called Geomatics Week, and has succeeded in arousing the interest of *Fira de Barcelona*, which decided to host Geomatics Week and accompany this congress with the GlobalGeo trade fair. The combined congress and trade fair is held in Barcelona, and in the last edition it brought together 1500 participants, including a considerable foreign contingent.

Since 2000, with its own funding, the Institute has organised the International Master of Science in Airborne Photogrammetry and Remote Sensing, which is divided into specialised subjects concentrated in weekly modules taught by international experts, and is attended by students from all over the world. Since 1999, the Institute offers a programme of continuing training that combines free lectures and short courses. Since 2004, the Institute has been a collaborating centre of the doctorate programme in Aeronautical Technologies (DOCTA) of the Technical University of Catalonia.

The activities of the Institute in the first few years of its existence have been carried out with limited resources (particularly of the research staff) that do not correspond either to the objectives of the Institute or to the budget involved in building its premises in the Mediterranean Technology Park. This temporary initial situation will be overcome with the signing of the Institute's Programme Contract, which augurs an unparalleled future: if the Institute has done so much with insufficient resources, now that it has a normal level of funding it will go on to even greater achievements.

The plans of the Geomatics Institute are ambitious. For the years to come, in the framework that will be created by the Programme Contract, the Institute has two major objectives: to reinforce research and – in very close collaboration with UPC – to include geomatics in the postgraduate courses of the European Higher Education Area.[6] Now, as in the period of its creation, the objective of the Institute is to become an international centre of reference, to make a decisive contribution to the creation of a Catalan geomatic industry of technology and services, and to develop geomatics everywhere. The original project has already been partly realised. However, the most important aspect that has been shown in the first six years is the great potential of the Institute and of geomatics, so the challenge is now both to move forward and to maintain the level that has been achieved.

[6] In other words, the so-called Bologna masters degrees.