Future of Earth Observation Systems and the Impact of Metric Satellites on Mapping Agencies

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Summary

Most satellite systems are being developed by private initiatives. This trend started in the telecommunication sector, including the television niche, where private companies invested and are still investing quite a lot on satellite constellations to provide a global service. This is now true in the earth observation sector, including positioning systems. Private ventures plan to launch multi-satellite systems for remote sensing with metric accuracy. In addition, a combination of public and private funding is going to be made available for a positioning system developed and operated in Europe (GALILEO). This trend, together with the search for synergy between military and civilian technologies may have a major impact on the mapping agencies in the world. This paper is a prospective discussion on the possible future of the geographic information sector and national mapping agencies as they are impacted by the emergence of more accurate and versatile earth observation systems.

Introduction

The first issue to be addressed is a discussion of the functional requirements of the user community and how geographic information that are created or combined from more and more diverse sources meet the user requirements. The usual answers from mapping agencies (digital image model, digital cartographic model, and digital landscape model) are discussed.

Another topic completes the scene and discusses the spread of positioning technologies, metric imaging satellites and DTM generating satellites. Mapping-related characteristics are addressed including geometric or radiometric specifications, stereoscopic capabilities, and ability to cover wide areas. Economic elements are discussed such as pricing policies, products, distribution mechanisms, and delays for producing requested raw and pre-processed data.

The impact these emerging satellite technologies have on mapping agencies is assessed through two perspectives. The production perspective analyses the impact of these technologies on the production lines widely in use in national mapping agencies. The user perspective is also interesting when assessing the influence of the satellite to NMA business: how may the availability of metric satellite images that are geo-referenced by the usage of positioning satellites cannibalise usual map market? How will the identification of geographic objects be facilitated by the availability (on the Internet) of user-friendly tools enabling users to extract just the information they require from available images? What will remain for the national mapping agencies then? How will the reasoning capabilities of information systems challenge the National Mapping Agencies to provide the information necessary to geo-reference potentially, but not yet geo-referenced, information?

Having set the scene, one can start to build scenarios of possible futures depending on key criteria. Depending on the degree technologies will spread into the user community, scenarios can be built and possible NMA strategies to face them can be devised: the ‘burying one’s head in the sand’ (the ostrich attitude), the ‘fireman attitude’ (curative attitude), the ‘insurance company attitude’ (reactive attitude) and the ‘prevention is better than cure’ attitude (pro-active attitude). Finally, how will innovation in the value adding service business secure (and economically justify) the existence of our ‘geographic information provider’ activities!

Functional requirements of the user community

Classical questions

The classical questions from a user point of view are two fold:

- The positional question: where am I, how do I get where I want to go?
- The geographic spread question: where is a given phenomena at a given time?

Cartography, either analogue or digital, is the classical way to provide answers to these questions. It requires, nonetheless, the reader’s skill to interpret maps (relating the signifier with the signified). National Mapping Agencies are used to complaints about the weakly educated user community and the need for continuous training of the users.

Fortunately, digital technologies partly compensate for these lacks and allow further queries to which answers are enabled by the analysis capabilities of modern information systems (such as what is the behaviour of a given phenomenon? What impact does this decision have on the landscape?). These technologies include functions enabling manipulation of digital geographic information (including geometric and semantic transformation, pre-analysis functions [queries, classification, measure, overlay, and so on], connectivity functions) and their analysis (interpretation of data in order to generate new information and knowledge).

How to answer

In order to allow these questions to be answered, geographic information are created or combined from a large number of diverse sources (computer assisted field work, CAD files generated by planners, aerial surveys, satellite images, as well as standard information systems). Geographic information products thus serve three main purposes that represent user requirements for:

- Contextual background: it allows the geo-referencing of user driven information, placing them into their geographical context, but forbidding any interaction between the background and the forefront.
- Identification of geographic objects: it allows the attribution (qualitative and quantitative) of geographical objects allowing interpretation by the reader.
- Structured geographic objects: it provides information on how geographic objects relate to each other, first step toward the provision of element for reasoning where analysing is computer assisted.

The usual answers from mapping agencies are threefold: digital image model (DIM) addressing the first purpose, digital cartographic model (DCM) addressing the second purpose, digital landscape model (DLM) addressing the third one.

Scanned maps, orthophotos, or space maps (the latter products being complemented by non-photo-visible information) exemplify DIM. It is a raster product used for background display.

DCM is exemplified by spaghetti data where each point, line, and polygon are attributed providing information on the characteristics of the real world objects they represent. DCM are often created from existing maps where the information is digitised as vectors representing how the information is drawn on the map. Symbols are applied to view the spaghetti data according to a user-specified legend.

DLM is exemplified by highly structured information such as the US DLG-E files, the German ATKIS products or the French BDTopo® and BDCarto®. In these cases structured datasets describe reality in an information system orientation where characteristics and relations of real world objects are modelled.

Space technologies in the near future

Positioning technologies

There are currently two operational systems for satellite based positioning systems: the US Global Positioning System (GPS) and the Russian GLONASS. GPS is largely dominating the market. It is now widely used by geographic information users to locate themselves or studied phenomena. GPS is used by National mapping agencies not only for geodetic purposes, but also for cartographic purposes such as in-situ capture of a geographic object's position for updating purposes.

In March 1998 the European Council concluded from a communication presented by the European Commission on GNSS (Global Navigation Satellite System) that a European approach to global navigation by satellite was required. In its latest communication (COM (1999) 54 final 'GALILEO – Involving Europe in a new generation of satellite navigation services' 10-02-1999), the commission said Europe is facing a key decision to develop a new system: '*The challenge consists of ensuring the European strategic requirements at low risk and acceptable costs. No decision will reinforce the US domination and will maintain Europe in a dependency situation towards the United States concerning several issues related to the European security.'*

Use of positioning techniques are spreading in day-to-day life. Satellite based navigation will increasingly have a fundamental role in many areas such as transport; it will be part of the intelligent infrastructure contributing to security, freeing traffic flow, reducing impacts on the environment and enabling multi-modal transport systems. GALILEO may substitute for existing terrestrial positioning infrastructures enabling significant savings on running costs and maintenance. Other future commercial applications of GALILEO include boating, maritime watching, merchant navy, terrestrial leisure, agriculture, geodesy, in-car navigation, fleet management, air transport and navigation. GALILEO will be a civil system open to any civil application.

GALILEO should be independent from, complementary to, and inter-operable with GPS. It should be open to non-European union members, specifically to Russia. It should use state-of-the-art technologies and should aim at a global coverage in order to ensure a real independence and offer a global outlet for applications and associated markets.

GALILEO will provide in, real time, a horizontal accuracy better than 10 m over the land areas and an independent time reference at any point of the Earth. As a compromise of cost, technical risk, and performance, it will consist of a principal constellation of satellites in medium orbit (options range between 21 to 36 satellites on a medium orbit and 3 to 9 on a geostationary orbit, depending on the level of co-operation with the Russian Federation and the US). During the 1999-2008 period, GALILEO will cost between 2.2 and 3 billion Euros being funded through a public and private partnership. European public financial sources are already identified such as AGENDA 2000 (the financial framework for 2000-2006), 5th FPRD (the framework programme for research and development for 1998-2002), TACIS (the co-operation programme with the Russian federation and other countries from the ex USSR). The European space agency (ESA) is ready to contribute. The shortfall of 1 to 1.7 billions Euros will be funded by long term loans, from international co-operators and from individual member states, to be repaid with revenues from GALILEO commercial operations.

From an organisational point of view, the European commission will make strategic decisions with the help of the current GNSS high level working party. During the preparatory period, an appropriate unit assisted by technical experts will ensure the programme management, this unit will be eventually replaced by a ‘vehicle company’ that will take over the operational duty of providing navigation services ensuring agreed performance. It will be monitored by a small GALILEO administration.

Metric imaging satellites and airborne digital camera

Table1 identifies several mapping capabilities characteristics of the most-likely-to-impact NMA systems.

Table 1: Metric imaging satellites

Satellite system	Ikonos 1 & 2	Orbview 3 & 4	Quickbird	SPOT5
Owner of the system	Space Imaging Inc.	Orbital Imaging Corporation (ORBIMAGE)	EarthWatch Inc.	CNES (French national space agency)
Date of starting operation	1994		1995	1983
Commercial organisation	Space Imaging Inc.	ORBIMAGE	EarthWatch Inc.	SPOT Image sa
Date of launch	Ik1 failed Ik2: Asap	Orbw 3: 4th T 1999 Orbw 4: 3th T 2000	4th T 1999	4th T 2001
Operational date		1st T 2000	1st T 2000	1st T 2002
Instrument			Pushbroom Linear	Pushbroom Linear
Geometric characteristic PAN XS	1 m 4 m	1 m 4 m	1 m 4 m	5 & 2.5 m 10 m
Imaging modes Snapshot: Area: Strip: Stereo:	13 km x 13 km 11 km x 1000 km	8 km x 8 km	22 km x 22 km 40 km x 40 km 22 km x 200 km 20 km x 20 km	60 km x 60 km 120 km x 120 km 60 km x 600 km 60 km x 60 km
Radiometric characteristic PAN: XS-Blue: XS-Green: XS-Red: XS-Near IR: XS Medium IR	450-900 nm 450-520 nm 520-600 nm 630-690 nm 760-900 nm	450-900 nm 450-520 nm 520-600 nm 625-695 nm 760-900 nm	450-900 nm 450-520 nm 520-600 nm 630-690 nm 760-890 nm	510-730 nm 500-590 nm 610-680 nm 790-890 nm 1580-1750 nm
Orbit Altitude: Inclination: Sun-synchronous: Average revisit	681 km 98° 10:30 (ik1) 13:30 (ik2) 1 to 3 days	470 km 10:30 equator <3 days	600 km 66° no 1 to 5 days	830 km 98° 10:30 equator 1 to 5 days
Space craft Pointing system: Fore and aft pointing capability: Side-to-side pointing capability:	Body pointed	Body pointed ±45° ±45°	Body pointed ±30° 45° max	Stearable mirror No ±27°
Design life		5 years	5 years	>5 years
Field of Regard			704 km swath	2823 km
On-board data storage			Yes	yes
Transmission policy: downlink to		U.S. ground stations located around the world and/or customer owned ground stations	EarthWatch-owned and/or customer-owned ground stations	SPOT Image main station (Toulouse & Kiruna) and/or more than 20 customer-owned ground stations
Product policy Radiometrically corrected Standard geometrically corrected Precision geometrically corrected Standard orthorectified Precision orthorectified DTM	 Yes Yes Yes Yes Yes Yes			 Yes Yes Yes Yes Yes Yes
Operationality of the distribution network	Based on IRS Landsat and radarsat network			Based on SPOT and ERS network

One must not assume that metric imaging satellites will be the only source for earth images. Airborne digital cameras will be available soon. IGN France has, for example, developed 6 in house airborne digital cameras that can be flown home and abroad. Compared with analogue photography, digital cameras enable significant relief from weather constraints. For example, the greater radiometric dynamic of digital images enables interpreters to easily perceive details within building shadows or cloud shadows.

Complementarity between images from space and airborne digital images is obvious: the flexibility of aeroplane operation for wide areas in a given country balance the easy accessibility to targeted areas by metric imaging satellites. Weather conditions and the thickness of the atmospheric stratum argue in favour of airborne technologies. Repeated surveys are, on the other hand, easier with satellite systems.

DTM generators

The shuttle radar topography mission (SRTM)

The shuttle radar topography mission (SRTM) objective is to obtain a complete high-resolution digital topographic database (DTM) of the earth. The SRTM instrument consists of radar electronics and antennas that operate from within the payload bay of the space shuttle and outboard antennas that are attached to the end of a mast that deploys out to 60 meters once the shuttle is in space. Launch date is currently scheduled 16 September 1999 and landing 27 September 1999. SRTM will use C-band and X-band interferometric synthetic aperture radar (IFSAR) to acquire topographic data over 80% of Earth’s land mass (between 60°N and 56°S) during an 11-day Shuttle mission. It will produce digital topographic map products which meet Interferometric Terrain Height Data (ITHD)-2 specifications (30 m x 30 m spatial sampling with 16 meter absolute vertical height accuracy, 10 m relative vertical height accuracy and 20 m absolute horizontal circular accuracy). Mission sponsors include US NIMA, the US space agency NASA, the German space agency DLR and the Italian space agency ASI.

Image and data products will be made available to the public through the USGS EROS Data Center for the cost of dissemination. Details concerning the distribution of the data are still being decided. It is expected to take about one year to process all the data acquired by the SRTM mission. Currently, the following types of data products are to be delivered by NIMA:

- The Level-2 Terrain Height Data Sets (digital topographic maps) contain the digital topography data processed from the C-Band data collected during the mission. Each posting in a Level-2 Terrain Height Data Set represents a height measurement in meters relative to the WGS84 ellipsoid surface. The data sets are composed of files covering areas 5° in latitude by 5° in longitude.
  - At the equator, these are spacing of approximately 30 meters by 30 meters. –
  - For data between the equator to ±50° latitude, the postings are spaced at 1” latitude by 1” longitude.
  - For data beyond ±50° latitude, the postings are spaced at 1” latitude by 2” longitude.

- The Strip Orthorectified Image Data Sets are generated during interferogram formation within the topography processor. Each data set is created from the inboard antenna data for a single sub-swath; a single file covers an area of approximately 60 km in width by 450 to 4500 km (1 to 10 minutes) in length. (Currently, data sets from different data-takes or from multiple regions of the same data-take are not mosaicked before delivery to NIMA.). The samples within the Strip Orthorectified Image Data Sets are spaced at 15 meters by 15 meters and are gridded along a local radar coordinate system.

High resolution stereoscopic (HRS)

Adding along-track stereoscopic capabilities to SPOT 5 was considered a strategic decision by SPOT Image in order to enable the easy production of digital terrain model with a 10 m accuracy. Late in 1998, CNES and Matra Marconi Space decided to embark a high resolution stereoscopic (HRS) instrument on board SPOT 5 to be launched in 2001. In the financial deal between the two partners and SPOT Image, the instrument will half paid for itself by the sale of DTM world wide. Business case shows the high revenue expectation complementarily with the data available from the SRTM.

HRS instrument has two telescopes allowing it to capture 10 m panchromatic resolution images along the track. A prism device enables the selection of which telescope will be used to send the luminous flux to the linear array of detectors (the same as used for the standard SPOT instruments HRG). This enables the capture of a 120 km x 600 km stereoscopic couple in one pass. All projections will be available upon request, the relative horizontal accuracy will be 10 to 12 m and the relative vertical accuracy will be 7 to 11 m. Relative accuracy will be independent from the scale of the map used for DTM calibration where the absolute accuracy will depend on the accuracy of the ground control points used for planimetric calibration of the images. High accuracy will be met with the use of GPS surveyed control points. The DTM will be used for impact studies, mobile telecommunication network engineering, structural geological studies, mission planning, defence simulations, and by geographic information systems.

Impact on mapping agencies

Production perspectives

The existence of modern positioning systems enables a reduction of the number of benchmarks in a geodetic and levelling network by creating a nation-wide active geodetic network. National mapping agencies were instrumental in providing highly dense networks of geodetic and levelling benchmarks. These enabled users to reference any survey to the earth within a geodetic system (ellipsoid and datum). Densities of 1 point every 3 km x 3 km square are common, at least in Europe. Global positioning systems now enable the calculation of positions (using geodetic network and soon the levelling network) with an absolute accuracy of several millimetres. Differential techniques enable users to obtain such accuracy almost in real time. The challenge for national mapping agencies is to switch from the maintenance of old-fashioned levelling and geodetic networks to active geodetic networks, that are considerably less dense (1 point every 50 km x 50 km). Active fixed beacon will compute corrections for positioning satellites and broadcast them to user receivers enabling them to acquire real time correction for the surveys they undertake. Several countries in the world are now embarking such an endeavour. Such techniques may simplify geographic object surveys such as newly built roads just by driving through them.

Digital technology in the processing of digital images is advancing rapidly. Stereo-plotters are progressively using digital images (either from space, from airborne digital cameras, or as scanned analogue photos). This enables the automation of feature extraction as well as the easy incorporation of features already in the data base. Feature extraction is quite operational for height information (contour lines) and solutions for planimetric details such as buildings, woodlands, water bodies, communication features (road, railways) are close at hand. It will lead to real 3D model of the earth where superstructures will be modelled as solids (digital elevation models). The earth surface will also be automatically extracted (if not yet available from SRTM or HRS). It will mean significant reduction of stereo-plotting steps in the production line. There will remain the costly work of including elements not visible from the air such as hidden features in woodland, administrative boundaries, or geographic names. Usage of digital cartographic systems, drawing systems, and 3D viewers enable a considerable increase of versatility in viewing geographic information as well as increasing, at the same time, operators productivity. It also enable the production of realistic images of existing or planned reality.

All these digital techniques require a change in the operator’s qualifications (from photogrammeter and cartographer skills to information system skills). At the same time, the skills required to produce geographic information may be lower, thus enabling non-mapping agency staff to produce data that meets their exact requirements.

User perspectives

The need for a contextual background may be facilitated by the availability of metric satellite images that are geo-referenced by the usage of positioning satellites. The user may then move away from scanned maps (always out of date and geometrically non-fitted with global reference systems) and use digital geo-referenced images instead. In the meantime, the image civilisation enables youngsters to be familiar with images. When they arrive at the working age, will they be accustomed to read images thus escaping from the burden of learning how to read maps?

Identification of geographic objects may be facilitated by the availability (on the Internet) of user-friendly tools enabling users to extract just the information required from available images. One could even think of a ‘LINUX’ type of approach where the Internet community generates its own geographic information and manages to get it updated in some communal fashion. What will remain for the national mapping agencies then? This may not affect the provision of topographic templates but may impact on the maintenance of that template. However, the availability of low cost professional cameras for the general public have not impacted the movie industry!

The last task (reasoning) challenges the ability to provide the information necessary to geo-reference potentially, but not yet geo-referenced, information. These links between geometry and semantics include indirect reference systems such as addresses, parcel numbers, enumeration districts and the like being themselves geo-referenced. A major challenge for the mapping agencies is to participate in the creation and maintenance of such links.

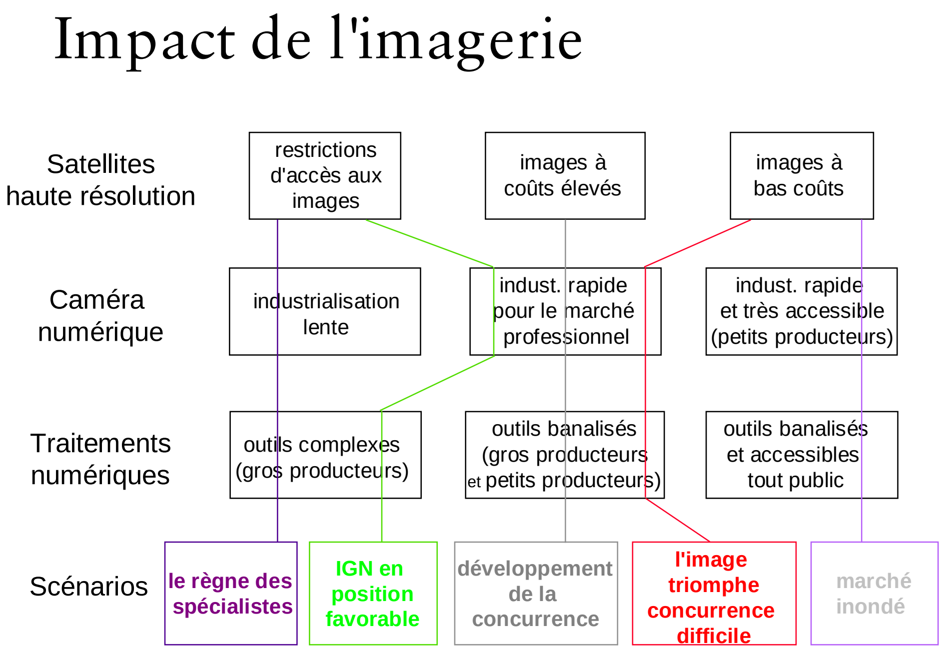
Scenarios of possible futures

Scenarios of a possible future depend on the key dimensioning criterion. Three of them are identified with regard to the impact of new imaging facilities: the metric satellites, the existence of digital cameras for aerial surveys, and digital processing capabilities.

High resolution satellites, from a technical point of view, will impact the national mapping agencies. Nonetheless several organisational elements may affect the actual image availability: access to images may be technologically of politically restricted, images may be made available at high or low cost. Digital airborne cameras may also be introduced at differentiated speed: industrialisation may be slow, rapid but costly, or quick and cheap. Tools for digital processing may have different futures. They may remain complex and only available to big players, they may become simple to use but still expensive, or they may become simple and available to any body.

The diagram below explores the impact of these hypothesis on national mapping agency. It reads as follows:

- Green situation (leftmost paths): if access to images is restricted, and digital camera industrialisation is rapid but expensive and digital techniques remain complex to use, National Mapping Agencies will remain in a comfortable dominant position.
- Purple situation (rightmost paths): if low cost images are largely available, as well as digital camera, and processing tools are banal and easy to use, the market will be flooded with geographic information. National mapping agencies will probably turn to a certification role (kind of policeman activity?)



Depending on these scenarios and their likelihood, NMA strategies to face them need to be devised:

- one can adopt a 'burying one's head in the sand' (the ostrich attitude): ignore the changes and continue as it always have been,
- the 'fireman attitude' (curative attitude): train the people to face any changes and fight the fire when it bursts,
- the 'insurance company attitude' (reactive attitude): analyse the risks and insure against changes and get the money when the change occurs,
- and the 'prevention is better than cure' attitude (pro-action): be active in the changing world and anticipate the changes; surfing on the innovation wave.

And the general public

Finally, but not the least in terms of general public products, we are not far from a single electronic device combining global positioning receiver, cellular telephone, palm organiser with colour screen which, when you switch it on, provides you immediately with the aerial view of where you stand, using the positioning antenna to determine where you are, the cellular phone to query a server to get the image, the server downloading a vertical image (map or photo) of where you are and possibly the best route for you to go where you want to go. This kind of dream illustrates what may be the only way forward of national mapping agencies: innovation into the value adding service business in order to secure (and economically justify) the existence as ‘geographic information and service provider’! Are we able, then, to determine the consequences of not having a geographic information infrastructure combining DIM, DCM and DLM all together?

Conclusion

In this paper I have deliberately taken a provocative attitude. National Mapping Agencies are entering the information society era. New ways of modelling, producing and accessing descriptions of the real world are coming. Computers are more and more common for every day tasks. But more and more people are excluded from the progress train either in developed countries or in countries in transition. How will national mapping agencies be instrumental in the reinforcement of democracy, sustainable development, and social well being, all issues high in political agendas? Will NMA convince political masters that investments on local, national regional and global geographical information infrastructure are required, geographical information being a key source for savings and not a costly burden? Technology may help in being convincing but also may turn as a lure hiding the forest of issues behind the tree of easy profit making.