"FAST MAPPING" FROM HIGH RESOLUTION SATELLITE IMAGES: A SUSTAINABLE APPROACH TO PROVIDE MAPS FOR DEVELOPING COUNTRIES

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ABSTRACT:

Imagery coming from high resolution sensors seems to become in the near future a tools to derive maps, comprehending large scales as well. At the current state-of-the-art, this dream is still infeasible: the main reason is the unavailability of stereo-pairs (barring few exceptions). Results of different researches on this topic has stated the usefulness of this kind of data to yield cartography in those countries where production based on traditional methods cannot be really afforded. This impossibility is due to the high skilfulness of operators involved in the process, to the expensive hardware required (stereo-plotters or DPW), to the availability of a company which may provide aerial photos over the interested area.
On the contrary, the use of satellite imagery is simpler: data can be purchased via Internet, choosing between different kinds of sensors and resolutions, processing can be completely performed by commercial SWs, control points can be measured by GPS, operations are simple and can be easily standardized. Furthermore, the technology transfer process from researchers to operators is sustainable.
Obviously the cartographic product that might be obtained in this way is different with respect to a numerical 3D map derived from aerial photogrammetry. The third dimension of object cannot be computed, due to the unavalability of stereo-pairs, and the pixel size does not allow to derive maps larger than scales up to 1:10,000-1:5,000. Due to difference from the traditional cartography, either in the production process and in the content of maps, we have termed such a product "Fast Mapping".

1. BACKGROUND

One of the topic challenge which have engaged the Earth Observation community in the recent years can be summarized by the following question: which is the practical use of high resolution satellite imagery (HRSI)? In spite of the large volume of research outputs yielded on this subject, the use of HRSI-derived products is relatively low.
According to some addresses given by several studies carried out at national and over-national levels (Holland *et al.*, 2002; Devriendt *et al.*, 2003; Holland & Marshall, 2003), the spatial resolution of this kind of data allows to reach the level of detail to resolve individual objects in the landscape, in a similar way than the airborne data does. As consequence, HRSI might be used as source for extraction of detailed, object-related information and for the production of large-scale maps. The pixel size of IKONOS images is corresponding to the information content of aerial images with scale 1:80,000, that of QuickBird to aerial photos at scale 1:50,000, resulting in the possibility of deriving topographic maps up to a scale in the range 1:6,000÷1:10,000. Concerning orthophotomaps, IKONOS images could be used up to scale 1:8,000 and QuickBird up to 1:5,000 (Jacobsen & Passini, 2003).
In traditionally well-mapped countries, such as West Europe and North America, where high-quality maps already exist, aerial photogrammetry is generally available and the infrastructure to process airborne imagery is well established, then the actual cost of high resolution space data is preserving its use in operational environments. The high interest in carrying on researches on this field is however motivated by the fact that the price of HRSI will lower in the years to come, as more suppliers of this kind of data will enter the market.
On the contrary, in countries where experience in mapping and aerial photogrammetry is not developed, and furthermore the infrastructure required to collect and process them is not available, the use of HRSI to derive topographic maps and orthophotos is an excellent opportunity at the present as well. In this context, satellite imagery can provide a rapid and high-quality data source for the production of different kinds of maps, such as vector maps, orthophotos, thematic maps and the like.
In this paper an approach to derive a such kind of cartography is discussed, giving some addresses to set up an operational process termed as "fast mapping" (Caprioli & Tarantino, 2001). As illustrated in the sequel, the proposed issue is not restricted to an operational concern. Recently, many papers have been reported to tackle typical problems about HRSI: *orientation* (Büyüksalih *et al.*, 2003; Fraser *et al.*, 2002a, 2002b, Fraser & Yamakawa, 2003, Tao & Hu, 2001, 2002, Valadan Zoej & Sadeghian, 2003), *orthophoto production* (Jacobsen & Passini, 2003), *image classification* (Neubert & Meinel, 2003). On the other hand, analysis of which features can be effectively and correctly derived from high resolution data is still to be further considered. Important results have been published by the Ordnance Survey of UK, which have tried to extract different kinds of features from IKONOS images (see Holland *et al.*, 2002, Holland & Marshall, 2003).
In order to better explain the topic issues of "fast mapping" (FMAPP) production process, an example of geocoded vector layers extracted form an IKONOS image will be presented along the paper.

2. FAST MAPPING GUIDELINES

The goal fo FMAPP is to provide mid-scale regional maps to countries of the so called "developing world". According to this purpose, the selection of source data, techniques for measurement of ground control points (GCPs), and processing softwares will follow accordingly.

Before decribing some practical production of a such kind of maps (from par. 3 on), basic guidelines are shown, collecting them in 5 main aspects.

2.1 Sustainable cost

It would seem an evidence that, speaking about of a cartography for the developing countries, the economic problem may represents a real bottle-neck. Results of a research project leaded by EuroSDR (Holland *et al.*, 2002) have shown a comparison between costs of upgrading topographic maps at 1:10,000 scale by means of three different data sources (we limit our interest only to products among those analysed, being the others of scarce interest for practical use):

1. aerial photos;
2. IKONOS Geo Ortho-Kit;
3. IKONOS Carterra Geo-Product ortho-rectified by PCI software.

Considering all tasks needed to upgrade maps, such as flight planning, imagery, aerial triangulation, GCP measurement, DEM, ortho-rectification and data capture/feature extraction, the process based on airborne data is the cheapest. The methods based on IKONOS data (panchromatic images at 1 m ground resolution are assumed) have results in a 56% of larger costs by using data-set (2), and only 6% larger in case (3). Authors noticed that costs of case (1) derived from a particularly favourable condition, because refers to an important mapping agency were aerial photography, GCPs, DEM and digital photogrammetric workstations are already available. The use of HRSI would be even more actractive in developing countries, where these resources are not so plentiful, resulting in the only sustainable approach to provide mapping.

2.2 Fast production process

As stated in its definition, one of the fundamental peculiarity of FMAPP is the fast acquisition process, due to the need to provide maps for large regions as well. In order to do this, the production workflow is the following:

1. satellite data acquisition (recovering of archives data or commission of a new capture);
2. GCPs measurement;
3. orientation and orthorectification (possibly the DEM generation, if not already provided);
4. data capture and feature extraction.

Concerning timely of this process, the critical stage is the data acquisition. Archives collecting already available images are directly accessible on-line via WEB by:

- Space Imaging (*www.spaceimaging.com*), which delivers IKONOS data;
- DigitalGlobe (*www.digitalglobe.com*), which delivers QuickBird data
- SpotImage (*www.sirius.spotimage.com*), which delivers SPOT-5 data.

Currently, no archive is available for Eros-A1 data, being necessary to ask vendors (www.imagesatintl.com) about which images have been already collected over the interested area.

However, in case images covering large areas are needed as in case of regional mapping projects, recent archives data will be very difficult to be found, and images must be ordered. The time nedeed to schedule the data capture over the required area may be even of a few months, and images with a too wide cloud coverage may easily happen. Nevertheless, the problem of waiting for the data acquisition exist also in case of using aerial photos.

All the other tasks need a smaller time to be completed, depending on the mapping organization and not merely on the image vendor. Furthermore, barring GCP measurement, other stages are only data processing operations, involving no logisthic and organizing problems.

2.3 Reduce need of infrastructures

The principal idea of FMAPP is the use on HRSI, avoiding the need of aerial photography and of all infrastructures connetted to this. The only HW and SW requirements are listed in the following:

- workstation for different stages of data processing;
- GPS receivers for GCP measurement (either one master and more rover stations);
- GPS data processing SW;
- SW for image registration/orthorectification;
- mapping SW for data capturecapture/feature extraction;
- GIS SW for management of the resulting spatial database and for the generation of digital and hardcopy maps.

2.4 Map contents

The basic geometric map data of FMAPP are digital orthophotos at mid-scale. It seems that for a not yet mapped region, a coverage of orthophotos at 1:10,000 scale may be a very important results for land planning and management. The availability of ortho-rectified data would allow to reduce the number of vector information to capture, with the obvious decrease of time and costs. We retain that, however, some vector layers should be derived, according to the particular needs of the country developing the mapping project.

Moreover, information about geographic names should be externally provided. Modern GPS technology have provided the users with a large variety of *GIS datalogger palm receiver*, which are able to acquire geocoded information directly on the field, by filling in a pre-defined DB. GPS signal recorded by these receivers may be processed in a differential mode, resulting in even sub-meters accuracies (depending on the distance from the master station). Thanks to a GPS receiver of such a kind, information that cannot be colletted from the imagery can be supplied and integrated in the spatial DB.

Collected vector layers and ortho-images have been thought as the initial data constituting a spatial DB, which will be then integrated by adding up further information. Each object in the database is linked to an *attribute table*, specifying some important characteristics of it. The attribute table is made up by a set of attributes which are common to all possible features. Then specialized attributes are introduced for particular kinds of features; e.g., in case of *roads*, attributes describing the class of the road, which kinds of vehicle can run on it and the like should be introduced.

2.5 Tecnology transfer

Thanks to its flexibility and independence from local infrastructures, the FMAPP process is largely prone to be transferred to the operator in the country where the project is carried on. Almost all the stages of the production workflow, barring GPS measurement, consist on data processing operations, suitable to be accomplished by means of commercial SWs. These are usually provided by ease-to-use GUI, by help and tutorial (on-site or on-line via WEB). Furthermore, the FMAPP process should include an initial training stage, where personnel involved can be adequately formed. Also operations concerning data acquisition by GPS can be performed by not very expert operators, thank to the ease on use of currently available GIS datalogger.

3. AN EXAMPLE OF FAST MAPPING

A more detailed description of the process to yield maps based on the FMAPP approach will be proposed in the sequel by presenting a pratical example.

3.1 Site selection

Due to the location of Politecnico's laboratory in Lecco (lake of Como, Northern Italy), we have preferred to use an image acquired over this area. This fact results in four main advantages:

1. a simplification in GCPs (and check points) measurement and in data acquisition on the ground by GPS;
2. the terrain presenting a very large variety of different scenarios, so that urban, rural, hilly and mountain contexts could be imaged in the same data set;
3. the large availability of other cartographic data to check the results, such as colour orthophotos (1:10,000), regional raster maps (1:10,000), vector map of urban areas (1:2,000); furthermore, new data acquisition are forthcoming and will be used for other comparisons;
4. the availability of a DEM.

3.2 Image data set

A pair of adjacent IKONOS panchromatic images have been acquired over the interested area (see Figure 1) – Lecco testfield. These data have been collected in June 2001, and are stored in the SpaceImaging on-line archive. According to the purpose of FMAPP approach, the lowest price IKONOS product has been choosen, i.e. the CARTERRA Geo product, a rectification of the image to a plane with constant height. More details about the satellite structure and the delivered data can be found in Gerlach (2000). In Table 2 some important features of the images are reported. As can be seen, images present a 1,200 m elevation range and could be considered as a very realistic test.

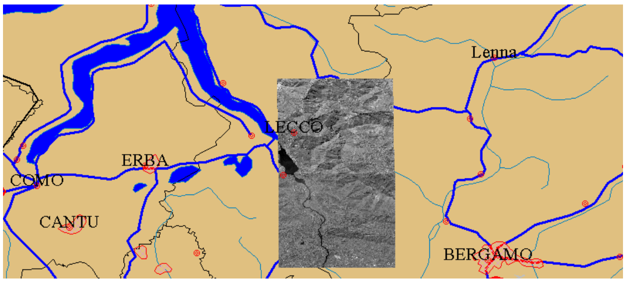

Figure 1 – IKONOS images over Lecco test field (from Space Imaging CARTERRA ONLINE).

Image Sensor	IKONOS
Image Type	Panchromatic
Spectral Range	450 - 900 nm
Processing Level	Standard Geometrically Corrected
Nominal GSD	0.84 m
Interpolation Method	Cubic Convolution
Datum	WGS84
Map Projection	UTM-32N

Table 2 – IKONOS image main features.

3.3 Orthoimage generation

The orthorectification process converts imagery into map-like form by accurately removing all camera and terrain related distortions. In order to georeferenced images acquired with spaceborne sensors, two different approaches have been developed, based on a *parametric* (physical) and a *non-parametric* (generalized) model.

Parametric models, based on the collinearity equations, are physical models that describe the physical imaging process. They need the knowledge of the sensor model and the position and the attitude of the sensor during the acquisition.

Non-parametric models are generalized sensor models (platform independent) that use general functions to compute the transformation between the image and the ground reference systems. As mapping function, the Rational Function Model (RFM), based on the ratios of polynomials with different degree, is widely used (Tao & Hu, 2001; 2002).

The sensor model for IKONOS images, as like as for the others HR satellites, is not available to users, but SpaceImaging is distributing the relation of the Geo-Image to the national coordinate system in form of rational functions coefficients (RPCs) - see Tao & Hu (2001, 2002). They do describe the scene position (r_n, c_n) as the relation of a polynomial (RFM) as function of 3D ground coordinates (X_n, Y_n, Z_n):

$$\begin{cases} r_n = \dfrac{p_1(X_n, Y_n, Z_n)}{p_2(X_n, Y_n, Z_n)} \\[2ex] c_n = \dfrac{p_3(X_n, Y_n, Z_n)}{p_4(X_n, Y_n, Z_n)} \end{cases} \qquad (1)$$

where:

$$p_i(X_n, Y_n, Z_n) = \sum_{i=0}^{m_1} \sum_{j=0}^{m_2} \sum_{k=0}^{m_3} a_{ijk} X^i Y^j Z^k \qquad (2)$$

are polynomial functions of maximum power limited to 3 and a_{ijk} are the RFCs' coefficients.

According to the purpose of FMAPP approach to provide a mapping coverage at medium scale for developing countries, where maps are aged or do not exist at all, we have chosen to orthorectify the IKONOS image with the RFM approach implemented in commercial SWs using the RFCs supplied with the IKONOS imagery and a DEM of the area with a step resolution of 50 m x50 m (see Figure 3).
Recently tests performed by the authors about QuickBird orthoimage production using non-parametric models, showed that using sequential polynomial geometric transformations, such as the RFM and the affine transformation, it is possible to obtain orthoimages with planimetric precision of about 1.0-1.5 meters using the RPCs supplied with image data and a very few GCPs (5-6 in our tests).

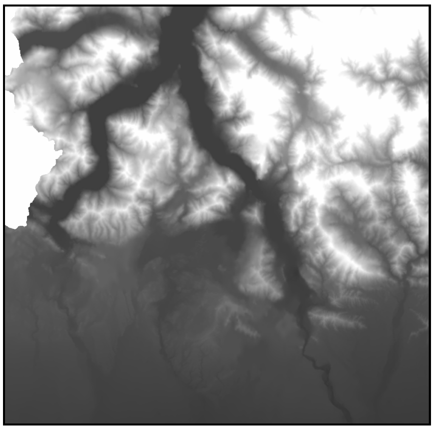

Figure 3 – DEM of Lecco test site used for orthoimage generation (step resolution of 50 m x50 m).

3.4 GPS data acquisition

GPS measurement concern two different purposes, i.e. acquisition of GCPs for HRSI georeference and collection of GIS data. Both tecniques must be used in relative mode to reach a sub-meter accuracy To do this, a *master station* consisting in a double frequency geodetic receiver must be setup. Moreover, position of the *master station* could be computed with respect to permanent GPS stations, in order to determine its coordinate in a global geodetic reference system (in practise a realization of ITRF).
Concerning measurement of GCPs, a *rover* GPS is moved over all ground control points to be measured. As illustrated in par. 3.3, HRSI can be used to generate mid-scale orthophotos based on a very small set of GCPs (usually 10-15 points per image, covering an area of about 200 km^2). The accuracy of their measurement should be better than the accuracy of image coordinate. Considering the ground pixel size of about 1 m for IKONOS, usually GCPs are manually measured so that a subpixel accuracy is very difficult to be reached. This fact leads to an accuracy for GPS measurement in the order of σ_{xy}=±40-50 cm, which can be obtnained with ease also by using L1 GPS receiver on long baselines with respect to the *master station*.
Kinematic and RTK techniques, which could be succesfully exploited in developed countries, are not yet suitable to be applied for the developing world. Firstly, the need for real time measurement does not exist; secondly online communication of differential corrections may represent a limitation, due to possible long distances involved (for radio modem) or to the the lack or the weakness of GSM signal; on the knowledge of the authors, tests about using satellite mobile phones did not yielded good results up today.
The second application of GPS in FMAPP is devoted to the acquisition of vector and GIS information to integrate the spatial DB. This task can be easily carried out by a GIS datalogger palm receiver, which allows to collect georeferenced features (points, lines, polygons) and to fill in their *attribute tables* directly on the field. Different classes of these kind of receiver exist, the most evoluted registering also phase measurement. This fact result in the possibility of signal post-processing, by differentiating it with respect to that acquired by a *master* station. Accuracy in the sub-meter order for kinematic points may be reached as far a distance of 30-40 km from the master. Moreover, some receivers (e.g. Trimble Geoexplorer CE XT) permits to determine also static points by registering several epoques during the stationement on the same position. This possibility, together with the an accuracy under 0.5 m, might lead to the use of only *GIS datalogger* as *rover receiver*, finalized to both purposes of GCP measurement and GIS data collection. Practical exploration of this chance in a testfield would be very interesting for development in FMAPP.

3.5 Cartographic reference system

The reference system of FMAPP must be linked to the use of GPS measurement for georeferencing satellite imagery, resulting in a given ITRF realization. This means that the ellipsoid to be used is WGS84.
The cartographic coordinate system which is the most suitable is undoubtely the UTM system, based on WGS84 ellipsoid (UTM-WGS84). This selection would unify cartographic reference systems used in different countries, following a trend which in European countries does as well (e.g. in Italy). Concerning transformation of points into own coordinate systems of each country, an approximate mathematical relation and one or more sets of suitable parameters should be provided. However, this problem is not typical of FMAPP only, but involves every mapping and surveying activity; in each context this concerns should be analyzed in detail.

3.6 Vector information capture

The orthoimage derived from HRSI is a potential source of a very huge information to be extracted. Nevertheless, barring the work of Holland *et al.* (2002) and Holland & Marshall (2003), a still insufficient effort has been carried out so far in analysing which kind of vector data can be derived.
We performed a small test on this topic, considering a portion of the orthophotomap generated from IKONOS image over the area of Lecco, and trying to extract vector layers typical of a 1:10,000 map. In particular, layer representing roads and buildings have been drawn.
In Figure 4 is reported a pacth from IKONOS image used for this test, showing an area typical of a mid size town suburbs, with cottages and intercity roads. In Figure 5 the same orthoimage with superimposed some extracted vector layers (buildings in red and roads in yellow) has been depicted.
Extraction of roads sounds to be the easier task, being these objects well-identified in the image background. More difficult has resulted the drawing of buildings, especially in case they are very close to each other or are partially covered by vegetations; however, in the second case the same problem would sussist also in case aerial photogrammetry is applied. The availbility of colour information would largely help in plotting, because

would allow to locate with more ease objects featuring a contrasting colour, such as roofs, trees, green area, water surfaces. A realistic possibility would be to use HRSI *pan-sharpened* images. Pan-sharpened images are generated by merging the colour information contained in the lower resolution visible (or visible/infrared) multispectral bands with the geometrical information contained in the higher resolution panchromatic band. The result of the processing is a natural (or false color) pan-sharpened image, with the resolution of the panchromatic spectral band.

It should be noticed that reported vector data directly come from interpretation of the image and have not been edited. In an operational production process, also this stage would be carried out, involving recovering of orthogonality, parallelism an the like.

In the test area, other two cartographic product were available, i.e. a colour orthophotomap at 10,000 scale and a portion of the regional raster map (CTR) at the same scale. Because these maps are geocoded into the Italian official cartographic system (Datum "Roma40" based on the Hayford ellipsoid) using a modified Gauss projection (termed as "Gauss-Boaga"), a transformation to UTM-WGS84 system used for the IKONOS orthoimage has been computed. Due to the limitation of the area, a 2D conformal transformation would result enough accurate.

Vector layers extracted from IKONOS orthoimage have been overlayed to both orthophotomap (Figure 6) and raster map (Figure 7). As can be easily understood, roads have been extracted with a high accuracy, completely conformal to tollerances adopted for 1:10,000 maps. In Italy, we usually adopt a cartographic planimetric tolerance which is twofold the size of the map resolution; in case of 1:10,000 maps, this tolerance adds up to 4 m.

Of high accuracy and completness is the drawing of building as well, in particular when compared to the orthophoto. Comparison with respect to raster map shows several differences in geometric positions of buildings, but this fact is probably not due to the quality of the IKONOS orthoimage.

Figure 5 – Overlapping of the extracted vector layers to the IKONOS orthoimage patch.

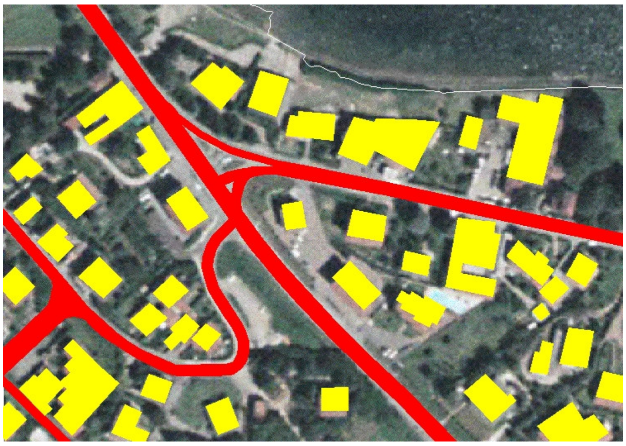

Figure 6 – Orthophotomap (1:10,000 scale) derived from aerial photogrammetry with superimposed vector layers extracted from IKONOS orthoimage.

Figure 4 – Patch of the orthoimage derived from an IKONOS over tha area of Lecco used in the test for evaluting the possibility for information capture from HRSI.

Figure 7 – Raster regional map (CTR at 1:10,000 scale) with superimposed vector layers extracted from IKONOS orthoimage.

4. OPEN PROBLEMS AND FUTURE STEPS

In the paper a sustainable approch to provide maps to developing country referred to as "Fast Mapping" has been proposed. The image data source are HRSI which are going to become more accessible in the near future, thanks to a possible reduction in price, acquisition and delivering time, ease in its processing.
In order to check possible critical topics and drawbacks in the production process, an experimental application involving an IKONOS image acquired over the area of university laboratory in Northern Italy has been carried out. Findings of this test have shown that, once the image is delivered, geocoding and orthoimage generation (if a DEM is available) can be easily performed by means of commercial software packages and by using a small set of GCPs. The quality of derived product seems to be good, either in geometric accuracy, and in the interpretability of imagery, allowing to extract vector layers. On the other hand, in case of mapping for a developing country, the avilability of a DEM with enough accuracy and resolution is the real bottle-neck. Derivation of DEM from InSAR techniques would be an interesting solution to this problem.

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REFERENCES

Büyüksalih, G., Kocac, M.G., Oruc, M., Akcin, H., and K. Jacobsen, 2003. Handling of IKONOS-Images from Orientation up to DEM Generation. In Proc. of ISPRS-EARSeL Joint Work. on "High Resolution Mapping from Space", Hannover, on CDROM.

Caprioli, M., and E. Tarantino, 2001. Utilizzo del laser-scanning per la produzione di cartografia "speditiva". Bollettino SIFET, n.2.

Carrion, D., Gianinetto, M., Colombo, A., and. M. Scaioni, 2001. Multi-spectral and multi-temporal imagery registration by image matching algorithms. International Workshop on Geo-Spatial Knowledge Processing for Natural Resource Management, Varese.

Devriendt, D., Goossens, R., Dewulf, A., and M. Binard, 2003. Improving Spatial Information Extraction for Local and Regional Authorities using Very-High-Resolution Data – Geometrical Aspects. In Proc. of ISPRS-EARSeL Joint Work. on "High Resolution Mapping from Space", Hannover, on CDROM.

Fraser. C.S., Baltsavias, E., and A. Grün, 2002a. Processing of IKONOS Imagery for submeter 3D Positioning and Building Extraction. *ISPRS Journal of Phot. & R.S.*, 56, pp. 177-194.

Fraser. C.S., Hanley, H.B., and T. Yamakawa, 2002b. 3D Position Accuracy of IKONOS Imagery. *Photogrammetric Record*, 17(99), pp. 465-479.

Fraser. C.S., and T. Yamakawa, 2003. Applicability of the Affine Model for IKONOS Image Orientation over Mountainous Terrain. In Proc. of ISPRS-EARSeL Joint Work. on "High Resolution Mapping from Space", Hannover, on CDROM.

Gerlach, F., 2000. Characteristics of Space Imaging's One-meter Resolution Satellite Imagery Products. *Int. Arch. of the Phot., R.S. and Spatial Information Sciences*, Vol. 33, Part B1, pp. 128-135.

Gianinetto, M., Scaioni, M., and A. Giussani, 2003. Cartografia speditiva da immagini satellitari ad alta risoluzione: un contributo alla ricostruzione dei paesi colpiti da eventi bellici. VII Conferenza Nazionale ASITA, Verona, on CDROM.

Holland, D., Guilford, R., and K. Murray (ed.s), 2002. Topographic Mapping from High Resolution Space Sensors. *OEEPE Official Pubblication*, n. 44.

Holland, D., and P. Marshall, 2003. Using High-Resolution Satellite Imagery in a Well-Mapped Country. Terrain. In Proc. of ISPRS-EARSeL Joint Work. on "High Resolution Mapping from Space", Hannover, on CDROM.

Jacobsen, K., and R. Passini, 2003. Accuracy of Digital Orthophotos from High Resolution Space Imagery. In Proc. of ISPRS-EARSeL Joint Work. on "High Resolution Mapping from Space", Hannover, on CDROM.

Neubert, M., and G. Meinel, 2003. Evaluation of Segmentation Programs for High Resolution Remore Sensing Applications. In Proc. of ISPRS-EARSeL Joint Work. on "High Resolution Mapping from Space", Hannover, on CDROM.

Scaioni, M. and M. Gianinetto, 2003. Fusion of aerial and satellite imagery over the city of Venezia. 2nd GRSS/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas (Urban 2003), Berlin, on CDROM.

Tao, C.V and Y. Hu, 2001. A Comprehensive Study of the Rational Function Model for Photogrammetric Processing. *PE&RS*, 67(12), pp. 1347-1357.

Tao, C.V and Y. Hu, 2002. 3D Reconstruction Methods based on the Rational Function Model. *PE&RS*, 68(7), pp. 705-714.

Valadan Zoej, M.J., and S. Sadeghian, 2003. Rigorous and Non-Rigorous Photogrammetric Processing of IKONOS Geo Image. In Proc. of ISPRS-EARSeL Joint Work. on "High Resolution Mapping from Space", Hannover, on CDROM.