A SUSTAINABLE APPROACH FOR UPGRADING GEOGRAPHIC DATABASES BASED ON HIGH RESOLUTION SATELLITE IMAGERY

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ABSTRACT

The availability of high-resolution satellite images could be exploited for upgrading geographic databases at medium scales (1:5,000-1:25,000) as alternative to aerial photogrammetry. The paper presents a procedure to carry out this task which is based on an automatic image-to-image registration procedure of new satellite data to existing ortho-photomaps that have to be upgraded. In order to get a regularization of control points extracted in automatic way, a technique implementing a neural network algorithm is applied. Once an image has been georeferenced, this can be ortho-corrected thanks to a DTM (nowadays available in almost all developed countries). However, the product which is obtained so far is still a raster maps. To cope with the increasing need of vector data in geographic geographic databases, some tests performed on the extraction of features (buildings and roads) from real high-resolution satellite images have been performed and results are shown here. Finally, to complete the data acquisition process, the use of GPS-GIS data-logger receivers in differential mode is proposed.

1. INTRODUCTION

Up today topographic maps have been derived from aerial photographs taken in film format by means of special cameras mounted on the bottom of airplanes. Concerning the mapping process, many technological innovations have been introduced in the latest 20 years. However, among these, the most important is the transition from analogue photos to digital images, which can be processed by techniques of digital photogrammetry. In the '90s, the appearance of photogrammetric scanners allowed to transform the high quality analogue aerial images into the digital form. In 2000, at the XIXth Congress of ISPRS held in Amsterdam, both major leader of surveying instruments market presented their first consumer digital aerial cameras. Actually, both analogue and digital imagery are used, but in the future the acquisition of images in digital form will become quickly overwhelming. Furthermore, the development and diffusion of direct georeferencing techniques, based on Inertial and Global Positioning Systems (INS/GPS), is leading to a photogrammetry where the sensor orientation is no more derived in a post-processing stage, but is already available just after the data acquisition stage is completed.

The use of aerial photogrammetry for mapping is widely diffused in industrialized countries, where infrastructures, instruments and skilled personnel are available (Holland *et al.*, 2002; Holland *et al.*, 2006). Not the same could be generally said for the other countries, for which a campaign to derive topographic maps is still an utopia.

Fortunately, satellite Remote Sensing (RS) has begun to provide his help. Space sensors have made their appearance in the late '50s, based on analogue cameras which through out their films on the ground (Corona project, USA); in a second phase, films were collected and printed. In the '70s and '80s, many kinds of digital space sensors were launched (Landsat, Spot, Meteosat, NOAA AVHRR, etc.), allowing acquisition of data at small and medium scale (pixel size ranging from some tens of meters up to a few kilometres). Recent advances in space sensor technology have made possible high-resolution satellite imaging systems, which become a reality at the beginning of the new century, resulting in the availability of space imagery with less than 1 meter ground resolution. With these new kind of images, one of the most fascinating task of all research communities interested in mapping has been to evaluate the feasibility of deriving topographic maps from them, as well to establish process and methods to do this.

Under usual conditions there is no problem with the mapping accuracy based on space images. The real limitation is coming from the information contents, that means, each object should be identified during interpretation (Li, 1998). We may easily detect a line, but we may have problems with the interpretation if that line is just a separation between agricultural fields or if it is a path or a road (Topan *et al.*, 2004). But the pixel size is not the only criteria for the quality of images; also the contrast is important like the spectral range and the colour information, depending upon the situation of the atmosphere and the sun elevation.

The generation of topographic maps by means of space or aerial images requires a sufficient relation between the pixel size on the ground and the map scale. In case of satellite RS, the current pixel size bounds mapping to medium scales (1:5,000, 1:10,000 and lower), which are however of great interest especially for not well-mapped countries (Gianinetto, 2008). Nevertheless, also in developed countries HR satellite could be an important contribution to the upgrade of geographical archives. Focusing on the European and in particular on the Italian reality, all landmarks are mapped at medium scale (from 1:5,000 to 1:25,000), while large scale maps exist in urban areas. Nowadays urban maps are prevalently numeric and are periodically upgraded because of the quick evolution typical of a town area. The photogrammetric data acquisition is repeated at a step in the range of about 5-10 years, and more frequent upgrade is continuously carried on by ground surveying. Not the same

happens for regional medium scale maps, which are still prevalently hardcopy or raster maps and the upgrade is very seldom performed. As clarifying example, in one of the most developed Italian Region (Lombardia) the regional raster maps at 1:10,000 scale was upgraded for the last time in 1994!
According to these considerations, currently there is a real need of upgrading the content of maps at a medium scale by a sustainable approach. Moreover, we would like to address a twofold aspect:

1. the demand of geographic databases (DBs) is continuously growing, so that vector data have to be acquired; as a consequence, existing raster map not only have to be upgraded, but also they need vectorization;
2. the widespread diffusion of GIS-based approach to cope with problems related to land management (e.g. hazard management, control of the land use, high resolution ground texture analysis to detect source of pollution) calls for the acquisition of a larger and larger number of georeferenced data. The data acquisition process typical of aerial photogrammetry is not suitable anymore to completely solve for this demand.

On the other hand, HR satellite images could be a sustainable solution to this problem, possibly integrated by other low cost acquisition techniques to complete data collection. However, the use of such kind of data is not a cheap approach on its own. Its application become realistic if would be devoted to derive vector data at a lower cost with respect to aerial photogrammetry. This is the purpose of the method proposed in this paper.
We could state three aspects which make it interesting:

1. image georeferencing technique and ortoprojection based on image-to-image registration to existing photo-based maps and on a DTM (in general both available); when photo-based maps are not available, ground control points needed for georeferencing can be measured by GPS;
2. vectorization of ortho-corrected images to derived vector data;
3. acquisition of companions data by means of low cost GPS-GIS data acquisition instruments.

However, these processes present several technical problems which have been partially afforded in previous papers and have been integrated here. In the following, different items are analysed in more detail and some application examples are reported.

2. MAPPING FROM HIGH RESOLUTION SATELLITE IMAGERY

Thanks to the decisions of U.S. Presidents Bush and Clinton operated in 1992 with the Land Remote Sensing Policy Act (U.S Congress, 1992) and in 1994 with the President Decision Directive PDD-23 (Federation of American Scientists, 2006), nowadays civil users can have access to meter and sub-meter data collected by U.S. commercial RS satellites.
IKONOS (launched on the 24th September 1999) was the first commercial satellite able to collect panchromatic images with 1 m resolution and multispectral imagery with 4 m resolution (Space Imaging, 2004).
On the 5th December 2000, ImageSat International (Israel) launched the first non-US commercial HR imaging satellite, called EROS-A1 (and then renamed EROS-A), designed to collect nadir and oblique (up to 45° angles) panchromatic imagery in a 13.5 km swath with a 1.8-meter resolution. In hypersampled mode ERSO-A provides customer-specified image acquisitions at 1 m resolution in a reduced 9.5 km swath (ImageSat, 2004).
DigitalGlobe's QuickBird satellite (launched on the 18th October 2001) was a milestone for civilian remote sensing users with its 0.61 m panchromatic and 2.44 m multispectral cameras (DigitalGlobe, 2004). However, the recent launch of DigitalGlobe's WorldView-1 (18th September 2007), equipped with panchromatic camera able to acquire images from an altitude of 496 km with a geometric resolution of 0.50 m, overcame the limit of the half-a-meter ground resolution from space. Moreover, other new satellites (e.g., WorldView-2, GeoEye-1) are already planned for launch in the next years so that the panorama of such kind of data is quickly becoming wider and wider.

2.1 Geo-processing of satellite imagery

The most interesting products which can be derived from HR satellite images are DTMs (see Zhang and Grün, 2006) and ortho-projections. In this paper we would like to focus on the second ones for the purpose of map upgrading, considering the widespread availability of a DTM in already well-mapped countries.
To carry out the orthoprojection it is necessary to have a geometric model of the sensor that is able to relate the 3-D ground coordinates to the 2-D image coordinates and a DTM. Regarding the geometric model, images acquired with spaceborne sensors are generally orthorectified using two different approaches: parametric and non-parametric techniques. The former, also called rigorous models, are based on the collinearity equations and they describe the exact acquisition geometry of the sensor. By solving a least squares adjustment, the sensor's external orientation and some additional geometric parameters are estimated. In the latter, the transformation between image and ground coordinates is carried out by some general functions, without any modelling of the physical imaging process.
If we presume that the sensor model is not available to the users, to remove the geometric distortions from the images it is necessary to collect a large number of GCPs in a conventional way, that is, through collimation of the homologous points on the maps/DTM or through specific GPS survey. Non-parametric models are of particular interest because sensor models for high-resolution satellites are really not available to users. Space companies supplies the relation of the georeferenced images to the national coordinate system in form of Rational Polynomials Coefficients (RPCs – see Fraser *et al.*, 2006). This means that using the RPCs supplied with the image data avoids to use a large number of GCPs, whose collection is a widely time-consuming operation and not always a simple task, but may not give satisfactory results in terms of planimetric accuracy. On the other hand, by computing the RPCs using a large number of GCPs and then using a non-parametric model for the geometric rectification is possible to obtain very accurate ortho-images.

2.2 The Rational Function Model

The RFM is the most commonly used non-parametric orthorectification algorithm, which is implemented in almost all commercial software packages for satellite image processing (Dowman and Tao, 2002). This technique is used by image

salesmen to allow the final user to obtain orthoprojected imagery without the need of knowing the sensor model, that is a secret in the most of cases.
The RFM allows to determine the relationship between the image coordinates (ξ,η) and the 3D object coordinates (X,Y,Z) through a set of polynomial relations as shown in the following equation:

$$\begin{cases} \xi = \dfrac{P_a(X,Y,Z)}{P_b(X,Y,Z)} \\ \eta = \dfrac{P_c(X,Y,Z)}{P_d(X,Y,Z)} \end{cases} \quad (1)$$

where P_a, P_b, P_c, P_d, are usually 3-degree polynomials

$$\begin{cases} P_a(X,Y,Z) = a_0 + a_1X + a_2Y + a_3Z + a_4X^2 + a_5XY + ... + \\ \qquad + a_{17}Y^2Z + a_{18}YZ^2 + a_{19}Z^3 \\ P_b(X,Y,Z) = b_0 + b_1X + b_2Y + b_3Z + b_4X^2 + b_5XY + ... + \\ \qquad + b_{17}Y^2Z + b_{18}YZ^2 + b_{19}Z^3 \\ P_c(X,Y,Z) = c_0 + c_1X + c_2Y + c_3Z + c_4X^2 + c_5XY + ... + \\ \qquad + c_{17}Y^2Z + c_{18}YZ^2 + c_{19}Z^3 \\ P_d(X,Y,Z) = d_0 + d_1X + d_2Y + d_3Z + d_4X^2 + d_5XY + ... + \\ \qquad + d_{17}Y^2Z + d_{18}YZ^2 + d_{19}Z^3 \end{cases} \quad (2)$$

In order to proceed with the estimation of the transformation parameters a_i, b_i, c_i e d_i (i = 0÷19), it is necessary to trigger a least squares iterative process, after having linearised equations (1), on the basis of the measurement of a large number of GCPs. To reach a stable solution for equation (1) the Tikhonov regularisation algorithms is often applied.

2.3 The Neural Network model

The Neural Network approach (NN) applied to orthoprojection can be considered an innovative attempt to solve the geometrical correction of satellite images through the use of non-parametric methods (Borgogno Mondino, 2004).
The computation process is structured as a flow of distributed information whose elaboration occurs inside dedicated calculation units, which are known as "neurons" of the network. Some of these neurons receive information from the external environment, others return answers to the environment and others, if there are any, communicate with only the units inside the network: they are called input, output and hidden units, respectively.
The neural panorama is extremely large and neural algorithms have been developed to solve very different kinds of applications. In this paper, attention has been paid to the MLP (Multi Layer Perception) algorithm to obtain a projection model that relates the image coordinates (ξ,η) to the object coordinates (X,Y,Z) through a training step on the basis of a set of collected GCPs (Bello, 1992). In the MLP each neuron performs a very simple operation that consists in generating, through a transfer function, a response to signals that converge on it through the communication channels. These channels simulate the biological synapses and their duty consists in "weighting" the intensity of the transmitted signals. Test have been made using a logical sigmoid transfer function for the hidden layer (neurons), while for the output layer a simple linear function has been considered, as shown in the reported equation:

$$\begin{cases} u_i = f(\sum_{j=1}^{N} w_{ij} p_{ij} + b_i) \\ f(x) = \dfrac{1}{1+e^{-\alpha x}} \end{cases} \quad (3)$$

where f is the transfer function, w_{ij} are the weights of the i[th] neuron, p_{ij} are the input at the i[th] neuron and b_i are scalar additives, called *bias,* that are considered as weights of unitary additional input.
The number of neurons (of the hidden layer) that drive to best performances has to be determined each time on the basis of repeated tests. Moreover, even if we are working in a non-linear ambit, it should be recalled that an approximate estimation of the maximum number of admissible neurons could be obtained by comparing the training pattern number (the GCPs) with that of the parameters to be estimated (weights and bias).

2.4 Application to a case study

For HR ortho-projection, the non-parametric RFM algorithm can lead to good planimetric accuracy but it is affected by numeric instability due to the GCP number and distribution, which may determine local image distortion. Bad configurations of GCPs can easily lead to heavy distortions over the corrected images, whilst the best results are obtained with a large number of GCPs with a regular distribution. On the other hand, the NN approach leads to a lower geometrical accuracy, but is characterized by an higher numerical stability.
As discussed before, by using the non-parametric RFMs high precision orthoimages can be obtained, but the numerical stability of the solution is related to the availability of a large GCP number, which should be also regularly distributed on the whole image. To overcome the problem of the manual GCPs collimation, authors have developed at the Politecnico di Milano a new technique, called Automatic GCP Extraction (AGE), to automatically extract homologous ground control points from satellite or aerial image pairs (Gianinetto and Scaioni, 2005; Gianinetto and Scaioni, 2008). Moreover, to manage the numerical stability of the RFM solution related to the geometrical distribution of GCPs, points automatically extracted by AGE have been regularized on a grid with a NN MLP algorithm (Gianinetto *et al.*, 2004).
The processing chain described was applied to an 1.8-m resolution EROS-A image taken over the city of Cuneo (Piemonte, Italy). This image has been orthorectified using the RFM approach and a 1:10,000 scale aerial orthophoto as reference map for the automatic detection of 192 gridded GCPs (AGE+NN MLP). Figure 1 shows the workflow of the AGE-NNMLP-RFM procedure.
To access the final geometric quality of the ortho-corrected EROS-A image, two tests have been performed. In the first, a digital map of the same area has been overlapped to the ortho-projection; the result can be seen in Figure 2. In the second, 10 Independent Check Points (ICP) have been measured on the ortho-projection for the evaluation of the geometric accuracy of the final product; results are reported in Table 1.

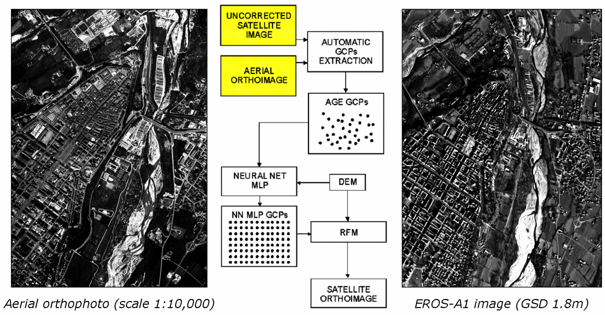

Figure 1. Workflow of the georeferencing procedure and input data for the case study over the city of Cuneo (Italy); on the left the aerial georeferenced orthophoto and on the right the un-georeferenced EROS-A image.

Figure 2. 1:2,000 digital map (white lines) overlapped to the orthoprojected EROS-A image of Cuneo, Italy.

Set of points	# of used points	Mean of residuals (pixel)		Mean of absolute values of residuals (pixel)		RMSE (pixel)
		Δξ	Δη	Δξ	Δη	Δξη
GCP	192	0.00	0.00	0.67	0.32	1.06
ICP	10	-0.11	0.30	0.18	0.20	5.42

Table 1. Statistics of residuals on GCPs used for ortho-correction and on measured ICPs.

2.5 Digital Terrain Model and satellite view angle influence: a case study

All orthorectification algorithms which are based on non stereoscopic image processing need a DTM for the Z coordinate computation. Usually, the DTM does not take into account buildings, so, in an urban area, orthorectified satellite images are also affected by geometric errors related to the poor estimation of the Z coordinate.

To investigate the influence of the building heights and the influence of the off-nadir satellite view angles on the final result, a Dense DTM (DDTM) considering also the height of the buildings has been computed using the GeneDDTM software implemented at Politecnico di Torino (Lingua and Borgogno Mondino, 2002). Displacements due to the presence of buildings have been defined according to their height (h_1=10 m, h_2=30 m, h_3=100 m). The negligibility limits reported have resulted to be 1 m, 2.5 m and 5 m respectively, corresponding to the tolerance of the orthophoto for 1:2,000, 1:5,000 and 1:10,000 scales (see Table 2).

Results reported in Figure 3 show the satellite view angle values for keeping the displacements within the accepted tolerance. For a building height of 30 m, the allowed view angle values are reported in Table 2.

In order to check the real impact of the DTM accuracy on the orthoimage generation process, non nadir QuickBird (0.61 m resolution) and EROS-A (1.9 m resolution) satellite images have been both orhoprojected with a traditional 50 m step DTM and with the DDTM previously generated.

In Figure 4 it can be seen somehow the viaduct is reported in its correct geometric position, thanks to the altimetric information that is derived from the DDTM, but the radiometric values that identify it are also repeated for the portions of scenes that were hidden from the sensor and which are "uncovered" after orthoprojection. This lack of information, in a "rigorous" approach, is resolved by removing the radiometric value from images acquired from other points of view and whose orientations are known. If no other data are available, it is possible to resolve this lack of information masking the hidden areas with a background value that can be easily identified.

Map scale	Off-nadir view angle (gon)	Negligibility limits (m)
1:2,000	< 2.5	< 1
1:5,000	< 6	< 2.5
1:10,000	< 11	< 5

Table 2. Negligibility limits and permitted off-nadir view angle for a building height of 30 m.

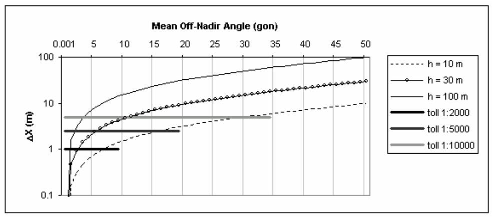

Figure 3. Negligibility limits and permitted off-nadir view angle to respect cartographic planimetric tollerances.

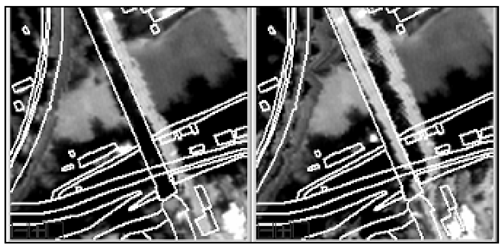

Figure 4. Details showing the overlap in correspondence to the viaduct using the DDTM (on the right) and the duplication of radiometric tones over the hidden area.

3. VECTOR LAYER EXTRACTION FROM ORTHORECTIFIED SATELLITE IMAGES

As previously described, imagery coming from HR sensors seems to become in the near future a tool to derive maps, comprehending large scales as well. Results of different researches on this topic has stated the usefulness of this kind of data to carry out mapping in those countries where production based on traditional methods cannot be really afforded. The use of satellite imagery for mapping is simpler with respect to traditional aerial photogrammetry: data can be purchased via

Internet, processing can be completely performed by commercial software, and GCPs can be measured by low cost GPS instruments. Obviously the cartographic product that might be obtained in this way is different with respect to a numerical 3-D map derived from aerial photogrammetry: the third dimension of the ground cannot be computed without stereo-pairs, and the (current) pixel size that does not allow one to derive maps larger than scales up to 1:10,000 (Scaioni and Gianinetto, 2003).
A first test on mapping production was recently performed by the authors in Lecco (Lombardia, Italy) using 1 m IKONOS data. The IKONOS image has been firstly orthorectified with the non-parametric RFM algorithm and then, from the orthoprojected image, road and building vector layers have been extracted (Figures 5 and 6).

(a)

(b)

(c)

Figure 5. Vector layer extraction test from 1 m IKONOS image taken over Lecco, Italy (test site 1). (a) Orthoimage from the IKONOS data, (b) Extracted vector layers, (c) Aerial orthophotomap (1:10,000 scale) with superimposed extracted vector layers.

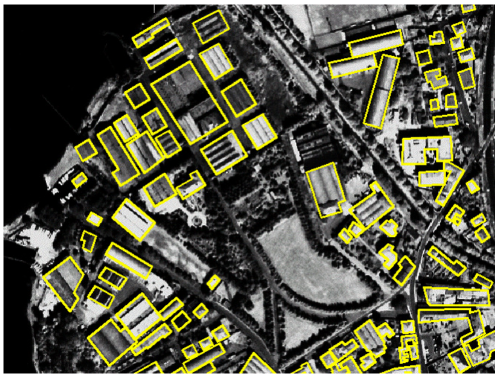

Figure 6. Vector layer extraction test from 1 m IKONOS image taken over Lecco, Italy (test site 2); overlap of extracted vector layers to the ortho-projected image

The 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.
Vector layers extracted from the IKONOS orthoimage (roads and buildings) are of high accuracy and completely conformal to cartographic planimetric tollerances adopted for Italian 1:10,000 scale maps (<4 m). Of high accuracy and completeness are drawings of roads and buildings, in particular when compared to orthophotos (Figure 5c).
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 (for example in dense urban areas) or are partially covered by vegetations. However, in the second case, the same problem would subsist also in case aerial photogrammetry is applied.
The availability of colour information would largely help in plotting, because it would allow one to locate with more ease objects featuring a contrasting colour (e.g. roofs, trees, green area, water surfaces, etc.). A realistic chance would be the use of pan-sharpened images, generated by merging the colour information contained in the lower resolution multispectral bands with the geometrical information contained in the higher resolution panchromatic band.

4. GNSS TECHNIQUES

GNSS measurement may be used for two different purposes in the mapping production, i.e. acquisition of GCPs needed for georeferencing aerial or satellite images, and collecting GIS data. Both tasks require the use of GPS in relative or differential mode, in order to reach the sub-meter and the meter accuracy needed for the former and the latter application, respectively. In developed countries, real-time methods (RTK) can be successfully exploited for GCP measurement.
The second application of GPS is devoted to the acquisition of vector and GIS information to integrate the geographic DB, task that can be easily carried out by a GIS data-logger palm receiver, which allows one to collect georeferenced features (points, lines, polygons) and to fill in their attribute tables directly on the field (see Alippi *et al.*, 2004). Different classes of these kind of receivers exist, the most evoluted performing also phase-shift measurement. This fact results 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 as a

distance of 30-40 km from the master station. Moreover, some receivers permits to register several epochs during the stationement on the same position in order to improve the accuracy of relevant points. This possibility, together with an accuracy under 0.5 m, might lead to the use of only GIS data logger as rover receiver, finalized to both purposes of GCP measurement and GIS data collection. The cost of such a GPS system (data-logger, related facilities and software for data processing) is in the order of a few thousand Euro. Differentiating the measurements is always dependent on the presence of a fixed GPS receiver station. On the other hand, satellites delivering wide area differential corrections (WAAS for North America, EGNOS for Europe and MSAS for Asia) may be used to obtain a real-time positioning in the range of accuracy about 2 m - 5 m.

5. CONCLUSIONS

Thanks to the data collected by new generation of high-resolution satellites, the new processing techniques recently developed and the use of low cost GPS receivers, now it is possible to derive a new generation of mapping products suitable for updating and augmentation of existing geographic DB.

Authors have developed a new approach for high-resolution orthoimage generation, based on the sequential use of an automatic GCP extraction technique by means of an Automatic GCP Extraction (AGE) strategy, a new Multi Layer Perception Neural Network approach (NN MLP) and on the Rational Function Model (RFM). The non-parametric RFM algorithm can lead to good planimetric accuracy in orthoprojection of high-resolution satellite images, but it is affected by numeric instability due to the GCP number and distribution which may determine local image distortion. On the other hand, the Neural Network leads to a lower geometrical accuracy, but is characterized by a higher stability. For this reason the NN MLP can be used as intermediate processing step to regularize the set of GCPs extracted by AGE and used by the RFM algorithm for the final orthorectification step. Tests on EROS-A data reported very interesting results, thinking of the very small human interaction and skill required (residual errors on GCPs of 1.06 pixel and residual errors on independent control points derived from 1:2,000 map of 5.42 pixel).

Tests have been made on EROS-A and QuickBird data to assess DTM and satellite viewing angle influence on the final orthoprojected satellite images. Results have shown the displacements due to the presence of buildings and the negligibility limits for the 1.2,000, 1:5,000 and 1:10,000 scales maps.

Preliminary tests have been performed in vector layer extraction from IKONOS imagery, which showed that these layers are of high accuracy and completely conformal to cartographic planimetric tollerances adopted for Italian 1:10,000 scale maps.

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