MIDDLE SCALE MAPPING OF CULTURAL SITES BASED ON HIGH RESOLUTION SATELLITE IMAGES

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ABSTRACT:
The availability and variety of high resolution satellite images (Eros, QuickBird, Ikonos, Spot5 supermode) have led us to consider the possibility of updating middle scale cartography. This paper presents a methodology to produce accurate orthocorrected images which can be used to generate updated maps at a scale of 1:10000. Even though commercial software already allow such operations to be made, we have implemented an alghorithm that is based on the RFM (Rational Function Model) in order to control the positioning errors and the influence of the ground control point distribuition on the results. Such an approach also permits us to investigate whether any of the 78 RPCs (Rational Polynomial Coefficients) are negligible. We assume that a DEM (Digital Elevation Model) of the investigated area is available (e.g. from SAR interferometry, SPOT5 mission,…). In order to define the maximum obtainable map scale (which depends on the geometric resolution of satellite images and on the adopted sensor model) accuracy tests have been carried out using a reasonable number of check points: the results are presented in this paper. The spectral information from multispectral data (XS, with a lower geometric resolution than the panchromatic band, PAN) can be used to produce thematic maps which can be considered as an added value of the process, especially in sites of cultural value. A Pan-Sharpening algorithm has been implemented paying particular attention to the file size management (through a partitional approach) and the corrispondences between PAN and XS spectral ranges. An example of a land cover map that was produced through a neural classification of such orthocorrected images is presented.

1. IMAGE ORTHOPROJECTION

Cultural site investigations require updated middle scale cartography to refer to. High resolution satellite images could be succesfully used to face such needs, but orthoprojection has to be taken into consideration. In literature remotely sensed satellite images have been orthocorrected using both rigorous sensor models and general non parametric models.

1.1 The Rigorous Sensor Model

Rigorous sensor models are based on collinearity equations; each line of the image, but not the entire image, can be considered a central perspective. Collinearity equations have to be modified to take into consideration the time dependence of the sensor's attitude and position. Starting values can be obtained from ancillary data, provided with images, by the reseller company: the position vectors, attitude values and the starting/end times of acquisition are usually provided. Otherwise, the starting values have to be calculated using linear models (i.e. time dependent linear transformed DLT equation).
A rigorous sensor model is often not available; this means that general projecting (non parametric) algorithms have to be used.

1.2 The Rational Function Model

One of the most commonly used non parametric models is the Rational Function Model (RFM). This model, proposed by OPENGIS consortium relates the image coordinates (>,0) and the three dimensional terrain coordinates (X,Y,Z) through a ratio of the 3rd order (maximum) polynomials (20 coefficients), as shown:

$$\xi = \frac{P_a(X,Y,Z)}{P_b(X,Y,Z)} \qquad \eta = \frac{P_c(X,Y,Z)}{P_d(X,Y,Z)} \tag{1.a}$$

These equations are called RFM *upward equations*. It can be useful to calculate the terrain coordinates from the knowledge of the image coordinates and of the *Z* values, according to the following equations, which are known as RFM *downward equations*:

$$X = \frac{P'_a(\xi,\eta,Z)}{P'_b(\xi,\eta,Z)} \qquad Y = \frac{P'_c(\xi,\eta,Z)}{P'_d(\xi,\eta,Z)} \tag{1.b}$$

In order to correctly estimate polynomial coefficients it is necessary to collect a sufficient number of Ground Control Points, ranging from a minimum of 7 (1st order polynomial) to a maximum of 39 (3rd order polynomial), considering that the first coeffincient in the denominators is assumed to be equal to 1.
Both the rigorous and the non parametric models are available in commercial software. A non parametric approach, which is based on a self developed RFM alghoritm (IDL programming language), is shown in this paper. The self developed

alghorithm permits us to keep the behaviour of such a methodology under control.
The equations (1.a or 1.b) have to be firstly linearized; in this way it is possible to solve system 2 through a least square solution:

$$
\begin{aligned}
V &= P \cdot A \cdot x - P \cdot L \\
X &= \left(A^T \cdot P \cdot A\right)^{-1} \cdot A^T \cdot P \cdot L
\end{aligned}
\tag{2}
$$

The first problem to face is the ill conditioning of the system that is obtained from the previous linearization. The Tikhonov regularization algorithm was used to solve the problem. As known, it is based on the addition of a small empiric coefficient (λ^2) to the diagonal elements of the A^TPA normal matrix . The following system can be written:

$$
X = \left(A^T \cdot P \cdot A + \lambda^2 \cdot I\right)^{-1} \cdot A^T \cdot P \cdot L \tag{3}
$$

This operation forces the system to converge after a few iterations.
The second problem is the occurrence of some asymptotes during the use of polynomials. An over parametrization test was carried out to evaluate which coefficients have to be used in the transformation. Firstly a χ^2 *t*est was carried out to understand whether raw errors are present or whether the model is overparametrized. If overparametrization is detected, further analyses (*t Student* tests) are performed to identify the coefficients that can be neglected.
It was found that both the number of coeffiecient to be used and the ill conditioning of the system are closely related to the geometric distorsion due to the sensor attitude and to the elevation range of the scene.

2. AVAILABLE DATA

2.1 Test site

Two test sites were chosen in the outskirts of the city of Turin (Piedmont, Italy): Stupinigi (fig. 1) and Venaria Reale (fig. 2). These represent two Italian cultural sites as they are old residences. Stupinigi was built in the first half of 18th century by the architect Juvarra as a hunting lodge and residence for the Savoia family; it is the nucleus around which a National Natural Park develops. An ancient medieval castle, Castelvecchio, which is well preserved, can be found near the hunting lodge.

Figure 1. Royal hunting lodge and national park in Stupinigi (Turin)

The Royal Palace of Venaria has been declared a Property of Humanity by U.N.E.S.C.O.
It was built by Castellamonte in the late 17^{th} century and it consisted of a village, royal palace and gardens and extended for an axis of 2 km. The building works were then assigned to the architect Juvarra in the early 18^{th} century.

Figure 2. Royal residence in Venaria (Turin)

2.2 Images, D.E.M. and cartography

A Spot 5 panchromatic oversampled image and a QuickBird panchromatic one were considered for two different scale analyses. Correspondent multispectral bands were also available for both the images. The main features of these images are shown in table 1.

	Spot 5	*QuickBird*
Date (dd mmm yyyy)	01 Oct 2002	22 Sep 2002
Pan Resolution (m)	2.5 (supermode)	0.61
XS Resolution (m)	10.0	2.44
Level	1B	1B

Table 1 – Remotely sensed images available of the test site

The Digital Elevation Model of the Piedmont Region was used during data processings. This model is characterized by a 50m x 50m grid and an accuracy of ± 5m.
According to the expected scale mapping (which mainly depends on the geometric resolution of the images) the following cartographic reference data were used:

- vector 1:10000 scale Technical Regional Map (CTR, used for orthocorrection of the SPOT image);
- raster 1:5000 scale Technical Provincial Map (CTP, used for orthoprojection of the Quickbird image).

These data were adopted to collect the Ground Control Points (GCP): Check Points (CHP) have instead been collected on larger scale maps (1:5000 and 1:2000) here called Test cartography.
Reference cartography photogrammetric flights were made in 1991 (CTR) and 1993 (CTP). This fact permits us to face the updating problem as the area of interest has been subject to intensive changes over these years. Our interest in particular is to demonstrate that satellite high resolution images can be useful:

- to investigate any modifications that have occurred in the cultural sites, such as heavy restoration and requalification activities;
- to investigate the management of the surroundings devoted to the context in which the cultural sites are situated.

3. ACCURACY TESTS

In order to proceed with a correct updating test, we paid attention to the accuracy of the positioning (planimetric) problem. It is necessary to say a few words about such problem to underline that a correct geometric positioning of the objects is as important as the recognition of their modifications.

The self-developed RFM algorithm was applied to orthoproject both images. It should be noted that the Rational Function Model is very unstable and depends on many parameters, such as the distribution of the GCPs, the range of the elevation values, the sensor attitude and the Tikonov coefficient: all these parameters have to be evaluated for each different image. Poor estimations of these parameters can lead both to a decrease in the positioning accuracy and to the occurrence of asynthops in the final image (raw distortions).

A detailed statistical analysis was carried out to evaluate which map scale the obtained orthoimages are suitable for, taking into consideration the map tolerances (in Italy the usually accepted value is of 0.2 mm at the map scale and the tolerance is interpreted as two times the RMSE of the coordinates). This means that a 1:10000 map has a 2 m tolerance and a 1:5000 map has a 1 m tolerance. Residuals can been considered as statistical variables (one for each test) and their mean and standard deviation can been calculated.

CHK	ΔE (pixel)	ΔN (pixel)	RMS (pixel)
1	0,16	-0,82	0,83
2	-0,26	0,63	0,68
3	-0,67	0,82	1,06
4	0,87	-2,15	2,32
5	0,02	0,07	0,07
6	-1,95	0,01	1,95
7	0,51	-0,03	0,52
8	0,73	-0,03	0,73
9	-1,24	0,97	1,57
10	-1,06	1,08	1,52
11	2,24	0,46	2,29
12	0,55	1,42	1,52
13	-0,06	-1,01	1,01
14	0,04	1,64	1,64
15	0,56	-1,47	1,57
μ	**0,03**	**0,11**	
σ_V	**1,0069**	**1,0817**	
RMSE	**1,43**		

Table 2. Residuals on CHK over the SPOT5 image

Fitting statistical tests can be made on each residual distribution in order to understand whether they would fit a normal statistical distribution or whether they are affected by systematic or raw errors. In particular, the χ^2 test was performed. The residuals (v) successfully passed this test in both cases.

In such situations, according to the Tchebycheff theorem ($\mu - 2\sigma < v < \mu + 2\sigma$), at least 95% of the residuals fall into following ranges for the Spot5 orthoprojected images:

$-4.95 < \Delta X < 5.11$ m

$-5.14 < \Delta Y < 5.67$ m

These results suggest that Spot5 orthoimages are not suitable for a 1:10000 scale map updating; however tolerance values can be accepted for a 1:25000 scale map.

CHK	ΔE (pixel)	ΔN (pixel)	RMS (pixel)
1	1,20	-1,82	2,18
2	1,23	-1,73	2,12
3	-0,19	-0,06	0,20
4	1,57	-0,26	1,59
5	0,16	0,10	0,19
6	-1,53	0,35	1,57
7	-0,92	1,31	1,60
8	0,87	0,12	0,88
9	0,50	0,18	0,53
10	-0,71	0,27	0,76
11	-0,13	1,06	1,07
12	0,23	0,47	0,53
13	1,05	1,79	2,07
14	0,54	-0,05	0,54
15	-0,05	0,16	0,17
16	0,86	-1,16	1,44
μ	**0.2531**	**0.1271**	
σ_V	**0.8724**	**0.9521**	
RMSE	**1,32**		

Table 3. Residuals on CHKs over the QuickBird image

As far as QuickBird orthoimages are concerned, their Tchebycheff relation appears, as shown below:

$-0.91 < \Delta X < 1.22$ m

$-1.08 < \Delta Y < 1.24$ m

Such results show that 95% of the residuals are lower than 1.25m and suggest a potential use of Quickbird orthimages for upgrading 1:10000 scale maps (whose tolerance is about 2.0 m).

Another tolerance evaluation method can be considered according to the technical rules that are adopted for the production of the used 1:10000 regional reference cartography. They indicate that the following relationship has to be satisfied:

$$RMS_i = \left[\left(E_i^{CHK} - E_i^{ORTHO} \right)^2 + \left(N_i^{CHK} - N_i^{ORTHO} \right)^2 \right] \leq 4.0m \quad (4)$$

However also this approach shows that Spot 5 orthoimages seem to be not suitable for a 1:10000 scale map updating.

It is important to note that a more rigorous test should take into consideration the check points precision σ_T (that is the same of the test cartography), according to te following relation:

$$\sigma_V \leq \sqrt{\sigma_U^2 + \sigma_T^2} \quad (5)$$

where σ_U = precision of the up-to-date cartography.

Such an approach is less limiting and so it has been cautionally decided to consider σ_T equal to zero.

4. CARTOGRAPHIC UPDATING

One of the main aims of this paper is to establish whether the geometric information of the orthoprojected remotely sensed images are suitable for cartographic updating (at a scale that depends both on the geometric resolution of the image and on the scale of the reference cartogaphy). A geometric answer gives indications on the scale of the map. But what about the image contents? Are particulars that are really changed distinguishable? Can they be correctly digitised? How can building relief displacement limit the graphical reproduction?
It is the authors opinion that visual interpretation of orthoprojected images can effectively be used for planimetric updating of any available cartography (depending on the map scale).
The simple adopted process is based on an accurate visual comparison between the reference cartography and the orthoprojected image; cartography overlapping onto the orthoimage is a simple and useful tool to proceed with the digitisation of the elements that are not present or changed.
The following three figures show the area of the Venaria Reale Gardens that is at the moment being restored: in this example the new positions and shapes of the gardens have been updated on the Regional Technical Map (1:10000)
The same example can also be used to demonstrate how the past territorial management damaged an important cultural site, permitting sports and factory buildings to be built in the immediate surroundings of the palace. A satellite orthoimage can therefore be considered an economic evaluating tool in the hands of administrative bodies.

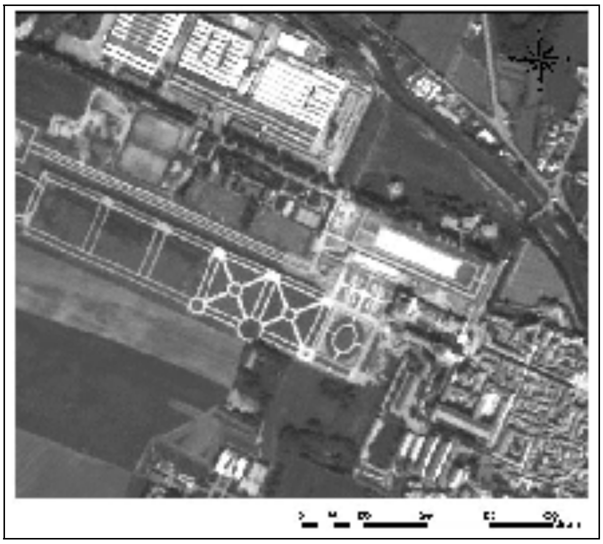

Figure 4. Spot 5 image (2.5m) of the *Venaria Reale* area

Figure 5. QuickBird image (0,61m) of the *Venaria Reale* area

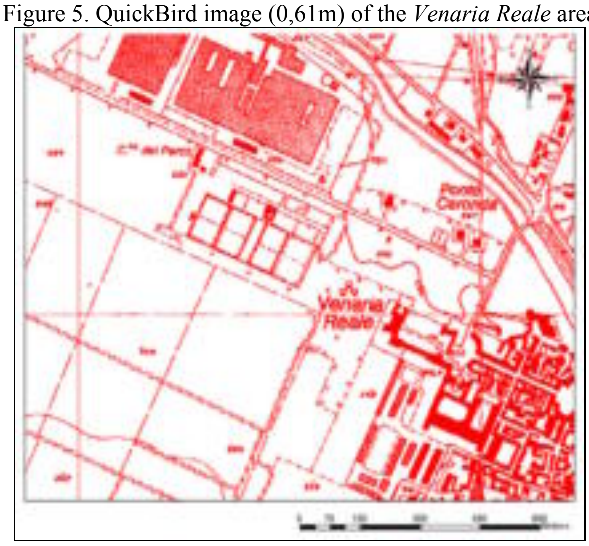

Figure 6. The 1:10000 Region Technical Map before updating

Figure 7. The 1:10000 Region Technical Map after updating (darker lines)

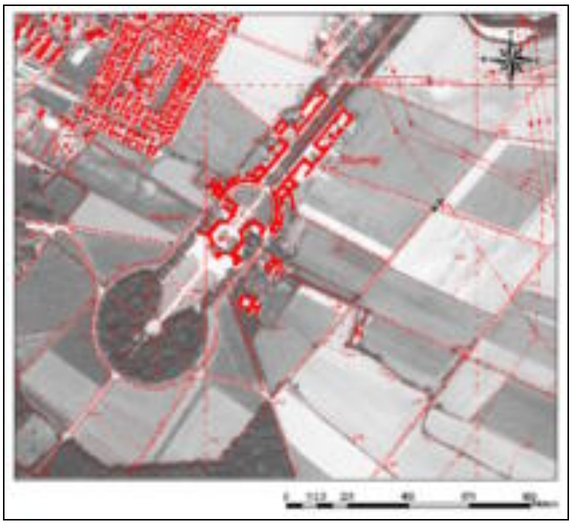

Figure 8. 1:10000 Regional Technical Map overlapping the Spot5 orthoprojected image of the Stupinigi test site.

Figure 8 shows how there is no obvious change in the Stupinigi test site that would require any updating of the cartography, if some agricultural boundaries are excluded

5. THEMATIC MAPS DERIVED FROM PANSHARPENED IMAGES

An added value of high resolution satellite images is due to the availability of different spectral bands, whose exploitation can be useful for map updating and cultural site management.

Remote sensing classification techniques, or simple visual image interpretation, can be used to derive auxiliary information both for the updating (allowing a better discriminations between the objects) and for thematic map generation devoted to cultural site management. Information about the territorial/urban context can be derived from such data. The lower geometric resolution of the multispectral bands suggests a classification approach that is based on pan-sharpened bands.

The pan-sharpening procedure generates a multispectral image, starting from a low resolution multispectral image (XS) and a high resolution panchromatic. In this case, due to the lack of correspondence between the spectral ranges of the panchromatic and the multispectral bands which results in radiometric anomalous pan-sharpened bands, a self-developed procedure was adopted. This procedure maintains the radiometric differences between the original multipsectral bands and the pan-sharpened ones (due to the previously mentioned problem) within an acceptable range, paying the price of a light smoothing of the data. The group is still working on this aspect.

6. CONCLUSIONS

This study leads us to conclude that the map updating problem based on high resolution satellite images must be considered from two different points of view:

- the geometric/positioning one;
- the information content one.

It has been shown that Spot 5 images have an information content that is suitable for a 1:10000 scale map; unfortunately it has been demonstrated through positioning tests that the reachable accuracy it is not sufficient for that scale. Improvement can be obatined:

- using a rigorous sensor model approach (we are currently working on this);
- collecting the GCPs on larger scale maps or through GPS survey (GPS measurement campaign is currently being projected)

Quickbird orthoprojected images instead present an accuracy that is suitable for a 1:10000 scale map. In this case buildings and relief displacements have to be considered: this problem can be dealt with by using a Dense DEM (DEM + height building information) while orthoprojecting. A DDEM could be generated trhough aerial laser scanner acquisition or dedicated softwares for numerical cartography processing (if height layer is available).

According to technical rules adopted for the production of the used 1:10000 regional reference cartography, updated entities should be characterized by a quality code that specifier the updating method and source (orthoprojected satellite images).

The solution of the correct orientation of along track stereopairs (i.e. Eros A1) could encourage map updating users towards map production.

Finally it has been shown that high resolution satellite images represent an economic and reliable solution to monitor cultural heritage sites according to the scale map requider from the customer.

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