DIGITAL IMAGES PROCESSING OF HYPERSPECTRAL AIRBORNE DATA: A CULTURAL HERITAGE EXAMPLE

P. Ardissone [(a)], P. Boccardo [(a)], E. Borgogno Mondino [(a)],
[(a)] Politecnico di Torino – Dipartimento di Georisorse e Territorio
Corso Duca degli Abruzzi, 24 – 10129 Torino – Italy
Email: paolo.ardissone@polito.it, piero.boccardo@polito.it, enrico.borgogno@polito.it

Commission V, WG V/5

KEYWORDS: cultural heritage, remote sensing, digital image processing, GIS, hyperspectral, warping, orthoprojection

ABSTRACT

This paper concerns the digital image processing of hyperspectral airborne data, devoted to landscape and cultural heritage analysis. The project completes a three years GIS case study devoted to the characterisation of a no more visible middle age landscape. The study area is located in the southern part of the Piedmont region (North-West Italy) and in particular in a valley whose height ranges from 600 m to 2500 m, called *Valle Po*.
The aim of the past analysis was to integrate different thematic data such as archaeology, geology, botany and cultural anthropology using a medium scale cartography (up to 1:5.000) and high resolution satellite images to georeference the above mentioned data. During the last year, a hyper-spectral survey, conducted with the MIVIS airborne scanner, has been orthoprojected and used to derive different thematic maps which give information related to:

- archaeological evidence;
- mine and quarry positions;
- lithotype characterization;
- vegetation cover and types.

All these thematic maps can be derived exploiting the 102 different spectral bands of the MIVIS sensor. Particular attention has been paid to the calibration of the sensor, extraction of the spectral signatures and to the georeferencing of the above mentioned images. Such operation was done orthoprojecting the images through a general sensor model procedure, self-implemented within the IDL programming language. At the moment the group is also working to the development of a rigorous sensor model (attitude and positioning parameters estimation) with the aim of improving the accuracy. Obtained thematic maps have then been linked to a relational database aimed to query and correlate different and previously disjointed information.

BACKGROUND OF THE PROJECT

The proposed procedure completes and integrates the project "*Landascape heritage and resource management: an integrated information system of the Marchesato di Saluzzo*" which was aimed at studying the settlement development and the use of land in the Po valley between X and XIV Centuries. During the last three years our work was based on archive and bibliography research with the aim of finding all the available information on the "material structures", such as castles, churches, settlements and roads from the Middle Ages. Subsequently, a field survey was carried out to locate these structures and to identify which have disappeared and which have remained. All the data was entered and structured in a GIS database together with most of the other available data about the Po valley area: technical, thematic, geological and botanical.
Over the last year the data queries and spatial analysis led us to select test areas on which to conduct an MIVIS hyperspectral airborne scanner acquisition. MIVIS data analysis has permitted a close examination of the selected areas to look for buried structures, exploit indications offered by radiometric and spectral anomalies on the ground.
It is worth to here underline that the goal of the current project is not only to increase knowledge about the past, nor simply offer a significant aid to historical and archaeological studies and data management, but also to provide aid to local administrations for correct environmental management and accurate cultural heritage safeguarding of the area.

1. AVAILABLE DATA

Investigations have been carried on using:

a) a numerical Technical Regional Map (scale 1:10 000);
b) a 50x50m grid Digital Elevation Model;
c) Archaeological, geological and botanical available data (derived from the "*Marchesato di Saluzzo"* GIS);
d) a MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) image of the Po valley mouth, acquired on 18th December 2002, with a ground resolution of about 4 meters.

The MIVIS hyper-spectral scanner is a modular instrument composed of four spectrometers which simultaneously measure the electromagnetic radiation from the Earth's surface by recording 102 spectral bands:

20 in the visible spectral region (0.43-0.83µm)
8 in the near infrared one (1.15-1.55µm)
64 in the middle infrared one (2.0-2.5µm)
10 in thermal infrared (8.2-12.7µm).

2. DATA PRE-PROCESSING

When dealing with territorial applications it is always important to correctly approach the scale mapping problem. This means that ground object positioning must be coherent for all the used data (often coming from different sources and reference map systems). Such problem can be easily solved for geocoded data such as the ancillary and the cartographic ones. Not so easy is to face the problem of the geocoding of MIVIS data maintaining the ground position accuracy within an acceptable tolerance range (depending on the nominal scale of the map base it is intended to be adopted). The MIVIS image geocoding is therefore a delicate step to pass through; further complexities come from the whiskbroom MIVIS sensor model which introduces many deformations it's important to take care of. Scene geometry has to be corrected. Usual methodology based on simple polynomial approach cannot model such geometry especially in a mountain region as the study one is. Orthoprojection has to be done to make MIVIS data suitable for the subsequent data integration.

The whole process path falls into four main steps:

a) Image orthoprojection;
b) Significant band selection;
c) Test area selection and image masking;
d) Image classification and validation.

Figure 1. Area acquired by MIVIS airborne scanner.

3. IMAGE ORTHOPROJECTION

The MIVIS sensor is a whiskbroom one. A rigorous sensor model is not easy to describe and ancillary data needed for such operation (attitude and position recordings) are often not available. In the rigorous model each pixel is acquired with its own perspective different from the other ones. Rigorous approach based upon collinearity equations is not appropriate in this case. Collinearity equations would have to be modified to take the dependence of the sensor attitude and position on the time into consideration. Such a complex model can successfully be substituted by general projecting algorithms. The Rational Function Model (RFM) is one of the most commonly used non-parametric one. This model relates the image coordinates (*>,0*) and the three dimensional terrain coordinates (*X,Y,Z*) through a ratio of 3rd order (maximum) polynomials P_i (20 coefficients), as shown below:

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

These equations are called RFM *upward equations*.

The model has been implemented in IDL programming language in order to control the behavior of this methodology.

It has been found that it is closely related to the geometric distortion due to the sensor attitude, to the elevation range of the scene and above all to the number and distribution of the used Ground Control Points (GCPs). In this particular case image orthoprojection was carried out using the complete RFM (3rd polynomial). 57 GCPs were collected to estimate the model coefficients. The residuals on the GCPs are presented below.

ID	**Residual** (pixels)	**Res x** (pixels)	**Res y** (pixels)	**ID**	**Residual** (pixels)	**Res x** (pixels)	**Res y** (pixels)
1	Check Point			32	1,84	1,84	-0,01
2	3,01	-2,74	1,24	33	0,74	0,10	-0,74
3	2,88	0,87	-2,74	34	2,32	-1,14	-2,02
4	2,52	0,80	2,39	35	1,29	0,13	1,28
5	1,76	-1,72	-0,36	36	2,86	-2,71	-0,89
6	5,52	5,51	0,16	37	2,43	2,12	1,19
7	Check Point			38	1,66	1,06	1,28
8	0,70	-0,43	0,55	39	2,01	1,70	-1,07
9	1,96	-0,98	-1,70	40	2,16	2,14	0,26
10	Check Point			41	3,11	0,60	-3,05
11	0,38	-0,23	-0,30	42	0,95	0,81	-0,49
12	Check Point			43	2,05	-0,49	1,99
13	1,38	-0,80	-1,13	45	Check Point		
14	0,85	0,69	-0,49	46	1,74	-1,25	1,21
15	3,15	-2,80	-1,45	47	0,56	-0,26	-0,49
16	3,47	3,36	0,85	48	2,94	2,92	0,37
17	1,71	1,48	-0,85	49	4,44	-4,18	-1,50
18	0,69	-0,62	-0,29	50	4,29	-2,38	3,57
19	1,03	-0,90	0,50	51	2,10	-1,07	-1,80
20	0,72	0,61	0,39	0001	1,24	1,18	-0,37
21	1,03	-0,99	-0,27	0002	1,23	0,98	0,75
22	0,09	0,08	-0,05	0003	1,27	-1,15	0,52
23	1,08	0,28	1,04	0004	0,94	0,84	-0,42
24	0,64	-0,00	0,64	0005	1,22	-1,21	0.20
25	1,82	-0,29	1,80	0006	1,02	-0,95	0,38
26	0,81	-0,77	-0,25	0008	0,75	0,71	-0,24
27	2,42	-2,38	-0,45	0009	1,16	1,04	-0,53
28	2,70	2,10	-1,69	0010	3,15	3,07	0,73
29	0,88	-0,71	0,52	0011	0,11	-0,04	-0,10
30	1,17	0,27	1,14	0012	0,91	-0,84	-0,35
31	0,90	-0,90	-0,05	0013	2,59	-2,30	1,20

Tab. 1- GCPs Residuals

The calculated total RMSE is 2.10 pixels, 8 m at the ground. Further residual investigations have been carried out on 5 check points .

ID	**Residual (m)**	**Res E (m)**	**Res N (m)**
1	28,68	11,52	26,24
7	15,48	1,12	-15,44
10	-15,6	-4,36	-15
12	14,16	-5,76	-12,92
45	10,6	-10,48	-1,48
μ	16,904	6,648	-14,216

Tab. 2- CPs Residual

They show a deteriorated situation basically due to the high variability of the area height and a low extrapolation capability of the model (low GCPs redundancy?). According to the results obtained with other simpler models have driven us to accept the former; nominal scale mapping our data could be reasonably good is a 1:50.000 (geometrically speaking).

1:10000 Vector map has been overlaid onto the orthoprojected image showing, however, a good correspondence (often better than the estimated accuracy).

figure 2- 1:10000 Vector map overlaid onto the orthoprojected image

4. SIGNIFICANT BANDS SELECTION

The second step was to select the most useful bands for the detection of archaeological features and anomalies. These can be identified by the texture, soil moisture and vegetation cover differences that are produced by buried structures.
The peculiarity of the investigated objects led us to select bands renouncing to the principal components analysis; we proceeded with a visual interpretation taking care of the bibliographic references. A total of 10 of the 102 available bands of the MIVIS sensor were chosen:

a) 4 in the visible range (b2= 0.4600 μm, b7=0.5600 μm, b11= 0.6400 μm, b20= 0.8200 μm) for the contextual location;
b) 2 in the near infrared range (b23= 1.2750 μm, b28= 1.5250 μm), for vegetation cover anomalies;
c) 1 in the medium infrared range (b52= 2.1790 μm) for soil moisture;
d) 3 in the thermal infrared range (b93= 8.3859 μm, b97= 10.0200 μm, b101= 11.9450 μm) for termal variation on the ground.

No calibration have been made as no calibration file was available for the test image. That has not be considered fundamental because relative, and not absolute, differences between objects had to be investigated.

5. TEST AREAS SELECTION AND IMAGE MASKING

Queries and spatial analysis performed on the data collected in the Marchesato di Saluzzo GIS permitted to choose 2 test areas responding to the appropriate archaeological needs:

5.1 The Sant'Ilario monastery.

This monastery is near the town of Revello, close to the Po valley mouth. The documentary sources refer to three villages in the second half of the XII Century. Today there is no sign of these settlements which in the documents were known as *Sant'Ilario*, *Viverio* e *Paralupo*. The XII Century documents also refear to a road called "*via publica*" which was situated near the monastery.

5.2 The San Massimo church.

The site of this church was between the Revello and Envie towns. Thanks to a document of the half of the XIII century, we know there was a very important road called "*via monnea superius*" which was near San Massimo church. The name of this road seems to suggest a paved road. This road was part of a longer, probably Roman route, which joined the town of Saluzzo with the town of Bricherasio.
We built and applied an opportune mask to bound these two areas. A mask is a binary image that consists of values of 0 and 1.When a mask is used in a processing function, the areas which have values of 1 are processed and the masked 0 areas are not included in the calculations. This procedure has permitted us to limit the investigation and the radiometric bothers.

6. IMAGE CLASSIFICATION AND VALIDATION

Nine regions of interest (ROI) were selected inside the sample areas: buildings, industrial buildings, water, streets, soil moisture, orchards, vegetated fields, non-vegetated fields, shadow zones.
A spectral angle mapper classification with an angle threshold of 0.10 (radians) was applied. For the validation of the classification of the eight classes the correspondent confusion matrix was calculated(table 3). It shows a correct classification of ROIs, although in the next future a certification on the ground could be necessary.

class	**unclassified**	**Industrial buildings**	**orchards**	**Streets**	**buildings**	**Non-vegetated field**	**water**	**Vegetated fields**	**Shadow zone**	**Soil moisture**	**Total**
unclassified	227651	0	0	0	0	0	0	0	0	0	227651
industrial buildings	0	846	0	0	0	0	0	0	0	0	846
orchards	0	0	31544	0	0	0	0	0	0	0	31544
streets	0	0	0	13219	0	0	0	0	0	0	13219
buildings	0	0	0	0	1191	0	0	0	0	0	1191
non-vegetated field	0	0	0	0	0	9356	0	0	0	0	9356
water	0	0	0	0	0	0	307	0	0	0	307
Vegetated fields	0	0	0	0	0	0	0	19414	0	0	19414
Shadow zone	0	0	0	0	0	0	0	0	1052	0	1052
Soil moisture	0	0	0	0	0	0	0	0	0	35870	35870
Total	227651	846	31544	13219	1191	9356	307	19414	1052	35870	340450

Tab. 3- Confusion matrix of the nine selected class

Rule images that were generated during the classification were considered. In rule images the dark pixels mean a similar spectral signature to the selected class, while the gray scale pixels mean a different one. Rule images are very helpful in highlighting the presence of buried archaeological structure on the bases of different spectral characteristics of the ground.
The rule image of the class "buildings" enabled us to recognize circular anomalies approximately 100 m from the west side of the Sant'Ilario monastery (figure 3).

figure 3- Sant'Ilario area and anomalies singled out in the rule image of "buildings" class.

In the San Massimo area, north to the church is possible to single out a linear trace in the rule images of the buildings and streets classes(figure 4). At the moment we are not able to interpret these anomalies and to understand if they are archeological features. A field survey have to be done to check these anomalies. This operation will be very important because it would prevent any kind of misidentification of non-archaeological features.

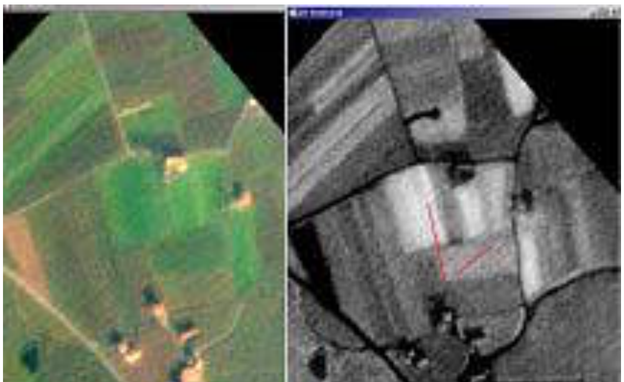

Figure 4- San Massimo area and linear traces in the rule image of "streets" class.

7. CONCLUSION

The test areas analysis has identified some interesting anomalies that have to be checked on the ground. A positive identification would permit us to enter and link data in the *Marchesato di Saluzzo* GIS. In this paper we have proposed a procedure to single out anomalies and archaeological features inside two areas selected by archive and bibliography research.

The next step will be to apply a SAM classification on the whole image. Before doing this, a correct radiometric calibration and lithotype and vegetation cover characterization are necessary. Moreover in the future we would like to try to better the image orthoprojection and to improve the accuracy, working on the development of a rigorous sensor model.

REFERENCES

Ardissone P., Rinaudo F., *Geomatic applications in archaeological research: the middle age in the valle po landscape*, Proceedings of CIPA XIX International Symposium, Commission V, WG5, Antalya, 2003.

Boccardo, P., Borgogno Mondino, E., Giulio Tonolo, F., 2003, *Urban areas classification tests using high resolution pan-sharpened satellite images*, Urban 2003 Proceedings, Berlin

Lingua, A., Borgogno Mondino, E., 2002, *High Resolution Satellite Images Orthoprojection Using Dense DEM*, Spie 2002 Proceedings, Creete

Boccardo, P., Borgogno Mondino, E., 2001, *Metric Quality Evaluation of Satellite High Resolution Images in Urban Areas*, Urban 2001 Proceedings, Rome

Tao, C., Hu, Y., 2001, *A comprensive study of the Rational Function Model for Photogrammetric processing*, Photogrammetric engineering & Remote Sensing, December 2001

Cavalli R.M., Colosi F., Pignatti S., Poscolieri M., Bianchi R., *Ricostruzione dell'impianto viario dell'antica Selinunte attraverso il telerilevamento iperspettrale*, Rivista Italiana di Telerilevamento Settembre 2000/Gennaio 2001.

Di Gangi G., Lebole C. (a cura di), 2000, *La gestione del territorio*, atti del convegno nazionale, Saluzzo.

7.1 Acknowledgements and Appendix (optional)

The study is part of a 2 year research project that is co-financed by MURST (2001) entitled "The study of remotely sensed images for environmental analyses".