APPLICATIONS BASED ON ORTHOCORRECTED HIGH RESOLUTION AND HYPERSPECTRAL IMAGES

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ABSTRACT:

The availability and variety of high resolution satellite and hyperspectral aerial images have led us to consider how image geometric aspects can condition remote sensing applications . Our main purpose is to underline the importance of images geometric correction; its quality conditions not only positioning, but also object dimensions measurements and shapes which can be very important in specific application as map updating and archaeological investigations, where some shapes could be buried.
In this paper two orthoprojection procedure, which have been validated, are presented. Both of them are based on non-parametric self-developed algorithms (*Rational Function Model* and *Neural Network*) applied to different types of images aimed to determined their limits and potentialities correlated to their geometric features. Firstly map scale suitability of such data (which depends both on the geometric resolution of images and on the adopted sensor model) has been investigated through planimetric positioning accuracy tests. Presented experiences refer to orthoprojection of a SPOT5 *supermode* image and to an airborne sensor MIVIS (*Multispectral Infrared Visible Imaging Spectrometer*) one.
Considerations have been then carried out about both geometric and content features of the obtained orthoimages. In particular SPOT5 image has been used for demonstrating how well it can be used for middle scale map updating and how its scale mapping suitability heavily depends on the adopted geometric calibration method. MIVIS image has been used to underline how metric issues are as important as the spectral ones in the particular field of the archaeological investigation. In the first case attention has been, therefore, mainly paid to the geometric content of the SPOT5, while in the second one interpretation problem is also taken into consideration.

1. ADOPTED GEOMETRIC CORRECTION METHODS

Many applications are strictly dependent on the quality of geometry of images. Object shapes, dimensions and relation between objects are more than a simple positioning problem. Geometry correction has, therefore, a semantic importance that has not to be neglected.
Geometric calibration of high resolution satellite/aerial images can be performed according to 2 different approaches: the rigorous and the non-parametric one.
Rigorous models are based on time-dependent collinearity equations. Due to the common lack of detailed information about sensors and platforms these methods have been, for a long time, neglected by the users community. In their place generic methods (non-parametric) have indeed been developed.
These are generic and independent both from the sensor and from the acquisition mode.
Nowadays commercial software are equipped with both types, but often, user has no possibility of controlling the whole process. That's why we have decided to face directly the problem, developing by ourselves, the necessary routines. In this way we can really regards any deficiency of the methods. Attention has been particularly paid to the non-parametric methods. It's not purpose of this work to deeply understand these methods, but simply to give some basic information necessary to understand our working philosophy and to quantify residuals resulting from the orthocorrection operations.
Results here presented have been obtained using two procedure developed in IDL and MATLAB programming languages. One performs the *Rational Function Mode (RFM)*, perhaps the most famous generic 3D generic method. The other, particularly innovative, performs a neural network approach to the problem.
All generic models require a high number of Ground Control Points (GCP).

1.1 Neural Network Model

Neural Network (NN) approach for geometric calibration purposes of remote sensing images can be considered an innovative and experimental solution. NN are mathematical models which simulate brain dynamics. Computational scheme can be thought as a flow of distributed information which are elaborated within computational node called "neurons" of the NN. Some of them (input) receive data from the external world , some give back information to it (output), some other simply communicate each other (hidden). Neurons are mathematically represented by weights, parameters of the model, which have to be estimated on the basis of the GCP through an iterative learning process.
As far as this work is concerned the developed orthocorrection procedure is based on an opportunely designed Multi Layer Perceptron (MLP) NN. This type of NN has been chosen for its function approximation and estimation features. It shows its high suitability especially for non linear functions as considered relations are. Basic idea is to substitute the upward projecting model relating image (ξ,η) and ground (X,Y,Z) coordinate with a well designed and trained MLP NN.
Reasons that have pushed us to consider this approach come from the will to solve recurrent problems associated to the RFM method described in the next paragraph. NN allow to avoid local linearisation of equations relating coordinates. They

represent a non linear solution to a non linear problem, whose effectiveness grows up with the increasing of the number of the Ground Control Points.

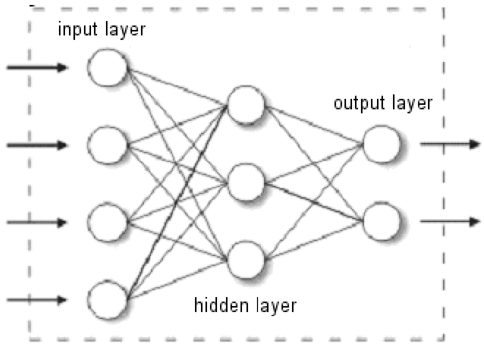

Figure 1 - MLP NN with 2 computational layers (hidden e output).

MLP NN belongs to the *feed-forward* NN family. Adopted training algorithm is the Back Propagation Levenberg-Marquardt one. Procedure make use of the Neural Netorl Toolbox i MATLAB 5.3.

NN architecture is the one shown in Figure 2. The most appropriate number of neurons has to be defined time to time according to the number of GCPs and image type. Only an expert user can successfully control it. Indications for the best architecture can be derived from RMSE (Root Mean Square Error) analysis. The NN approach is quite sensible to the initialization of the weights of the neurons.

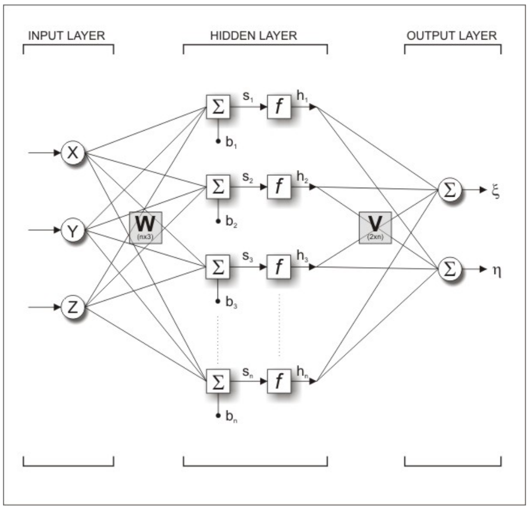

Figure 2 - MLP NN mathematical model with 2 computational layer (*hidden e output*) designed for the ortho-correction problem.

1.2 Rational Function Model

This is the most famous and used non-parametric model. It is present within almost every remote sensing commercial software. It allows to relate image coordinates (ξ,η) with object-terrain 3D coordinate (X,Y,Z) through rational polynomials as shown in (1):

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

P_a, P_b, P_c, P_d, are polynomials of maximum 3° degree (78 parameters to be estimated) whose equations are (2) o (3):

$$P_a(X,Y,Z) = a_0 + a_1X + a_2Y + a_3Z + a_4X^2 + + a_5XY + ... + a_{17}Y^2Z + a_{18}YZ^2 + a_{19}Z^3 \tag{2}$$

$$P_a(X,Y,Z) = \sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} a_{ijk}X^iY^jZ^k \tag{3}$$

$0 \le m_1 \le 3\,;\, 0 \le m_2 \le 3\,;\; 0 \le m_3 \le 3$ e $m_1 + m_2 + m_3 \le 3$

Equations (1) are known in literature as *RFM Upward*.

2. EXPERIENCES

Here are presented two experiences carried out on images of the type previously described which both take into consideration the geometric quality of the orthocorrected images.

2.1 Technical Map Updating

Problem is to evaluate if SPOT 5 images can be successfully used for map updating problems, and which scale map they can be rigorously suitable for.

As far as such validation is concerned two test sites have been chosen in the outskirts of the city of Turin (Piedmont, Italy): Stupinigi (Figure 3) and Venaria Reale (Figure 4). These places are sited in an area that has been subject to intensive changes over these years.

They 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 3. 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 17th 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 18th century.

Figure 4. Royal residence in Venaria (Turin)

2.1.1 Dem And Reference Map

A Spot5 panchromatic oversampled image has been considered. The main features of this image are shown in table 1.

	Spot 5
Date (dd mmm yyyy)	01 Oct 2002
Pan Resolution (m)	2.5 (supermode)
XS Resolution (m)	10.0
Level	1B

Table 1 – Remotely sensed images available of the test site

The Digital Elevation Model of the Piedmont Region was used during process. This model is characterized by a 50m x 50m grid and a vertical accuracy of ± 2.5m.
According to the expected scale mapping (which mainly depends on the geometric resolution of the images) the vector 1:10000 scale Technical Regional Map (CTR) has been used as reference.

2.1.2 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.
A detailed statistical analysis was carried out to evaluate which map scale the obtained orthoimage is 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 this value). This means that a 1:10000 map has a 4 m tolerance and a 1:5000 map has a 2 m tolerance.
Residuals can been considered as statistical variables (one for each test) and some their statistical features can calculated. Table 2 shown such values both for the RFM and MLP approach applied to the SPOT5 image.

Method	N° GCPs	N° CHKs	$\Delta\xi$ mean CHK	$\Delta\eta$ mean CHK	RMSE CHK (pixel)	RMSE GCP (pixel)
RFM	50	5	-0.02	-0.09	2.09	1.01
MLP NN	50	5	-2.04	0.02	2.96	1.38

Table 2 – Accuracy tests results obtained with the RFM and MLP NN self-developed orthoprojection routines on the SPOT5 image.

Fitting statistical tests have also to be made on each residuals distribution in order to understand whether it would fit a normal statistical distribution or whether it is affected by systematic or raw errors. In particular, the χ^2 test was performed. The residuals successfully passed this test.
Considering RMSE values it is possible to say that Spot5 orthoimages, obtained with well trained generic methods, are geometrically suitable for a 1:10000 scale map updating.

2.1.3 Map Updating

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.

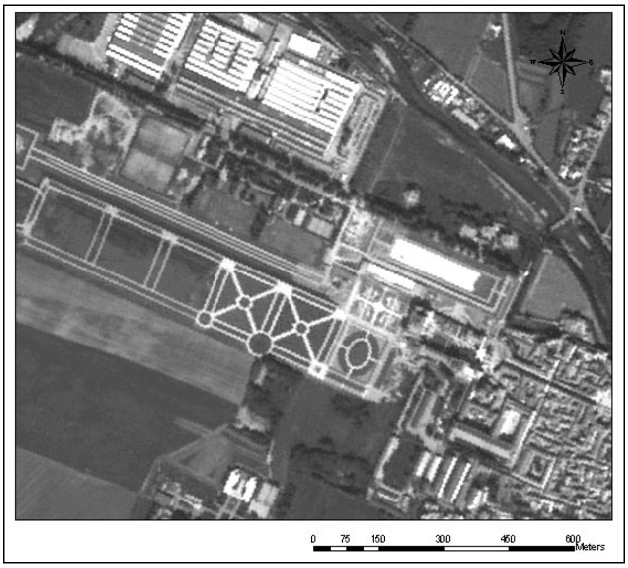

Figure 5. Spot 5 image (2.5m) of the *Venaria Reale* area

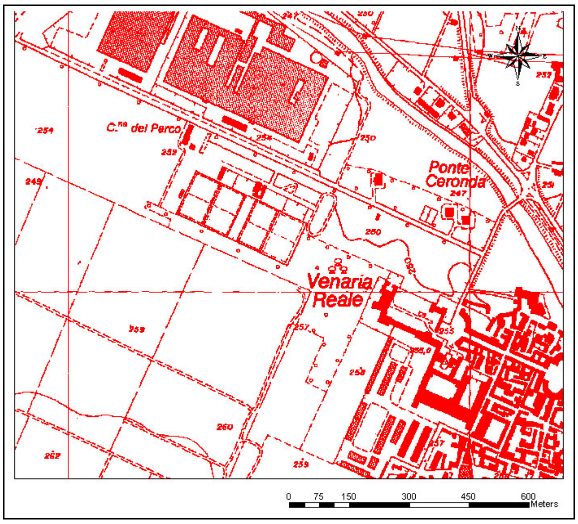

Figure 6. The 1:10000 Region Technical Map before updating

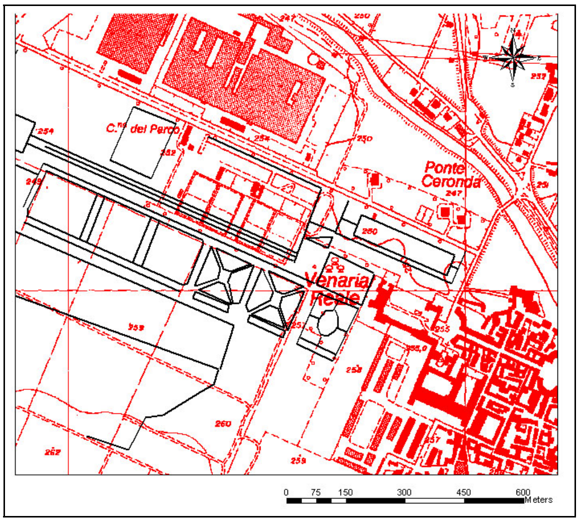

Figure 7. The 1:10000 Region Technical Map after updating (darker lines)

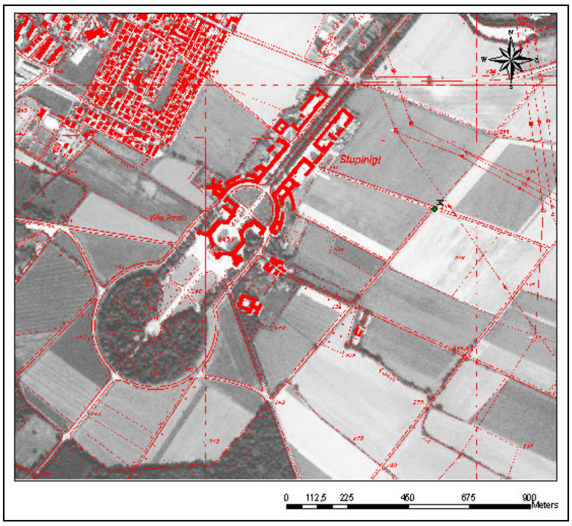

Figure 8. 1:10000 Regional Technical Map overlapping the Spot5 orthoprojected image of the Stupinigi test site.

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

2.2 Archeological application

This section is intended to consider potentiality of hyperspectral data acquired by the airborne sensor MIVIS in the archeological field. The following work 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 (North Western Italy) between X and XIV Centuries. It is worth to here underline this type of analysis is not only aimed 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.
Again is necessary to define the map scale which such data are suitable for. It is worth to underline the fact that MIVS scanner is a whiskbroom one, and image presents a strong geometrical deformation which has to be corrected both for a positioning problem and for object shapes reconnaissance.
Besides, due to the usual need of data coming from survey campaigns, positioning problem has to be considered also for effective dialog between image and terrain data. No rigorous model is available to treat MIVIS data and metadata necessary for eventual rigorous approach are often missing especially for old images.

2.2.1 Available data

Investigations have been carried on using:

- a numerical Technical Regional Map (CTR scale 1:10 000);
- a 50x50m grid Digital Elevation Model;
- Archaeological, geological and botanical available data (derived from the "*Marchesato di Saluzzo*" GIS);
- 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).

Bands acquired by the 3rd spectrometer are, for the used images, damaged and not useful.

2.2.2 Geometric Correction

When dealing with territorial applications it is always important to correctly approach the scale mapping problem. 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 considered to make MIVIS data suitable for the subsequent data integration.
Again both RFM and MLP NN approaches has been tested to correct available image, whose pixel size is about 3 meters. In Table 3 are some results concerning reached accuracy.

Method	N° GCPs	N° CHKs	Δξ mean CHK	Δη mean CHK	RMSE CHK (pixel)	RMSE GCP (pixel)
RFM	72	10	0.00	0.00	6.13	5.09
MLP NN	72	10	0.00	-1.07	4.00	2.56

Table 3 – Accuracy tests results obtained with the RFM and MLP NN self-developed orthoprojection routines on the airborne sensor MIVIS image.

Results show a better performance of the MLP NN approach and underline the need of a high number of GCPs especially in a mountain region as the one considered is. Best performance of MLP we guess it can be due to the better generalisation capability of this techniques. It is in fact known that RFM are mathematical model suitable for pushbroom type images, and they can presents some limits for other image geometry.
Figure 9 shows a qualitative verification of correction performance by overlaying the 1:10000 CTR map.

Figure 9 - 1:10000 Vector map overlaid onto the orthoprojected image.

2.2.3 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:

- 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;
- 2 in the near infrared range (b23= 1.2750 μm, b28= 1.5250 μm), for vegetation cover anomalies;
- 1 in the medium infrared range (b52= 2.1790 μm) for soil moisture;
- 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.

2.2.4 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:

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.

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.

2.2.5 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 (SAM) 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 (here not reported) was calculated. It shows a correct classification of ROIs, although in the next future a certification on the ground could be necessary.
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 10).

Figure 10 - 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 11). 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.

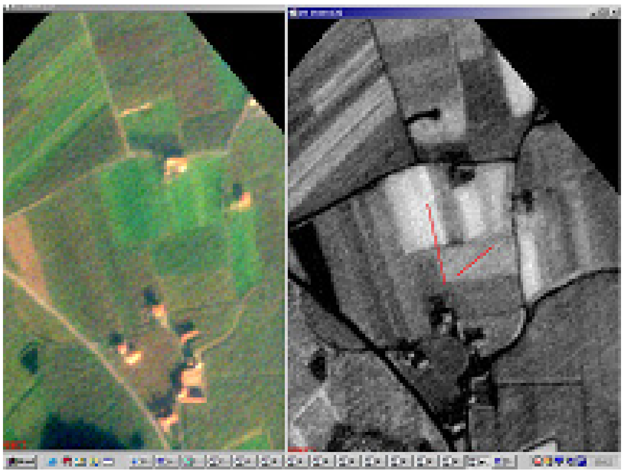

Figure 11- San Massimo area and linear traces in the rule image of “streets” class.

3. CONCLUSION

As far as map updating problem is concerned it has been shown that geometric and content features of orthoimages have to be seriously considered. Their quality strictly depends on the adopted correction method. Non-parametric approaches, if well conditioned, can successfully been used for such purposes.
In particular Spot 5 oversampled images demonstrate a suitability for a 1:10000 planimetric scale map updating.
Correct satellite stereopairs orientation could further encourage map updating users towards map production.
As far as archeological instances are concerned dimensions and placement of terrain anomalies that could be correlated to archeological evidences show how the geometric problem is again important. Accurate positioning is necessary for precise terrain investigations. Shapes are important for understanding nature of the anomalies. The test areas analysis has identified some interesting anomalies that have to be checked on the ground.

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