Hyperspectral MIVIS data to investigate the Lilybaeum (Marsala) Archaeological Park
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ABSTRACT

In the last 20 years air photograph and remote sensing, both from airplane and satellite, allowed to gain, from the analysis of the superficial land unit characteristics, useful information for the location of buried archaeological structures.

For this kind of investigation, hyperspectral MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) data revealed to be very useful, for example, since 1994, for the purpose CNR-LARA research project, many archaeological studies have been supported by MIVIS data on several Italian archaeological sites: Selinunte, Arpi (Foggia), Villa Adriana (Tivoli) and Marsala.

Marsala town, the ancient Lilybaeum, lies on the western coastline of Sicily, at about 30 km south of Trapani. Founded by the Phoenicians, it intensely lived during the Punic, Roman, Arab and Norman periods, whose dominations left many important remains.

This archaeological area was investigated by means of several techniques, such as excavations, topographic studies based on airborne campaigns, etc. On this site the main archaeological information were provided by the analysis of the VIS-NIR spectral bands and by Thermal Capacity image.

Keywords: remote sensing, archaeology, cultural heritage, MIVIS airborne hyperspectral sensors, Lilybaeum.

1. INTRODUCTION

Because of the processes of swift landscape transformation and the possible destructive effects deriving from this, it is indispensable make to the preliminary study of the document archaeologically interesting areas, in order to plan research activities or landscape planning actions.

In past years archaeologists used air pictures to investigate the archaeological areas. In the last years the development of advanced technologies has provided an additional investigation instrument, useful for the analysis of the territory and to integrate the information derived from field work survey. This new method is the application of the remote sensing as an aid to a better understanding and characterization of buried elements in different archaeological sites; in particular relevant archaeological features have been pointed out in several studies making use of optical multispectral remote sensing sensors, such as Landsat TM and MSS, SPOT XI, Terra ASTER, etc. [5, 6, 17, 26, 28, 29, 34, 41, 42], while Barnes [3] showed the combined use of LIDAR and CASI images to identify archaeological earthworks in England.

In Italy since 1994 the CNR-LARA (Airborne Laboratory for Environmental Research) has carried out research activities involving both remote sensing and archaeology, by using Daedalus AA5000 MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) airborne hyperspectral scanner to recognize the soil discontinuities connected to buried anthropic elements, on the basis of their geometric and spectral properties, which differ from those of surrounding materials. The presence of structures in the subsoil can be revealed by studying the spatial discontinuities of the soil’s mechanic characteristics that cause variations on surface spectral responses [7, 12, 16, 25, 27, 29, 35, 41].

2. MIVIS REMOTE SENSING TO STUDY ARCHAEOLOGICAL REMNANTS

The MIVIS spectrometer is a passive remote sensing instrument which collect the earth surface radiation from an airborne platform. The detector separates incoming radiation into four optical ports (see table 1) covering the Visible (0.43 - 0.83 µm), the Near-InfraRed (1.15 - 1.55 µm), the Mid-InfraRed (2.0 - 2.5 µm), and the Thermal-InfraRed (8.2 - 12.7 µm) region; total 102 spectral bands. It operates with an Instantaneous Field Of View (IFOV) of 2 mrad. The air platform aboard of which MIVIS is installed is a CASA 212/200 [8, 9].

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MIVIS data acquired revealed to be very useful on several archaeological sites: Selinunte (Trapani) [2, 12, 13, 18], Arpi (Foggia) [14], Villa Adriana (Tivoli-Roma) and Lilybaeum (Marsala) [33].
In this paper we present the results of the analysis of the MIVIS data collected over the Archaeological Park of Marsala (western Sicily, Italy, see figure 1) to detect the ancient urban street network.

### 3. LILYBAEUM: HISTORICAL, ARCHEOLOGICAL AND TOPOGRAPHIC CONTEXT

Marsala (*Lilybaeum*), one of the major urban centers of Sicily, is located along the island’s western coastline, at about 30 km south of Trapani. The present city covers roughly 70% of the Punic-Roman town, and the remaining 30%, free from buildings, constitutes the Archaeological Park under the protection of the local Monuments and Fine Arts Department. Lilybaeum, the ancient town, took up a rectangular area on Boeo Cape, a low and rocky promontory sloping gently down towards the sea [44] (figure 1).

![Figure 1: Sicily island in Italian geographical context.](image)

The origin of Marsala is linked to the end of Mothia, the town nearby founded in 397 BC by the Phoenicians and burnt down by Dionysius the Elder, the Tyrant of Syracuse. The survivors sheltered among the local population settled on the promontory of Boeo Cape and founded the town of Lilybaeum. Under the Carthaginians, the town was a powerful colony which held out against Dionysus’ and Pyrrus’ attacks. In 350 BC the new settlement was surrounded by walls and defended by a deep moat, and in the 3rd century BC it assumed the appearance of an Hellenized town. In 241 BC, after the Punic wars, the town was conquered by the Romans, who made it the main naval base of the Mediterranean sea and an important junction between Rome and the African continent. Once conquered by the Arabians in 830 AD, the town, probably reduced just to a small village, changed its name to *Marsah el Ali* (the harbor of God), from which the present denomination Marsala derives [10].

Lilybaeum’s topography has not yet been studied in depth. The first scientific study on the ancient center is owed to Schubring [40] who provided us with a description of the ruins still visible in the half of the 19th century. Only after 1960 Schmiedt, by studying some airphotos, proposed a reconstruction of the urban street network [38, 39]. This one was constituted by a regular grid of *cardines* and *decumani*, which, crossing at right angle, formed *insulae* 3 x 1 *actus* (35.52 m. x 106.56 m) size, as shown in figure 2.

<table>
<thead>
<tr>
<th>Spectrometer</th>
<th>Spectral Region</th>
<th>Bands Number</th>
<th>Spectral Range (µm)</th>
<th>Band Width (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Visible</td>
<td>20</td>
<td>0.43-0.83</td>
<td>0.02</td>
</tr>
<tr>
<td>II</td>
<td>Near Infrared</td>
<td>8</td>
<td>1.15-1.55</td>
<td>0.05</td>
</tr>
<tr>
<td>III</td>
<td>Medium Infrared</td>
<td>64</td>
<td>2.0-2.5</td>
<td>0.009</td>
</tr>
<tr>
<td>IV</td>
<td>Thermal Infrared</td>
<td>10</td>
<td>8.2-12.7</td>
<td>0.34-0.54</td>
</tr>
</tbody>
</table>

*Table 1: MIVIS spectral characteristics*
The urban scheme can be dated to 2nd century BC, following a more ancient plan [20, 24]. Both *decumanus maximus*, coinciding with the main NW-SE trending axis of the promontory, and the orthogonal *cardo maximus* follow the track of two actual main urban streets: they are considered as reference elements in the description of the geographical distribution of detected lineaments (see the bold lines in figure 2). A fortification, reinforced by two powerful towers and a moat, surrounded and isolated the town [21]; nowadays, only very few traces of this defensive system can be seen. The big moat is completely buried. According to the local tradition the acropolis of the Punic and Roman center was located near the NE side of the walls, namely the highest place in the town. Among the ancient buildings the excavations brought to light an *insula* with its thermal baths and rich mosaics, and the so called Roman Villa, located at the NW side of the Archaeological Park and dated back to 193 AD. Outside the walls, along the eastern side of the town, starting from the external edge of the moat, there was the necropolis of Lilybaeum [22, 23].

4. DATA ANALYSIS AND METHODS

The campaigns over the Marsala archaeological Park was performed by the CNR IIA (Atmospheric Pollution Institute) on July 20th 1994, 10:15 (local time), at an altitude of 2000 m. a.s.l., thus achieving a ground resolution of 4 m/pixels (LIL1994) and on July 25th 2002, 11:55 (local time) at an altitude of 1500 m. a.s.l. (3 m/pixel ground resolution, LIL2002).

MIVIS data were radiometrically calibrated and geometrically corrected [1, 4]; finally the data were normalized according to a known spectral response (concrete square) by the *Flat Field Calibration* method, in order to obtain an apparent reflectance.

The present study is based on the principle that any buried remnants, either of human or natural origin, affects over time soil surface characteristics creating anomalies, due to different factors, such as:
- vegetation cover status;
- soil physical and chemical features.

To highlight the surface anomalies identified in the MIVIS images different hyperspectral data processing procedures were used:

<table>
<thead>
<tr>
<th>Procedure</th>
<th>LILYBEAUM 1994</th>
<th>LILYBEAUM 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Components Analysis (PCA)</td>
<td>PC1994n</td>
<td>PC2002n</td>
</tr>
<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>NDVI-1994</td>
<td>NDVI-2002</td>
</tr>
<tr>
<td>Thermal Capacity (CT)</td>
<td>CT-1994</td>
<td>CT-2002</td>
</tr>
<tr>
<td>Supervised classification: Spectral Angle Mapper (SAM)</td>
<td>RI1994-roi</td>
<td>RI2002-roi</td>
</tr>
</tbody>
</table>

The digital products derived from different processing techniques, have been interpreted from archaeological and topographic points of view. The results have been compared to earlier archaeological findings.
An archaeological trace is meant to be the effect on an image of the interaction of different elements which encompass or hide the archaeological object; these elements, of chemical-physical, biological and morphological nature, are humidity, humus, vegetation and relief [15, 36].

The archaeological traces can be classified [37] as follows:

- **Humidity traces**: moist soil can be assimilated to an imperfect reservoir in which the presence of buried archaeological elements produces anomalies in water distribution, giving origin to areas with differentiated humidity; in the image these areas exhibits a colour shade different from the surrounding soil, as they are lighter in case of positive archaeological elements (walls) and darker in case of negative elements (ditches, canals, etc.). The perception of this phenomenon depend on the depth of the burial, the firmness of the structures and the climatic and environmental conditions.

- **Vegetation traces**: even though similar in behavior to the foregoing class, they differ as occurring on surfaces where vegetation grows more luxuriant and green, due to abundance of humus and humidity.

- **Soil composition alteration traces**: they depend on the presence of fragmented material (remains of ancient destroyed structures, large amount of fectile elements, etc.) in some part of the soil, highlighted by a colour changes due to grain size differences with respect to the soil nearby.

- **Survival traces**: some examples are the Roman centuriae or current roads precisely corresponding to ancient routes.

- **Microrelief traces**.

- **Underwater remain traces**.

- **Anomaly traces**: not included within the previous ones.

### 4.1 Principal Components Analysis (PCA)

The PCA is a statistical technique used to produce uncorrelated output bands and to reduce the dimensionality of data sets. This is done by finding a new set of orthogonal axes that have their origin at the data mean and that are rotated so the data variance is maximized. This transformation allows to synthesize the information present in the original spectral channels into a number of new bands. The first principal component (PC1) represents the averaged sum of all bands, that is an image carrying the overall radiance and most of information initially distributed among all bands and the second one contains the second largest data variance, and so on. The last PCn bands appear noisy because they contain very little variance, much of which is due to noise in the original spectral data [11].

The MIVIS images of airborne campaigns of the 1994 and 2002 were processed using the PCA. The PCA was first applied to the bands of the 1st MIVIS spectrometer and afterwards, in sequence, to those of the three others. Among the PCs derived from a given spectrometer, the one providing more significant archaeological information was selected.

For LIL1994, the spectrometers # 1 and 2, the two first PCs were more significant (hereafter named respectively as PC1994a-PC1994b and PC1994c-PC1994d), while for spectrometers # 3 and 4 only the first one (herein PC1994e and PC1994f) was taken into account (see table 2).

For LIL2002, as regard to the spectrometers # 1, the two first PCs were analyzed (named respectively as PC2002a and PC2002b). The PCs relative to the NIR, MIR and TIR regions have provided significant archaeological results only in the 1st PC (PC2002c-PC2002d and PC2002e). This could be due to the high proportion of the variability explained by the first PCs alone (see table 2).

<table>
<thead>
<tr>
<th>SPECTROMETERS</th>
<th>LILYBEAUM 1994</th>
<th>LILYBEAUM 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>PC1994a, PC1994b</td>
<td>PC2002a, PC2002b</td>
</tr>
<tr>
<td>II</td>
<td>PC1994c, PC1994d</td>
<td>PC2002c</td>
</tr>
<tr>
<td>III</td>
<td>PC1994e</td>
<td>PC2002d</td>
</tr>
<tr>
<td>IV</td>
<td>PC1994f</td>
<td>PC2002e</td>
</tr>
</tbody>
</table>

Table 2. Definition of PCs obtained by combining MIVIS bands as a function of spectrometers.

**LIL1994**

The analysis of the PC1994 images (figure 3) enables to recognize a series of linear anomalies referring to a wide extension of the ancient area. SW of the decumanus maximus several traces related to 3 decumani (NW-SE orientation) and 5 cardines (NE-SW) were located. NE of the decumanus maximus seven traces, following a NW-SE orientation (decumani), and two parallel axes with NE-SW orientation (cardines) can be outlined. Northward of the investigated area the ancient moat (darker trace) can be located with particular clearness; before reaching the sea, it turned slightly northwards perhaps following the maximum slope line. Moreover NE of the decumanus maximus, one dark anomaly...
characterized by a rectangular shape is visible. It can be identified as a building with remarkable size (occupying a whole *insula* in length) situated in the area where there was the acropolis of the Punic and Roman town.

LIL2002
Within the considered subsets the first five PC2002s have been photo-interpreted. The lineaments, which can be sketched from the PC2002, confirm the information acquired by means of the PC1994’s. In the archaeological area different traces of the ancient buried street were found: 5 linear traces parallel to the *decumanus maximus*, identified as the *decumani*, and 3 *cardines* were individuated. In the PC2002a image 3 *decumani* and 2 *cardines* were found, NE of the *decumanus maximus*. In the PC2002b picture 2 linear parallel anomalies were found SW of the *decumanus maximus* crossing it at right angles: they can be identified as *cardines*. The PC2002c analysis let us identify a linear trace parallel to the *decumanus maximus*, while in the NE sector of the studied area two *decumani* can be seen. At last, the PC2002d and PC2002e images, NE of the *decumanus maximus*, 2 *decumani* were identified.

![Image](http://example.com/figure3.png)

Figure 3. All linear features identified by examining the PC1994’s computed from selected MIVIS bands groups

### 4.2 Normalized Difference Vegetation Index (NDVI)

To determine the density of green on a patch of land, researchers must observe the distinct colors (wavelengths) of visible and near-infrared sunlight reflected by the plants. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) to use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are affected, respectively.

Nearly all satellite Vegetation Indices employ this difference formula to quantify the density of plant growth on the Earth near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. The result of this formula is called the Normalized Difference Vegetation Index (NDVI):

\[
\text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})}
\]

Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A value equal to zero means vegetation absence and close to +1 (0.8 - 0.9 µm) indicates the highest possible density of green leaves [30, 31].

LIL1994
The linear anomalies detected in this site were linked especially to vegetation cover status. By analyzing the image of the NDVI many archaeological information has been derived so improving the topographic knowledge of the ancient site of Lilybaeum. In particular in the NDVI-1994 has been detected: a series of the traces corresponding to 7 *decumani* (NS direction) and 4 *cardines* was identified.

**LIL2002**

In the NDVI-2002 image the following features have been detected: SW of *decumanus maximus*, a series of traces corresponding to 2 *decumani* (north-south direction) and 3 *cardines* was identified. Also in the area to Westward of the *decumanus maximus* several linear anomalies were recognized corresponding to the road axes of the ancient city; 3 road axes with NS direction (*decumani*) can be seen as well as 2 EW parallel axes (*cardines*) can be also observed (figure 4).

![Figure 4: Linear characteristics found by examining the NDVI-2002 index.](http://proceedings.spiedigitallibrary.org/)

### 4.3 Thermal Capacity (CT)

To investigate the spectral contrast between the TIR and the VIS regions the ATI image has been calculated. It represents an approximation of the true Apparent Thermal Inertia (ATI) which is a physical variable related to thermal conductivity, density and thermal capacity. ATI is defined in remote sensing as the ratio, within a given time interval, between the energy absorbed by surface materials, in visible spectral region, and the corresponding temperature changes. In the case of the Lilybeaum’s MIVIS data, ATI is computed according to the following formula:

$$\text{ATI} = \frac{1 - A}{T_1 - T_2}$$

(2)

where \( A \) is the mean albedo computed by averaging the reflectance value from MIVIS bands 1 (0.43-0.45 \( \mu m \)) to 13 (0.67-0.69 \( \mu m \)), and \( T_1 \) represents single pixel daytime temperature derived taking into account all MIVIS thermal bands, while \( T_2 \), usually pointing out nigh-time temperature, has been simulated, lacking a night overpass, with a constant value equal to:

$$T_2 = T_{\text{min}} - 0.1(T_1 - T_{\text{min}})$$

(3)

where \( T_{\text{min}} \) represents the lowest temperature in the scene [13, 19, 43], Thermal Capacity (CT) is obtained by the following formula:

$$\text{CT} = \frac{1-A}{(T_1 - (T_{\text{min}} - 0.1(T_1 - T_{\text{min}})))}$$

(4)
Data obtained by processing the Thermal Capacity are particularly relevant. In the archaeological area, four linear anomalies parallel to the *decumanus maximus* and three anomalies, crossing at right angle with the *decumanus maximus*, they can be identified as *cardines*, were distinguished.

LIL1994
The analysis of the CT-1994 image carried out by partitioning the studied area into the already mentioned subsets, has been detected 4 well defined N-S trending lines (the longest corresponding to the *decumanus maximus*) and other 3 perpendicular to them.

LIL2002
Significant archaeological results have been obtained by interpreting: from the CT-2002 image. In this area small segments of 5 linear features, with N-S orientation (the longest seems to correspond to the *decumanus maximus*), and other 4, orthogonal to these, have been recognized (*cardines*) (figure 5).

![Figure 5: Linear characteristics found by examining the CT-2002 image.](image)

**4.4 Spectral Angle Mapper (SAM)**
To completely exploit the information content of MIVIS images, the “supervised” classification SAM method [32] [45] was applied. The results of the SAM method are expressed as angular differences (radians from 0 to $\pi/2$) between two spectra, treated as vectors in N-bands space.

The SAM technique provides as output a number of images, the *Rules Images* (RI), equal to the number of spectral classes beforehand selected as representing meaningful surface units. In the RIs the dark tones correspond to pixels characterized by a spectrum similar to the reference one, while the light tones represent pixels spectrally farther. Moreover, SAM classifier provides a synthesis thematic image, which describes with same colour the uniform class units, corresponding to the earlier chosen surface units (named as *Regions Of Interest* or ROI).

For this study the ROIs have been the following:

- Cover material of current main roads (asphalt and dirt roads, RI-road);
- Buildings (RI-build);
- Vegetation (RI-veget);
- Soil (RI-soil);
- Waters (RI-water).
In particular among the RIs derived from the “supervised” classification of the MIVIS images (LIL1994 and LIL2002), the one showing more significant archaeological information was selected:

<table>
<thead>
<tr>
<th>LILYBAEUM 1994</th>
<th>LILYBAEUM 1994</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI1994-build</td>
<td>RI1994-veget</td>
</tr>
<tr>
<td>RI1994-veget</td>
<td>RI1994-soil</td>
</tr>
<tr>
<td>RI1994-soil</td>
<td>RI1994-water</td>
</tr>
</tbody>
</table>

The Colour Composite of MIVIS bands 13 (0.671-0.694 µm) - 7 (0.531-0.573 µm) – 1 (0.431-0.452 µm) was used to define the ROIs. The thematic map produced by SAM classification method does not allow to discriminate any traces: it represents, in fact, a thematic map where pixel is assigned as a unit code indicating the class with the minimum angular distance with respect to the other possible classes; the assigned code, therefore, is not exhaustive of the real inter-class pixel distance that could be related to lineaments. Linear anomalies can be, instead, detected as tonal lineament pattern on the RIs where the pixel-class distance, quantitatively expressed by means of angle cosine values, accounts for evenly small spectral variations due to physical/chemical differences.

LIL1994
The analysis of the selected RI1994-build, RI1994-veget, RI1994-soil and RI1994-water have allowed to recognize 17 road axes with NW-SE orientation, which can be identified as decumani of the ancient town, and 3 NE-SW oriented parallel lines, namely cardines, which perpendicularly cross the decumani, so forming some blocks. The decumani, located to NE of the decumanus maximus and visible in the RI1994-build and RI1994-soil, are particularly important as they clearly outline the urban pattern of that sector. The analysis of RI1994-veget, RI1994-soil and RI1994-water highlighted, on the plateau to S-W of the archaeological area, some linear anomalies which criss-cross forming a grid of insulae with pattern different from that currently documented. This result seems to be interesting since it could prove the superimposition of urban elements testifying a street and block pattern change over the time.

LIL2002
All RI2002 images show enough clearly 6 N-S trending axes (decumani) of the ancient town street network in the archaeological area. Moreover, 2 main W-E trending street axes (cardines), orthogonal to the previously mentioned roads, can be easily identified in the RI2002-veget, RI2002-soil, while another one, parallel in between the others, is visible in RI2002-water and hasn’t been previously recognized (figure 6).

![Image](http://proceedings.spiedigitallibrary.org/)  
Figure 6: The image (RI2002-veget) deriving from the application of SAM classification algorithm with the located archaeological structure.
5. INTERPRETATION

The comparison of the results derived from the analysis of the MIVIS images of the 1994 and of the 2002 stresses some differences: most linear traces shown by the MIVIS images of 1994 airborne campaign are not present in MIVIS scenes of the 2002.

Interpreting the RIs and PCs the results appear comparable to the detail of Lilybaeum street pattern; in general, the RIs show more continuous features and locally new and extended lineaments.

Main information about the ancient street network of Lilybaeum are visible in the PCs obtained from the 1st MIVIS image spectrometer, for both MIVIS data-set (LIL1994 and LIL2002). The PCs computed from the other three MIVIS spectral windows contain only complementary information.

By analyzing the CT images (CT-1994 and CT-2002) we are able to recognize the main Lilybaeum road axes. This outcome seems to support the hypothesis that the detection of linear features, as surface evidence of ancient buried structures, is strictly related to the moisture content and evapo-transpiration of surface material, depicting a lineament distribution comparable to that identified in all RI-roi (figure 6). This relation is confirmed, in fact, by the analysis of the SAM procedure (RI1994 and RI2002), which is mainly controlled by terrain wetness.

More evident and spatially continuous features, instead, are obtained by analysing the NDVI (NDVI-1994 and NVDI-2002) and give us archaeological information about vegetation cover.

All features individuated in Marsala Archaeological Park as surface evidence of ancient buried structures appear to be mainly related to physical properties of the terrain such as moisture instead of land cover types (vegetation cover).

The linear features, as identified by interpreting the MIVIS images have been then compared separately with each segment of the urban street pattern shown in figure 2. A precise archaeological meaning then was ascribed to each anomaly trace taking into account the actual state of art of the archaeological knowledge.

All this archaeological information, resulting from the analysis of MIVIS hyperspectral data, enables to hypothesize a Lilybaeum topographic setting of different from that accepted so far [23, 24, 38, 44].

In fact, taking into account the urban blocks (insulae) determined by decumani and cardines criss-crossing, SE decumanus maximus, they are elongated with a NE-SW trend, while, NE of the same decumanus, their longer axis exhibits a NW-SE orientation (figure 7). It is possible that this urban setting (analogous to that characterizing Selinunte Acropolis) was adopted because of local morphology and problems linked to meteoric water drainage. This archaeological scenario [23, 24, 38, 44] appears to disagree with earlier reconstructions, according to which the whole Lilybaeum territory was partitioned into blocks of the same size (3 x 1 actus), the same orientation and direction.

Figure 7: Lineaments considered as relating to the scheme, white rectangles indicate the insulae: SW insulae are orientated differently from NE ones.
6. CONCLUSIONS

MIVIS hyperspectral data processing enabled us to acquire information useful for the identification of the ancient street network of Lilybaeum, located on the basis of anomalies due to the variations of textures, humidity and vegetation of the earth’s surface caused by the presence of buried human remnants. These results confirm and sometimes change archaeological hypotheses based on traditional investigation methods. They must be obviously confirmed directly in situ, in order to plan a precise strategy for future excavation campaigns.

REFERENCES


