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INTEGRATION OF MIVIS HYPERSPECTRAL REMOTELY SENSED DATA AND GEOGRAPHICAL INFORMATION SYSTEMS TO STUDY ANCIENT LANDSCAPES: THE AQUILEIA CASE STUDY

The research aims at the evaluation of the potentiality of the Hyperspectral MIVIS data for the identification of the possible unknown archaeological areas in the Communes of Aquileia, Terzo d'Aquileia, Fiumicello (UD). The possibility in fact to locate by spectral recognition unidentified archaeological sites is an interesting addition to the traditional survey method. A GIS, created on purpose for managing the archaeological thematic cartography, supports the interpretation and the contextualization of the remotely sensed images.
The work has consisted of three phases: treatment of the images (Vegetation Indices, P.C.A., Soil Index), where the spectral informative content of the MIVIS images was used to give prominence to the presence of ancient buried sites and structures on the base of the different spectral characteristics of the terrains and of the vegetation; analysis of the archaeological issues, where a methodic collection of published data and of reference thematic cartography was realized, in order to build up an archaeological thematic map in digital format; finally, a phase of managing of the images in a total architecture (GIS), where the archaeological information and the MIVIS images, processed and georeferenced, were inserted in a information system that provides and manages the data necessary to eventually recognize the surface anomalies as ancient origin traces.

1. Introduction

In spite of the still sparse usage of the multispectral Remote Sensing methodology, Italy holds a long tradition of studies of its applications in archaeology, starting with the appliance of multispectral sensors at the end of the '70s (Marcolongo 1978; Barisano *et alii* 1984). After these first pioneering works, from the latter half of the '80s to the first half of the '90s there has been a multiplication of the applications in various areas of Italy, often sponsored by local administrations in conjunction with Universities.[1] More recently, a particular attention to airborne hyperspectral systems (or sensors) applied to archaeology has occurred: most of the researches have been based in Sicily where Selinunte (Cavalli, Pignatti 2001) and *Palmyra* (Colosi *et alii* 1996), Mozia and Alesa (Belvedere *et alii* 2004), Piazza Armerina (Emmolo *et alii* 2003) have been target areas for MIVIS shots; in northern Italy the case of the Po Valley (Ardissone *et alii* 2003) is a prime example.

[1] Specific examples are: the applications of Landsat T.M. and Ikonos images for the study of Tuscany landscape: Campana 2003 (refer to this for author's previous bibliography); Cremaschi, Forte 1999's studies about the Po Plain; Diceglie 1992, investigating Lampedusa Island 'stone circle'; Forte, Montebelli 1998, studying the Belice Plain area; Pieri, Pranzini 1989 on the Pisa Plain.

The Regione Friuli Venezia Giulia holds a consistent collection of remotely sensed images, both panchromatic and hyperspectral, that together with the digital Regional Technical Maps (CTR) constitute an important source of data and tools suitable for the archaeological research and the investigation of the development of regional settlement patterns in ancient periods.[1] In particular, the coverage of MIVIS hyperspectral images is almost complete, covering a large part of the extension of the region, with shots taken in a period going from 1998 to 2003. The MIVIS images have already provided in the cited cases encouraging results that demonstrate how they align with and enhance the goals of archaeological studies. This article will stress the results that can be provided with the integration, through a GIS, of hyperspectral data with more traditional tools, such as orthophotos, historical pictures, previous archaeological maps and survey data.

2. Objectives

This study aims to evaluate the potential of the remotely sensed hyperspectral MIVIS data and ascertains their usefulness in identifying traces that can be physically explained through the presence of buried structures in the suburban area of Aquileia. The methods for the characterization and identification of unknown archaeological sites are based on the measurement of some specific physical property that differentiates these sites from the surrounding soils and vegetation. Secondarily, the goal is to create a GIS operating as a management system for the integration of the information extracted from different remotely sensed data at disposal and any other useful data (aerial pictures, survey data, previous researches' results etc.) of the target area in order to provide a valuable instrument for the study of the ancient landscape and for landscape planning.

In order to better evaluate the capacities of hyperspectral images and their possible applications to the archaeological research, it is extremely important to define some issues that need to be faced and that define trends in the current research.[2] It is very easy in fact, to get lost in the excessive attention to technical details of informatic applications in archaeology, losing sight of the real, final goal that is the standardization of a tool for a better understanding of the landscape settlement patterns. Due to its intrinsic characteristics and capabilities (a surface resolution 3 m by 3 m), MIVIS can theoretically identify, on the ground, objects having a minimum average area of 35/40 m^2 or a length of at least 6 m. From an archaeological point of view this means that, while it can deal well in the identification of large built structures or settlements, canals or street networks, a large quantity of small archeological remains can not be detected. For this reason it is important to investigate if the resolution at the ground provided by MIVIS images is suitable for the needs of the archaeological research and

[1] I would take here the opportunity to thank the Servizio sistema informativo territoriale e cartografia, department of the Direzione centrale pianificazione, mobilità e infrastrutture di trasporto of Regione Autonoma Friuli Venezia Giulia for allowing the use of tools and data indispensable for this work (MIVIS images, Orthophotos, CTR). MIVIS images, Orthophotos, Regional Technical Map (CTR): received authorization from Regione Autonoma Friuli Venezia Giulia, P.M.T./1295/2100, Jan. 25th 2005. Orthophotos: property of Compagnia Generale Ripreseaeree S.p.A. Parma.

[2] About the importance of defining research goals see CAMPANA 2003.

the study of the settlement dynamics of the target area on the base of the expected types of remains and which kind of archeological structures the sensor can be expected to identify. Equally important is to investigate when hyperspectral sensors could play a contributing role in the identification of archaeological targets that cannot be provided by well-established methods like aerial photographs. Another step of the research is to define how successful the employment of hyperspectral images can be in a landscape, like Aquileia, that has been strongly modified by human behavior and the land reclamation works in the postwar period.

Other issues exist that are related to the methodology of the research. First of all the results provided by hyperspectral sensors should be quantifiable and provable and it is fundamental, in order to evaluate them, to have a method to test credibility of the results. This is a datum extremely important since the use of a hyperspectral sensor can affect considerably the budget of an archaeological research compared to the cost of, for example, panchromatic pictures. Another problem that needs to be faced when dealing with large quantities of image processes is the redundancy of the data: many of the different processes produce similar results that provide the same features or traces. The number of identified and recorded features in this way becomes exponential: it is prudent for this reason to set a methodology for investigating the traces and to define criteria for listing in order to reduce the time of cataloging and the tedious work from repetitive processes. To develop this methodology, it is important to identify how many anomalies does anyone given process allow to identify and with which level of certainty. Nevertheless, the sort of environment or conditions these processes work best in must be extrapolated in order to define their repeatability.

3. Case study area

The area used as a case study includes the urban and suburban area of Aquileia and the neighboring Communes of Terzo di Aquileia and Fiumicello (UD). Until now, the archaeological researches have favoured the issues related to the urban area included among the different city walls' circuits,[1] aiming to analyze mainly the planimetric characteristics of the ancient town. With regard to the surrounding landscape, only recently has there been topographic research, aiming at the reconstruction of the settlement system, of the resource exploitation and of the distributive arrangement of the suburban spaces (Oriolo 1998; Maggi, Oriolo 1999; Buora 1992). This represents a serious lack of the studies since the suburban area constitutes a fundamental investigation area for the full comprehension of spatial organization forms of the town itself and the surrounding dependent countryside (Maggi, Oriolo 1999, p. 99).

A whole string of archaeological problems concerning the area, such as the uncertainty of the communication networks connecting Aquileia to the other main roman towns,[2] the growth or contraction of sea areas – the current landscape morphology results in fact from a long and complex process linked with the sea level variations (Bottazzi, Buora 2001; Gaddi 2001) –, the migration of area rivers (Maggi, Oriolo

[1] For the urbanistic organization, see, listed in inverse chronological order, Bertacchi 2003; Maselli Scotti, Zaccaria 1998; Verzàr Bass 1994; Strazzulla 1989.

[2] For studies of the track of the roman streets: Grilli 1979; Mirabella Roberti 1990; Bosio 1991; *Aquileia Romana* 1991, p. 71.

1999, pp. 113; BERTACCHI 1999, pp. 227-253) and the suburban topography of Aquileia (MAGGI, ORIOLO 1999, pp. 99-123) can benefit by the integration of hyperspectral data and the other information.

The reasons for choosing this target area are multiple. First of all, there is a long tradition of studies and research through extensive archaeological excavations, field-walking survey, aerial photography interpretation and ancient and historical sources that can provide a large amount of information essential for the understanding of the traces detectable by the hyperspectral sensor. Secondarily, and related to the previous reason, the strong archaeological potential and the consequent opportunity to easily find archaeological sites are extremely useful in defining a methodology and testing a system. It is enough to say that the opportunity to have an image showing the situation before an archaeological excavation and to have the opportunity to compare the results of that excavation with the original situation is an optimum way for calibrating the methodology of identification of traces. Thirdly, and in connection with the second point, in an area where the archaeological density is so elevated, like in Aquileia, it is necessary and essential to have a tool able to provide support to the territorial planning. Fourthly, the existence of two recent groups of MIVIS shots of the area taken in very close time (daytime and night) that allow the investigation of multitemporal approaches. Finally, the landscape surrounding Aquileia, which has been for a long time subjected to severe agricultural exploitation, is potentially suitable for the identification of traces of the ancient settlements (MAGGI, ORIOLO 1999, pp. 104).

The investigated area is equal to the extent of the hypersectral images, approximately 105 square Km, distributed in a sort of rectangular shaped polygon around 7 km in width and 13 km in length. The target area, which includes a coastal tract, consists of flat land, whose current morphology strongly depends on modifications where the sea level variations play a fundamental role. The presence of medium and small size rivers strongly shaped also the area in the past, giving to it the current aspect: existence of palaeo-riverbeds can be easily recognized through the simple visual analysis of aerial pictures.

4. METHODOLOGY

In order to test and evaluate the MIVIS hyperspectral images, a flow of operations was followed, involving the processing of the images, the selection of the most significant among them, the submission to visual analysis and the interpretation through the usual methods of ancient topography science. A set of analysis' procedures was applied to the MIVIS images with the purpose of displaying the data in a more effective way, emphasizing specific alterations of the superficial texture. The goal of the enhancement techniques is to increase and improve the optic distinction between features and traces recorded in the scene by generating a new image where the useful information is more easily identifiable. Several enhancement techniques were tested on the data and in some cases were useless to the goals of the research or unsuccessful as products. In actuality, it has become clear that there is not a specific process that can produce an image to fulfill all the archeological needs and that the research must be realized through the identification of the techniques that work best for the specific goals.

However, as in the case of aerial pictures, the produced images are not completely useful and do not provide knowledge or new information by themselves, except in rare cases: what they show are anomalies and traces on the landscape that can have, with equal probability, an ancient or modern origin. In order to 'decode' these images and to give a significance to the anomalies of the scene it is vital to put them in relation with other information sources, first of all the archaeological ones. The integration of the information for the interpretation of the data is reached through GIS architecture. The intent of data merging through the GIS has been to combine the MIVIS data with archaeological, topographical, hydrological, altimetric and administrative information, collected in the form of geographically referenced data sets or geodatabase created from the specialized literature on the topic. Traces and anomalies identified on MIVIS scenes have been recorded by drawing them and compared in the GIS with the other sources of information and a value of 'archaeological reliability' has been attributed to each of them, inferred from the integration of available data. This also allows the comparison, in quantitative and statistic ways, of the number of drawn features in order to evaluate the potential of each performed process in terms of capability of emphasizing the traces: this constitutes the method which makes possible the identification of the process that is more successful at reaching a given goal.

5. Background data

A systematic collection of data was used at the beginning of this work in order to acquire as much information as possible that might aid in the process of decoding the features extracted from the remotely sensed images. As already stated, they have been stored and managed using G.I.S. based technology. This section has been divided into subsections, organized by the typology of the background data collected; it should be pointed out that while the cartography subsection only covers the maps collected and acquired, the G.I.S. section will list the thematic cartography that has been generated during the research activities by the use of base cartography and data from literature.

5. 1. *Cartography*

The maps that have been acquired and introduced in the GIS can be divided into 3 different types: base cartography, thematic and historical maps. The base cartography has been represented by the numeric Regional Technical Map at scale 1:5.000 and at scale 1:25.000 (vector format) of Friuli-Venezia Giulia. Beside the numeric technical map, the previous paper format of the Regional Technical maps have been used in order to record possible modifications in the use of soil: in some cases it is possible to have coverage over different years for the same quadrant and to trace the modifications, for example, of the orientation of irrigation canals, that are often changed and that can easily confuse the interpreter. As regards the thematic cartography, Planning Prescriptions of Archaeological Encumbrances (Piano regolatore di Aquileia. Vincoli, 2000) and Archaeological Encumbrances Map (Carta Tecnica della Regione. Vincoli legge 1089/39) have been introduced in the G.I.S. in order to collect information about areas already under the tutelage of the local Soprintendenza. As third group of background cartography, historical maps have been scanned and acquired in order to be able to manage information related to post-antiquity transformations of the use of the countryside. Among them, the ones delivering most interesting and useful information have been the different Asburgic Land Reclamation Works Maps (*Theil des Görzer Districts*, 1784; *Indice alfabetico e numerico che spiega i lavori fati e da farsi in Aquileja e sue vicinanze*, sec. half XVIII cent.; *Plan der Aquilejer Situation*, 1885?) and a *Centuriatio* traces Map (*Carta della Lombardia, del Veneto e dell'Italia Centrale. Foglio H.4*, 1877).

5. 2. *Remotely sensed images*

The utilized remote sensed images of the target area can be divided in three typologies: hyperspectral sensor images, orthophotos and vertical aerial photographs of the past years. The hyperspectral images are represented, as stated, by MIVIS images. MIVIS is a simultaneous multispectral imaging system that operates in the wide range of wavelengths from visible to Thermal-IR regions of the spectrum, with a high spectral resolution and elevated number of channels (102).[1] The broad spectral range and the multiple, narrow channels of MIVIS provide a fine quantization of spectral information that permits accurate definition of absorption features from a variety of materials, allowing the extraction of chemical and physical information of the environment. The MIVIS images used in this research have been captured on two different days during October 1998 (October 13th and 15th) in two shots: a daytime shot (about h. 12 noon) and a so-called night shot (about h. 9-10 a.m.). The shots taken in the early morning, before the sun could warm the earth surface, can be considered as holding temperature values close to the nighttime low. There are 10 runs, divided in 5 runs for each day, that cover the target area (see FIG. 1). The MIVIS images have been provided at a low level of pre-processing, as a cost-benefit compromise in order to evaluate the effective utilization of this instrument. They have been in fact acquired in only the radiometrically corrected format (so-called *level 1*). Even though it is common belief that remotely sensed data should be radiometrically, atmospherically and geometrically calibrated in order to be considered ready for spectral analysis (LILLESAND *et alii* 2004, pp. 492, 494-496), it has been chosen to not subject them to the geometric correction as a pre-process while it has not been possible to apply the atmospheric one. These choices have been made based on considerations that are going to be exposed in the following section (see Section 6).

The second group of remotely sensed images that have been imported in the G.I.S. are Orthophotos of the target area, shot in 1998 (May 12th). Finally some historical aerial photographs from Aquileia area have been used: they have been introduced for the same reason for which also old cartography has been introduced, that is to say to provide a comparison between older and current situation and avoid misinterpreting recent modification of the soil mistaking them for old ones.

[1] For technical information about the sensor see BELVEDERE *et alii* 2004.

FIG. 1. Mosaic of MIVIS runs 1, 2, 3, 4, 5 (October 15th 1998) of the Aquileia area (authorization: Regione Autonoma Friuli Venezia Giulia, P.M.T./1295/2100, Jan. 25th 2005).

5. 3. *Data collection*

Systematic bibliographic researches have been performed in order to identify the largest number of mapped or mappable information regarding the Aquileia area, subsequently stored in a geo-database related to the G.I.S. module. The data have been extracted from updated and less recent archaeological literature[1] that contained both textual information and maps. While the published archaeological thematic maps contained in volumes have been inserted in the G.I.S. directly as raster layer and then digitized, it was necessary to transform the simple textual information into mappable data that were added to the ones already mapped (see below 7.1).

6. Digital Image Processing

6. 1. *Pre-processing*

When dealing with MIVIS images, a primary difficulty that has to be afforded is the rectification and georeferencing of the data (De Paulis, Cavazzini 2001, pp. 19-25). The images in fact are strongly affected from panorama distortions due to scanner geometry and from effects introduced by perturbations in position and attitude of the airborne platform. From one side, a geometric correction that rectifies the images is necessary not only to make more understandable and recognizable the features on the landscape but also to integrate the MIVIS data in a G.I.S.; from the other side, all of the most common procedures followed to rectify multispectral and hyperspectral images (like R.S.T., Polynomial, Delaunay Triangulation) risk to compromise the radiometric information of the data set. This is particularly relevant if, like in this research, radiometric analyses are going to be applied on the transformed data (Lechi 2000, pp. 233-238). On this base, in the analysis stage only raw data have been used and in a second moment they have been rectified and georeferenced for their integration in the G.I.S.

Another aspect that has been taken in consideration during the pre-processing phase was the atmospheric distortion and the consequent need for a correction. As for other hyperspectral sensors, atmospheric components have two main types of effects on the radiance recorded by the MIVIS sensor. One is related to the fact that, at specific wavelengths, the atmosphere absorbs light, decreasing in this way the quantity of radiance that can be observed. The second effect lies in the light scattered from the atmosphere into the sensor's field of view that adjoins an unwanted source of radiance that has no real connection with the features on the earth's surface. At the current state of the research, the C.N.R. is still working on the developing of appropriate algorithms to apply to MIVIS images, so it has not been possible to perform a specific atmospheric correction to the used data. In addition to that, no ground truth information at the time of the shot have been provided with the images, so that they could be used to implement the corrections. However, it can be said, at least for the majority of the available images, that in the kind of analysis and processes that have been ap-

[1] As regards the urban area of Aquileia, for one of the most recent, see the vast bibliography in Bertacchi 2003; as regards the suburban area see the bibliography in Maggi, Oriolo 1999 and Prenc 2002.

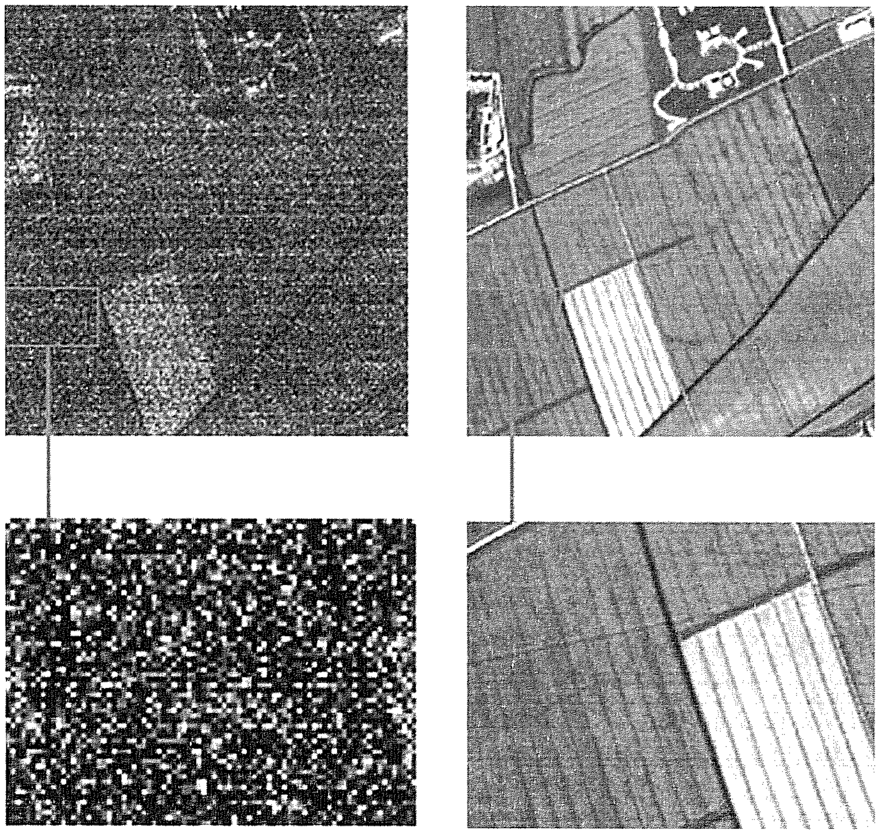


FIG. 2. Comparison of original M.I.R. band of a MIVIS run to the relative inverse M.N.F.: note the improvement of the information in terms of signal noise.

plied the distortion introduced from atmosphere has been very small and not relevant, considering the low altitude flights and the good weather and atmosphere conditions at both the times of the acquisitions.

In order to overcome the shortcomings of the available data sets due the system noise and improve the accuracy of the obtainable results, a pre-processing of the data has been tested and applied, obtaining a drastic reduction of the unwanted disturbance due to limitations of the signal digitization and data recording process. In some cases, in fact, noise was not only degrading the true radiometric information content of the images but also masking it, at the point that several of them were to consider totally useless. The noise removal process is composed of the two steps: the first, the M.N.F. (*Minimum Noise Fraction*), extracts the noise through the inherent dimensionality of image data, segregates it and reduces the computational requirements for subsequent processing (BOARDMAN, KRUSE 1994), the second consists in the inverse transformation of the previous step (*Inverse* M.N.F.) that allows for the elimination of the system noise from the original bands by performing the calculation excluding the noise components.

The obtained results have shown a clear improvement of the information in terms of signal noise and have been used in lieu of original data for most of the below described analysis processes (see FIG. 2).

6. 2. *Processing*

The first goal of this research has been to test the MIVIS images in the identification of archaeological traces: in order to do that, various digital image processes, involving the manipulation of the image, have been performed to treat the image itself for the subsequent step of the interpretation.[1]

6. 2. 1. Vegetation Indices

Studies about the quality of the vegetation, monitoring variations in its vigor, can enable the identification of archaeological deposits that allow or, in opposition, limit the growth of the vegetation: this has made them some of the most used applications in the archaeological research. As well known, heterogeneity of the texture of the subsoil has a strong reflection on the growth of the vegetation, determining the appearance of the so called 'crop-marks'. The mechanism of formation of these traces relies in the fact that, when archaeological remains are present in the subsoil, the vegetation over them will have a later growth compared to the surrounding plants, as well as a slower growth and a premature yellowing. From the other side, when in the subsoil there are ditches of some sort, the growth of the plants will be faster than the surrounding ones and the vigor more accentuated and the final maturation of the plant delayed (ALVISI 1989, pp. 51-52; WILSON 2000, pp. 67-80).

Arithmetic operations (that is to say the process of addition, subtraction, multiplication and division of the pixel values of one image to the corresponding ones in another image) on Red and N.I.R. bands find large application in the study of vegetation monitoring since they have demonstrated to be sensitive indicators of the presence and the condition of green vegetation. As a result, they provide a black and white image that can show variations in the state of health of the plants, where vegetated areas appear in bright color (the higher the value, the healthier the vegetation) and remaining object have darker colors.

For the current research three vegetation indices, chosen to represent general vegetation indices and indices with correction for soils, have been calculated, tested and compared to determine the best method for evaluating vegetation health in the target area: 1 based on simple math (D.V.I.) and 2 based on ratioing (N.D.V.I. and M.S.A.V.I. 2).

The D.V.I. consists in a subtraction operation, involving the use of the Red and N.I.R. bands and performed on a pixel-by-pixel basis, to assess the degree of change in the used images (TUCKER 1979; LILLESAND *et alii* 2004, p. 468).

The formula to obtain the index is well known:

$$\text{D.V.I.} = \text{N.I.R} - \text{Red}. \qquad \text{eq. (1)}$$

As result of this arithmetic operation, healthy vegetated areas in the picture show high values because of the relatively high Near InfraRed reflectance and low visible reflectance, less healthy vegetated areas show lower values, while rock and bare soil areas have resulted in vegetation indices near Ø. As a non-ratioing vegetation index,

[1] The software that was used for the processing of MIVIS images is R.S.I. Envi 4.0 +, that has been provided in temporary license from R.S.I Italy (thanks to Dr. P. Filippi).

D.V.I. has demonstrated to be able to provide satisfactory results as long as the data were input to the D.V.I. computation after external and sensor noise removal.

A consistent number of ratios applicable to the vegetation studies have been created (JACKSON 1983; LOGAN, STRAHLER 1983) but most of them are equivalent (PERRY, LAUTENSCHLAGER 1984, pp. 169-182): they all are based on the fact that vigorous vegetation reflects strongly in the N.I.R. and absorbs radiation in the Red wavelength. It is the case in this research that the N.D.V.I. and M.S.A.V.I.2 have shown strong similarities. It is common knowledge that he N.D.V.I. (ROUSE *et alii* 1973; TUCKER *et alii* 1985; NOGI *et alii* 1993) is the difference of the Red and Near InfraRed band combination divided by the sum of the Red and Near InfraRed band combination or:

$$\text{N.D.V.I.} = (\text{N.I.R}-\text{Red})/(\text{N.I.R}+\text{Red}) \qquad \text{eq. (2)}$$

Like in D.V.I., areas with vegetation yield high values and appear brighter in the picture, having their brightness varying on the base of their health and maturation. N.D.V.I. is correlated with crop biomass accumulation, with leaf chlorophyll levels and photo synthetically active radiation absorbed by the crop canopy. The strength of the N.D.V.I. is in its ratioing concept, which reduces some of the types of noise (illumination differences, cloud shadows, topographic variations) present in multiple bands. Moreover, it is moderately sensitive to the soil background and to the atmosphere except at low plant cover. It has the best dynamic range of any of the other tested Vegetation Indices and it has demonstrated a very good sensitivity to changes in vegetation cover. The main disadvantage of the N.D.V.I. is the inherent non-linearity of ratio-based indices and the influence of some additive noise effects, such as atmospheric path radiances. The N.D.V.I. also shows evidence of scaling problems and is very sensitive to canopy background variations. Usually N.D.V.I. is preferred to simple D.V.I. index for vegetation monitoring because it helps compensate for changing illumination conditions, surface slope, aspect and other extraneous factors. However in the application of the index over the target study area it demonstrated to be in some cases less effective in providing the pursued results such as the discrimination of the growth of vegetation and of its health compared to the D.V.I.

In order to bypass the problems of the N.D.V.I. in areas of low plant cover, M.S.A.V.I.2 (second Modified Soil Adjusted Vegetation Index), a recursion of M.S.A.V.I,[1] has been tested. It is computed through the formula:

$$\text{M.S.A.V.I.2} = (1/2)*[2(\text{N.I.R.}+1) - \sqrt{(2(\text{n.i.r.}+1)^2\text{-}8(\text{n.i.r.-Red})}]$$

As the MSAVI, it has been created to minimize the reflectance effects of the soil background on the Vegetation Indices: these effects are particularly evident in areas where the coverage of the turf or of the cultivations is lean and/or scattered. Being this the case in the target area, since the shots were taken during the autumn, when most of the crops are reaped, the index has been performed for comparison with the others. It is important to stress, however that, despite the improvement in the attainable results in terms of accuracy, a difficulty that has to be kept in mind in using a vegetation index like this one is an increase in the sensitivity to variations in the atmosphere, which al-

[1] MSAVI2 was developed by QI *et alii* (1994) from the M.S.A.V.I.

ters the light seen by the instruments. This can cause variations in the calculated values of vegetation indices (QI *et alii* 1994; LEPRIEUR *et alii* 1996). Since no atmospheric correction has been performed on MIVIS images, as already explained, the atmospheric distortion could be the cause of some of the not so satisfying results obtained.

All the gained Vegetation Indices were compared among themselves and with the original MIVIS image in order to verify the level of visibility of traces they can show. The comparison of the process results using a multicriterial analysis has shown that the type of surface under examination must be previously taken in consideration and that the same type of vegetation index can not be applied to all the situations. This means that in studying a vast area presenting different situations of vegetation coverage, the vegetation indices must be singularly applied based on the type of canopy of the target fields. Better results in terms of discrimination of quality of the vegetation (and consequently in visibility of surface traces) have been reached in fact using the D.V.I. in case of low vegetation cover versus N.D.V.I. (see FIG. 3). This last has demonstrated instead to have the best sensitivity to changes in vegetation cover in high cover areas of vegetation. M.S.A.V.I.2 has been profitably applied in situation in which the background soil introduces significant variations in the spectral response of the vegetation. Another positive aspect in M.S.A.V.I.2 and N.D.V.I. is that, being ratios, they annul the effects of shadows, allowing to better discriminate the traces previously hidden by the shadow itself (see FIG. 4).

6. 2. 2. Soil Indices

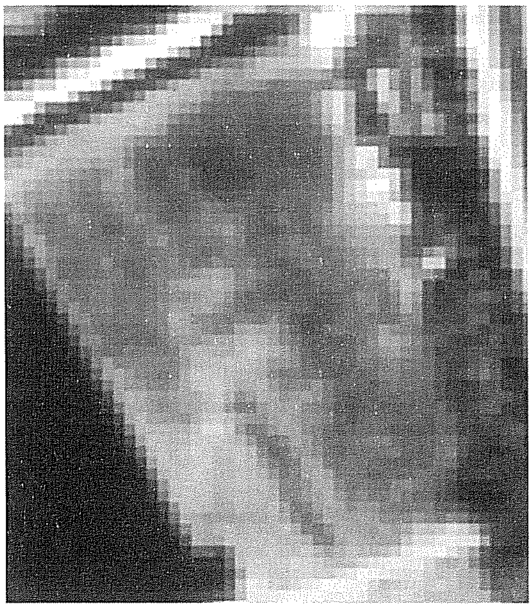
The study of tone variations of bare soil ('damp marks') has a long tradition in archaeological research: their occurring in fact can be an indication of the presence in the subsoil of archaeological structures or ditches that respectively inhibit or facilitate the absorption of raining water and the rising of the humidity. The soil in fact assumes different tonality when it lies over ruins of constructions, roads etc., that is to say in all the situations in which in the past there was a presence or accumulation of materials having a different nature with respect to that of the surrounding soil.

In this section will be presented a Soil Index for MIVIS data that aims to provide an aid in the identification of anomalies on bare soil, allowing to emphasize the wetness or the dryness of a portion of the ground. The Soil Line is a well-known linear relationship between the Near-InfraRed and Red reflectance.[1] The concept that a definable region in a Red-N.I.R. scatter plot of the 2-dimensional space (based on the multispectral bands) is occupied by agricultural crops and that a region occupied by pixels recognizable as soil is a thin, lengthened ellipsoid in this 2-dimensional space was introduced in the 1970s for identifying agricultural crops.[2] In the axis of this ellipsoid, pixels representing soils range from soils of low reflectance to those of high reflectance. The locations occupied by vegetation, soil and water can be seen in three distinct areas forming a triangle as described from Kauth and Thomas.[3] Later studies have shown some of the limits of the equa-

[1] The first studies treating the topic were KAUTH, THOMAS 1976, for Tasseled Cap Transformation and RICHARDSON, WIEGAND 1977 for the P.V.I.; more recently see also WIEGAND, RICHARDSON 1982 and BARET *et alii* 1993 and the related, updated, bibliography.

[2] Studies applied to Landsat MSS; for a short resume about the principles of the various theories of Soil Line see MATHER 2004, pp. 145-148.

[3] Kauth and Thomas (1976) described the famous «triangular, cap shaped region with a tassel» in Red-N.I.R space using MSS data.



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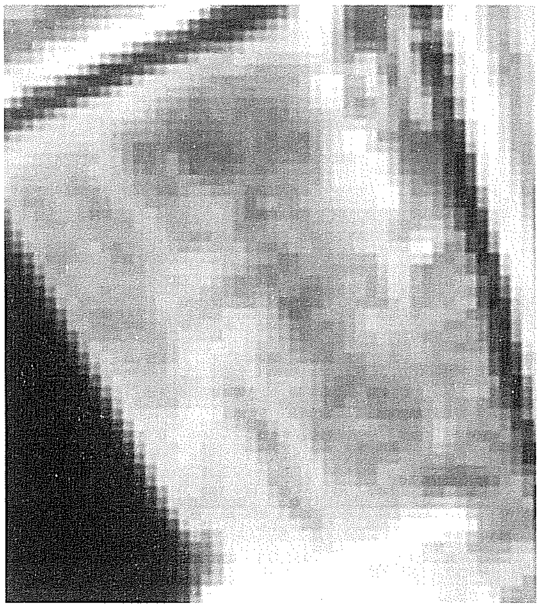

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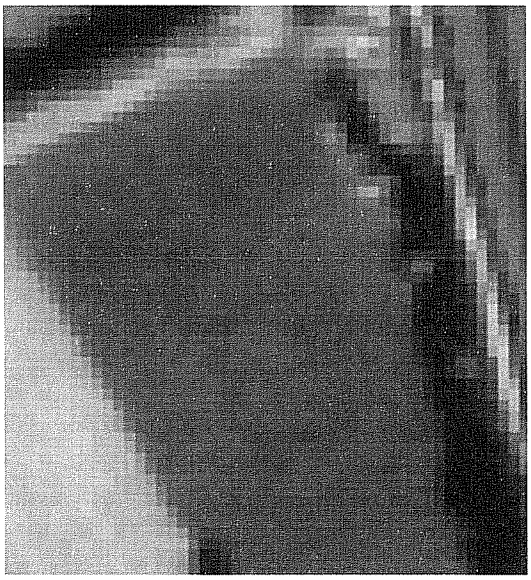

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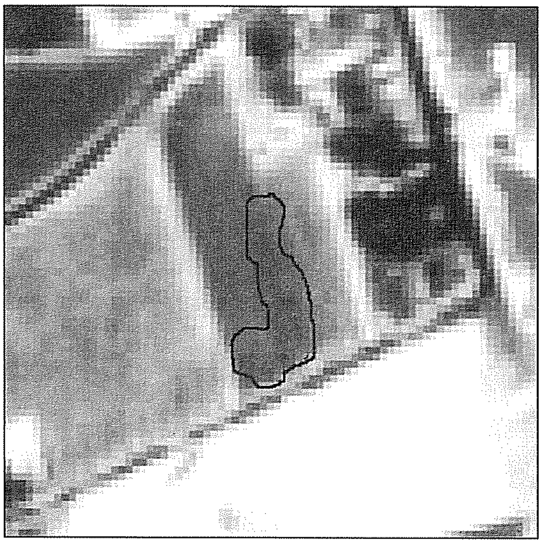
FIG. 3. 1-3. Comparison among D.V.I. (FIG. 3. 1.), N.D.V.I. (FIG. 3. 2.) and true color image (FIG. 3. 3.) of a MIVIS run: the D.V.I. shows better results in terms of discrimination of quality of the vegetation in case of low vegetation cover versus N.D.V.I.

tion defining the soil line[1] theorized in the P.V.I. (Perpendicular Vegetation Index) and the need of the definition of the soil line using empirical data. Starting from this concept, and verified that the assumption of the location of the three types of pixels created for Landsat data was true also for MIVIS data, the Soil Index was determined by identifying a Soil Line directly in the scatter plot of the radiance measured in the visible Red band against radiance in the N.I.R. (see FIG. 5), then determining mathematically the slope 'm' through the application of the Slope Equation formula:

$$m = y_2 - y_1 / x_2 - x_1 \qquad \text{eq. (3)}$$

[1] See MATHER 2004, p. 146 for a short report.



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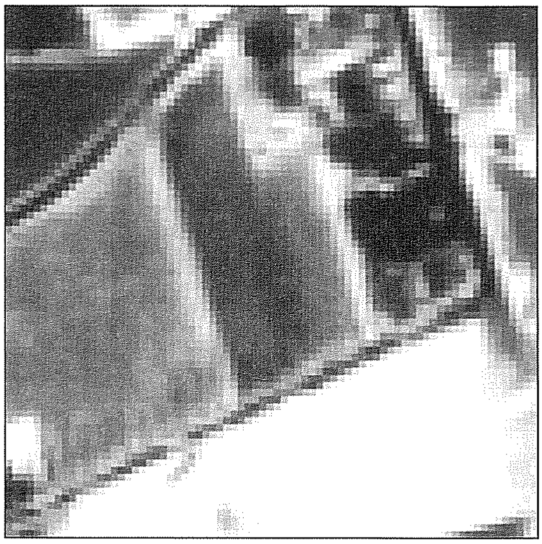

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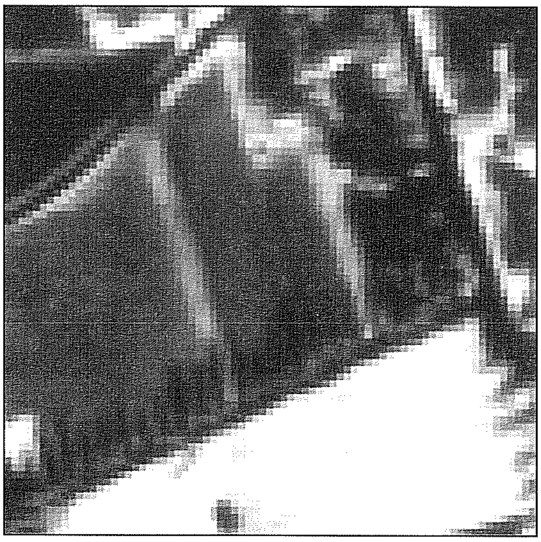

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FIG. 4. 1-3. M.S.A.V.I.2 (FIG. 4. 1.), N.D.V.I. (FIG. 4. 2.) and D.V.I. (FIG. 4. 3.); note the reduction of the effects of shadows in M.S.A.V.I.2 and N.D.V.I., that allows to better discriminate the surface traces.

and subsequentially by applying the Line Equation formula:

$$y = mx+b \qquad \text{eq. (4)}$$

A point (Z) has to be now identified in the scatter plot: it is chosen arbitrarily, identifying the very first and lowest pixel[1] among the ones lying between the Soil Line and the vegetation threshold, and represents the most left pixel of the ones representing wet soil, that is to say the highest humidity of the scatter plot area: it can be taken the lower left most point on the scatter plot. The distance from the projection of point Z to the projection of any pixel in the scatter plot onto the soil line (FIG. 6) can be con-

[1] Some researches suggest to use the y-intercept of the soil line and some even suggest the x-intercept, which could be done mathematically. The process used here gave better distribution of DN values and avoided the need for further image enhancement (i.e. stretching).

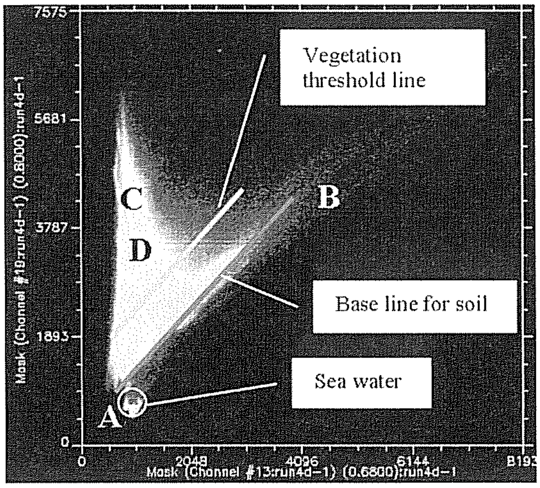


FIG. 5. Soil line placement and water position in the scatter plot of a MIVIS image. The Soil line extends from darker soils with low R. and N.I.R. image intensity (point A) to an upper region of bright soils with high R. and N.I.R. image intensity (point B). Point C represents a pure vegetation pixel and Point D represents a partially vegetated pixel.

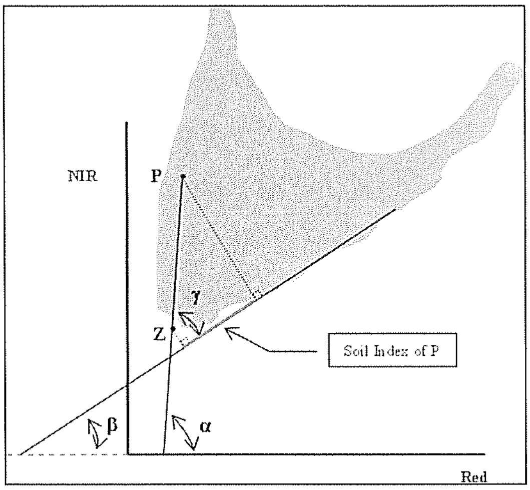


FIG. 6. Graphic interpretation of segment ZP's projection onto the Soil Line in the scatter plot of a MIVIS image (see previous figure).

sidered as an indication to the moisture content of the soil, ignoring the differences due to soil type and texture. The distance formula is a simple application of the Pythagorean Theorem. However this provides the distance from Z to a pixel and not the value projected along the Soil Line; so it is necessary to look for the Soil Index component of that distance measure by projecting the distance on the soil line. This is done trigonometrically through the function Cos of the angle (γ) formed between the segment connecting the point Z to each point P and the soil line:

$$\text{S.L.I. (Soil Line Index)} = D_{ZP} \cos(\gamma) \qquad \text{eq. (5)}$$

When applying the formula, the obtained image represents a soil humidity index, where light colors represent the dryness of the soil and dark colors the humidity.

For most of the sample areas, the application of the S.L.I. has shown a clear improvement in the differentiation of the typologies of the soils, accentuating the dry-wet discrimination (see FIG. 7).

6. 2. 3. P.C.A. (Principal Component Analysis)

As many other multispectral images, MIVIS images have a strong interband correlation: contiguous bands of the images convey basically the same information as well as bands belonging to nearby different spectral region. This produces adjacent bands very similar to each other where the dimensionality of the data set is increased and the redundancy in the data is high.

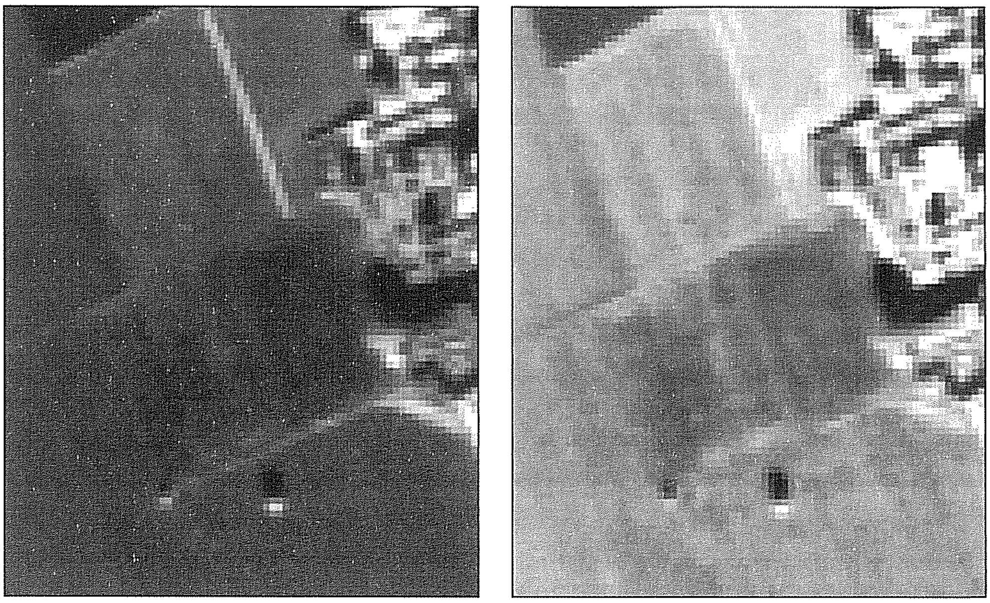


FIG. 7. 1-2. A detail showing the result of the application of a Soil Line Index (S.L.I.): a better discrimination of the soils can be noticed when applying the S.L.I. (FIG. 7. 2.) compared to the original Red band (FIG. 7. 1.).

The Principal Components Analysis[1] is a procedure for reducing this redundancy in data by transforming a set of correlated variables into a new set of uncorrelated ones. This transformation entails a rotation of the original axes to new orientations which are orthogonal to each other and therefore there is no correlation between variables. The goal of the process is to reduce the information previously contained in the original n-band data set into a smaller number of new bands that can be used in place of the original ones. Usually, the first Principal Component image (P.C.1) expresses the majority of the variance present in the scene, the following (P.C.2, P.C.3) contains a smaller percentage of the total variance and the last tends to be dominated by system noise. Moreover, the first two P.C. images include the greatest part of the total variance of the scene (commonly over 99.1 %) and consequently of the total information. This is what is referred to as intrinsic dimensionality of the data, that is to say, the number of the first P.C. images that provide the largest part of information and that can be used in lieu of all the bands. Useful in multispectral analysis, P.C.A. finds an even better employment in hyperspectral data sets, where the increased number of bands magnifies the need for reducing the dimensionality of the data. This type of transformation has been employed in this research mainly in the enhancement processes preceding visual interpretation of the data and as a pre-processing procedure prior to further data process such as classification of the data.

In archaeological terms, P.C.A. allows for a better discrimination of different surfaces, which become more distinguishable in visual analysis: variations on the texture

[1] For an overview about the general topic see, among the most recent literature, DERMANIS, BIAGI 2002, pp. 143-153; LILLESAND *et alii* 2004, pp. 536-542; MATHER 2004, pp. 149-160; about archaeological application see CAMPANA, PRANZINI 2001, pp. 34-39.

of bare soil or of vegetated areas can lead to the identification of archaeological buried sites.

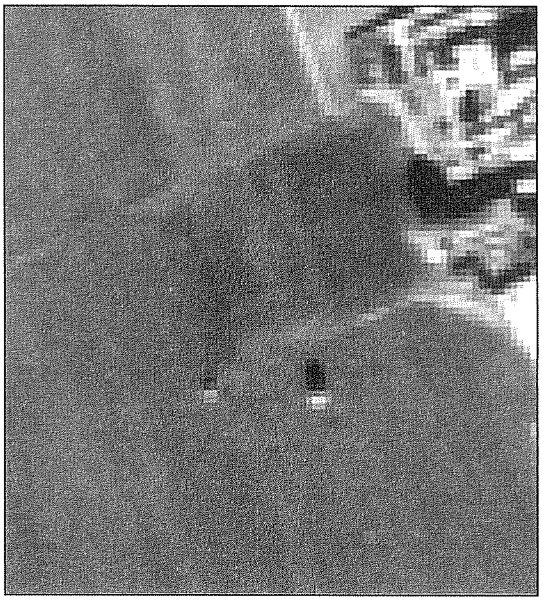
When performing a Principal Component Analysis, usually the number of output P.C. bands is calculated as the number of input spectral bands. In the case of MIVIS, in order to reduce the computational need and to save disk space, the number of output P.C. bands has been selected using the eigenvalues. In computing Principal Components through subset, the relative statistics are calculated and each band listed with its corresponding eigenvalue, together with the cumulative percentage of data variance contained in each P.C. band for all the input bands. Only P.C. bands with large eigenvalues, containing the largest amounts of data variance, are selected and the number of bands to output is entered in the computation. The output P.C. rotation will contain only the number of bands that have been selected.

The results of all the computed P.C.A. have been subjected to visual interpretation of the data as single P.C. images and composite of P.C. images: their enhancements have been generated by displaying contrast stretched images of the transformed pixel values. A problem than needed to be afforded was the choice of the number of P.C. images to take in consideration for both the visual inspection and the subsequent analysis. Since in the P.C.A. process the information is accumulated in the lower order components and in the data set the noise is evenly distributed, the lower order principal components might be expected to have a higher signal-to-noise ratio than the higher-order principal components. This could lead one to think that high order principal components are not worthy of consideration. This was not always the case with MIVIS images. The necessity to check the P.C. images by eye, singularly, using the knowledge of the study area, rather than relying solely upon the magnitudes of the eigenvalues as an indicator of information content was evidenced when in fact some of the higher order P.C. images showed additional information that was not present in some of the lower orders.[1] While analyzing the images through naked eyes, searching for traces or anomalies on the landscape, it also became clear that usually many of the tonal patterns in individual components do not spatially match specific features or classes identifiable in the MIVIS bands and represent simply linear combination of the original values instead: this had to be kept in mind when identifying the nature of each anomaly.

P.C. images have been analyzed as separate black and white images (see FIG. 8) or any three component images have been combined to form a color composite. In interpreting singularly the created P.C. images, all of the images for each run have been taken in consideration,[2] at least in the first stage of the work, in order to define which of them contained information that could be consider useful for the research. In a second step, a small percentage of the ones that passed the first selection were chosen to be subjected to the visual analysis and to be integrated in the G.I.S. for the subsequent archaeological interpretation. As expected, P.C. images in most cases have demonstrated that more than 74 % of the variability in the data was carried in the first principal component and around 24 % in the second principal component: together the P.C. 1 and 2 in most cases accounted for 98.90 % of the total variability in the origi-

[1] About utility of lower-order P.C.s see TOWNSHEND, HARRISON 1984, pp. 68-70.

[2] Usually the output bands number was selected between 20 and 30.



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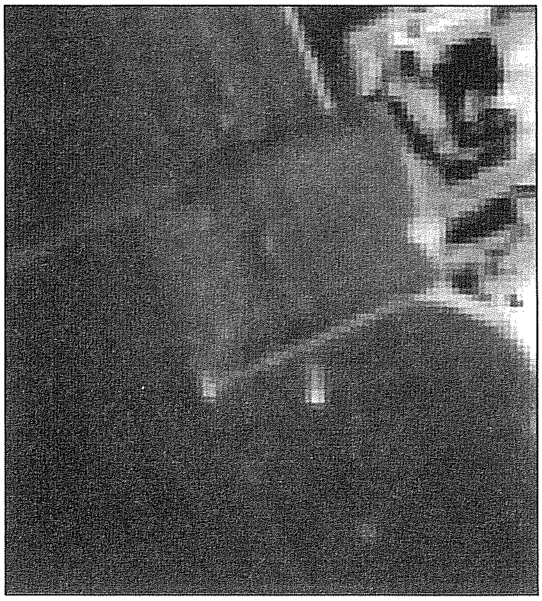

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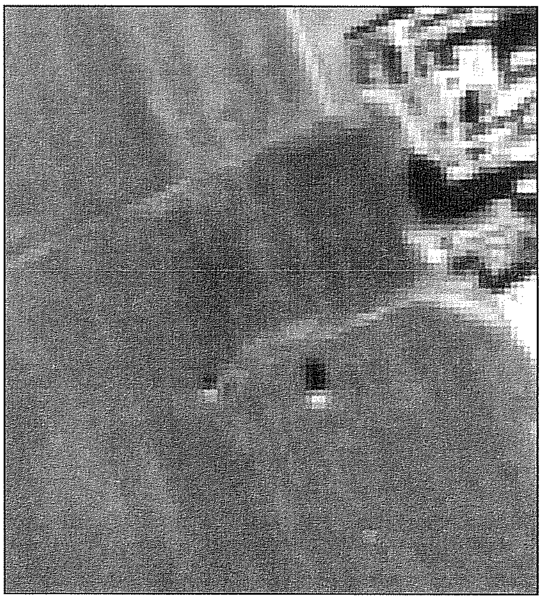

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FIG. 8. 1-3. Zooms of P.C.1 (FIG. 8. 1.), P.C.2 (FIG. 8. 3.), P.C.3 (FIG. 8. 3.) of a MIVIS image: the amount of information decreases in the higher orders components.

nal bands. Usually about 1 % was found in third principal component: P.C.1, P.C.2 and P.C.3 showed virtually all of the variance in the scene (on average 99.6 %) – see FIG. 9. Principal components from 4 to the number of the output components chosen usually together contain only 0.60 % of the variation in the data. However, as stated, some of them have demonstrated to carry useful information, recognizable and identifiable only through a visual check of the image itself; the presence of significant information has been noticed even up to the 30-40th principal component, the value varying from run to run.

In addition to the traditional P.C.A. performance, a number of P.C. images were created through spectral subsetting, in order to convey only the information of spectral regions of interest: a Selective Principal Component Analysis (S.P.C.A.) was computed for groups of bands (see TAV. 1), each group having as output number of P.C. images the same number of original bands used in input.

The P.C. images produced using all the run's bands have turned out to be a good starting point for a reading of the landscape: they provided supplementary information in comparison with the original bands and avoided useless loss of time in case of a preliminary surveying of the images. However many details that are visible analyzing singularly the original bands not always can be recognized in the P.C. because in there they are covered by the overlaying of information from other bands. The visual analysis of the principal components of the spectral subset (S.P.C.S) instead revealed that the lower order P.C. of each grouping could provide a large amount of information that could not be recognized in the original bands of each relative spectral group. The first principal components of the subset of the visible bands show what could be considered the best results of the group of the subsets: several of the traces and anomalies on the investigated surface can be identified and better discriminated from the surrounding environment. The lower order components of the subset of the 2[nd] spectrometer, summarizing the N.I.R. bands, have shown to be a

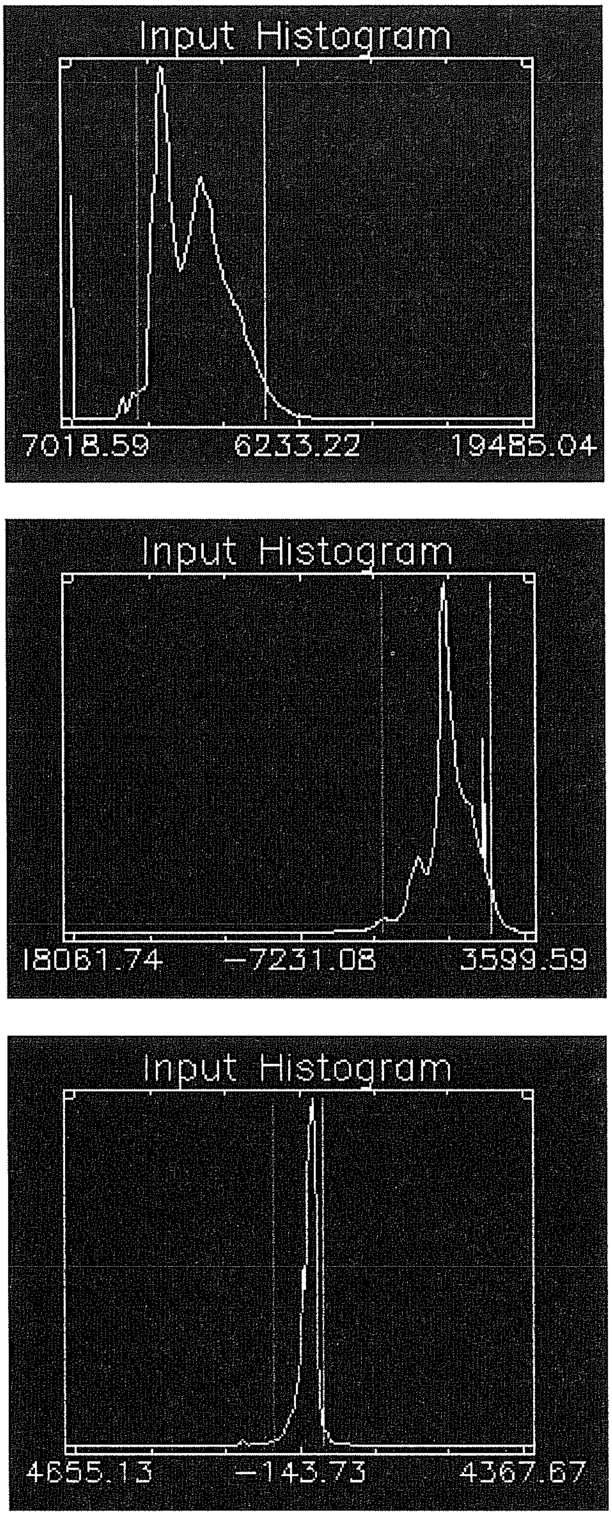

FIG. 9. 1-3. Histogram plots of P.C.1 (FIG. 9. 1.), P.C.2 (FIG. 9. 2.), P.C.3 (FIG. 9. 3.) of a MIVIS image showing the decreasing amount of variability in the three components.

TABLE 1. Table of the Spectral Subset for MIVIS runs.

GROUPING	USED BANDS	BAND EDGES	SPECTRAL REGIONS INVOLVED	TOTAL # OUTPUT PC IMAGES
Optical port 1	1-20	0,431-0,833	RGB+NIR (3 bands)	20
Optical port 2	21-28	1,15-1,2	NIR (8 bands)	8
Optical port 3	29-92	1,985-2,479	MIR	64
Optical port 4	93-102	8,21-12,7	TIR	10
Blue spectral region	1-4	0,481-0,512	B	4
Green spectral region	5-9	0,52-0,611	G	5
Red spectral region	10-17	0,611-0,773	R	8
N.I.R. spectral region	18-28	0,772-0,833/1,15-1,55	NIR (11 bands)	11
N.I.R. O.p.1	18-20	0,772-0,833	NIR (3 bands)	3
Visible spectral region	1-17	0,431-0,773	RGB	17

valid instrument in studying the vigor of the vegetation; they have from the other side shown few reliability in the discrimination of different soils. These can be better analyzed through the first P.C. image of the thermal subset of bands (i.e. Spectrometer 4) where possible variations due to the presence of particular kind of sediments, rocks or lateritious material in the subsoil can results in variation of the temperature. The useful information that can be provided by the single thermal bands is magnified and more clearly observable here. The least useful appeared to be the M.I.R. subset of bands, where the differentiation between soils or quality of vegetation is slightly recognizable.

As told, P.C. images have been analyzed also as any three component images combined to form a color composite. Principal Component bands produce more colorful color composite images than spectral color composite images because the data, once run through the process, are uncorrelated. The most common procedure consists of generating a R.G.B. false color composite with the first 3 principal components of a scene (P.C.1, P.C.2, P.C.3): this allows for creating 6 different combinations, but, in the case of MIVIS data, this meant excluding from the composite many of the lower order principal components that have been previously tested and proved to carry interesting information. In order to overcome this problem, tests were executed increasing the number of principal components used, bringing it to 4: any three of these four P.C. images have been made into color composite with various assignments of blue, green, and red for a total of 24 different combinations (see FIG. 10). Of those, the image composed of P.C.4 shown in blue, P.C.1 shown in green, and P.C.3 shown in red has proved to be the most interesting in terms of visibility of the soil irregularities and the combination of P.C. 2-4-6 in R.G.B. display have provided extremely interesting results in terms of visibility and clarity of the feature and in terms of water penetration.

The use of P.C. images has proven to be satisfying in the recognition of anomalous features on the landscape. Condensing in a few bands all the information previously scattered in hundred of bands, it permits to perform a faster and more accurate research of traces over vegetation, bare soil and water. Visual interpretation of the data has been strongly aided by the combination of P.C. images to form a color composite: this has been particularly valid when applied to principal components obtained from subsets of bands. As a method to apply in using this kind of process, it can be advised to use primary P.C.s calculated using all the bands to gain a general knowledge of the studied landscape: it can provide the first information that can later on be probed through P.C.s

FIG. 10. R.G.B. false color composite of P.C.3, P.C.1 and P.C.4 from all the bands of a MIVIS run.

of the subsets. However, the Principal Component loaded using all the bands at disposal or a portion of them (meaning the exclusion of the thermal bands) shows to be the least satisfactory from the numerical point of view of landscape features identification but to be the best process to apply in terms of visibility of the traces. Consequently the composite realized through the use of these types of Principal Components provides poorer results than the ones that are possible to obtain by separating the bands.

The best results in terms of recognizable features have been reached through the composite of spectral subset, using a dedicated correlation matrix in order to identify the best usable subset able to provide with no loss of the information stored in bands.

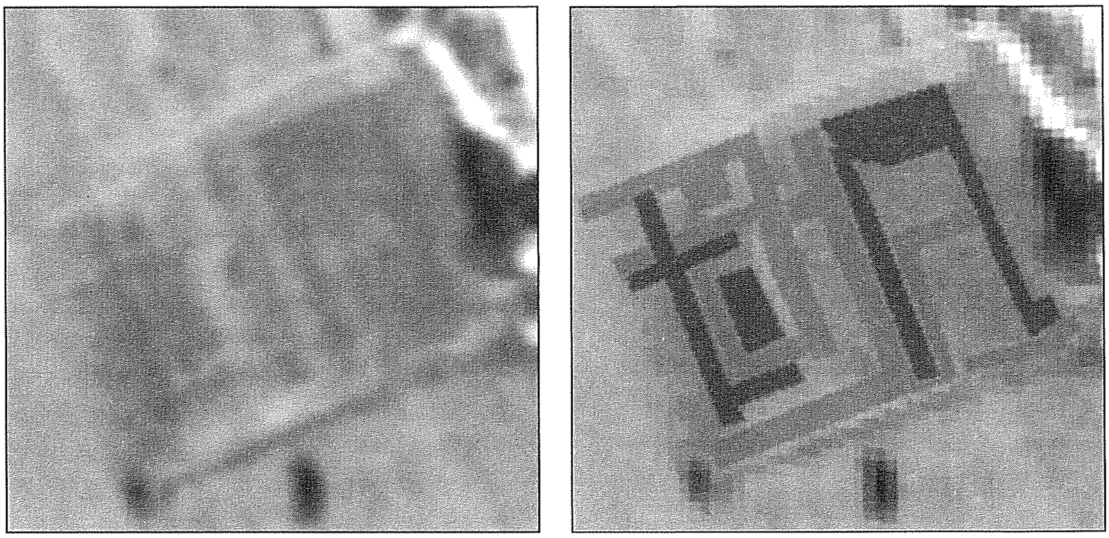

FIG. 11. 1-2. Traces recognized on a processed MIVIS image (FIG. 11. 1.) and reported in a drawn layer of the G.I.S. (Fig. 11. 2.); they are differentiated on the base of the nature of their formation (positive, negative, unknown) by different colors (dark color: negative trace, light color: positive trace).

The features that were better emphasized applying this flow of operations were lineations of dry or wet soil in contrast with the surrounding soil, alterations in the health of the vegetation and its growth, filled riverbeds, unexplainable alterations in the surface texture. From the archaeological point of view, this can be translated into the opportunity to identify archaeological objects (bigger than the geometric resolution of the sensor, i.e. larger than 3 meters) like structures, traces of centuriation, ancient river beds, concentrations of scattered lateritious or fictile materials.

7. ANALYSIS OF ARCHAEOLOGICAL ISSUES THROUGH A GIS

As well known, there is not a unique way to test the results of the image processing: the successes or failures of specific processes are determined from the meaningful information that can be extracted from them according to the branch of study. In remote sensing application to archaeology, the positive results correspond to the identification of traces over the landscape, but in order to determine if they are of archaeological nature they have to be compared with other data. Thus, for the archaeologists, to test the results of the remotely sensed images' processing it is necessary to perform a procedure where the interpretation of the traces as archeological traces through a GIS, which combines the data, leads to validate the remote sensing procedure.

The MIVIS images processed applying vegetation indices, soil indices and P.C.A. were imported in the GIS, where they have been georeferenced, read and interpreted following the criteria of archaeological photo-interpretation. The first step in the process of recognition of archaeological features consisted in the observation and reading of the images, basically a visual analysis aiming to simply identify categories of objects and presences on the landscape. The features have been identified through the recognition of the traditional factors of photo-interpretation: proximity, dimension, alignment, orientation, shape, texture, pattern, tone, size of the features have been taken in consideration to compare the anomalies and the traces of the pictures. In the majority of the cases, the features have shown to be due to humidity, vegetation, alteration in the composition of the soil, anomalies on the distribution of elements on the landscape and to micro-relief. Mechanisms of formation of the traces over different type of surfaces have consequently been analyzed to understand the nature and the typology of the traces. The more common situations encountered were relative to traces over bare soil and over vegetated soil. In case of bare soil, the types of observable traces were alterations of colors accordingly with the probable presence of subsoil structures (ending in light color traces) or underground ditches or canalizations (ending in darker color traces). In case of vegetated soils, the traces were probably depending from the alteration of the growth of the vegetation, determining both an increase of the vegetation over past dug areas and a decreasing of plants' health over areas of ancient construction. As obvious, only one part of the traces visible on the landscape surface can be ascribed to factors of archaeological origin, since the mechanism that produce them could have happened in every historical period. For this reason, in a second step, relations among the different elements were looked for by synthesizing in a digital mapped report the result of the analysis of the remote sensed imagery with all the other data deductible from sources that can concur to the definition of the picture of the situation. This second step has been a phase of thorough examination of the first step: nature and characteristics of each element have been determined and their causes have been investigated also in relationship with the surrounding elements of the landscape. Relations with type of soils, vegetation and hydrography have been examined and put in relation with the presumed archaeological traces. The next level was to take in consideration the collateral documentation: as stated, a methodic collection of published information and thematic cartography has been realized, in order to create an archaeological thematic map in digital format. As a final level of the interpretation process, the traces and anomalies identified through MIVIS and aerial pictures have been compared with the orientations of the identified or hypothetical ancient road layouts, canalizations, building structures and every other element over the Aquileia's landscape having an archaeological nature. Having these new elements, a selection was done to eliminate the features which, through the comparative study of the elements characterizing the landscape, resulted not from archaeological presences but, more realistically, from modern interventions on the territory.

While performing or after the completion of the photo-observation and interpretation, the traces recognized on the images have been recorded by drawing them in separated layers of the GIS, differentiating them on the base of the mechanism of their formation (positive, negative, unknown) by different colors, as visual resource, and by attributes, as text resource (FIG. 11). As well, they have been distinguished and labeled on the base of the type of process from which they have been extracted.

A very important next step would have been the direct control on the ground of the information collected by Remote Sensing imagery. It has already been stated that ground-truth information is irreplaceable in order to give support to the analysis, interpretation and confirmation of the data and to gather information that allows the

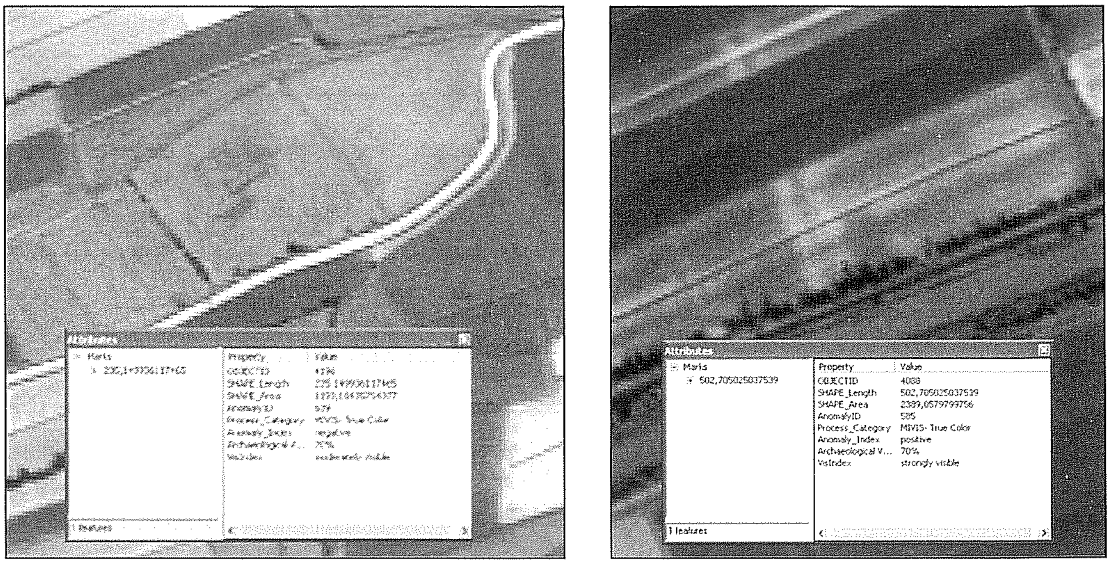

FIG. 12. 1-2. Different levels of archaeological reliability: detail of a traces with 20% of probability to be an archaeological site (FIG. 12. 1.) and another one with 70 % (FIG. 12. 2.).

understanding of human activities.[1] Unfortunately it was not possible to insert a module of intensive field-walking survey in this research project in order to test the results achieved by MIVIS images: it is important to stress that a remote sensed imagery based interpretation can lead to formulate hypothesis completely wrong if not supported by a phase of validation of the conclusions which were inferred from the images themselves and the other archaeological data. With this in mind, it was clearly necessary to create one or more indices that could make up for the lack of an empirical method of validation of the traces. For this reason a most-possible-unbiased scale of the levels of reliability of the features and an index of the visibility of the traces have been created. If not able to substitute the value of a session of field-walking survey, they can at least emphasize those locations on the landscape in which there is a high probability to be in front of ancient remains. For this reason other two indices, archaeological reliability value and visibility index, express an evaluation about the quality of the observed feature.

The Index of 'archaeological reliability' derives from the combination of the various sources of information about the area surrounding a specific trace which are contained in the various informative layers (base cartography and bibliographical data). The index is expressed by a percentage from 10 to 100 %: this indicates what is the level of reliability that can be attributed to a specific trace on the landscape expressing the possibility that it represents a feature of archaeological origin. When multiple data concur to confirm the hypothesis that the feature could be archaeological, the value of the percentage is elevated; on the contrary, when there are one or more hints showing that the feature could be due to the transformation of the landscape oc-

[1] See CAMPANA 2003, p. 223 for multispectral images; see also ALVISI 1989, pp. 47-48 about aerial photo-interpretation.

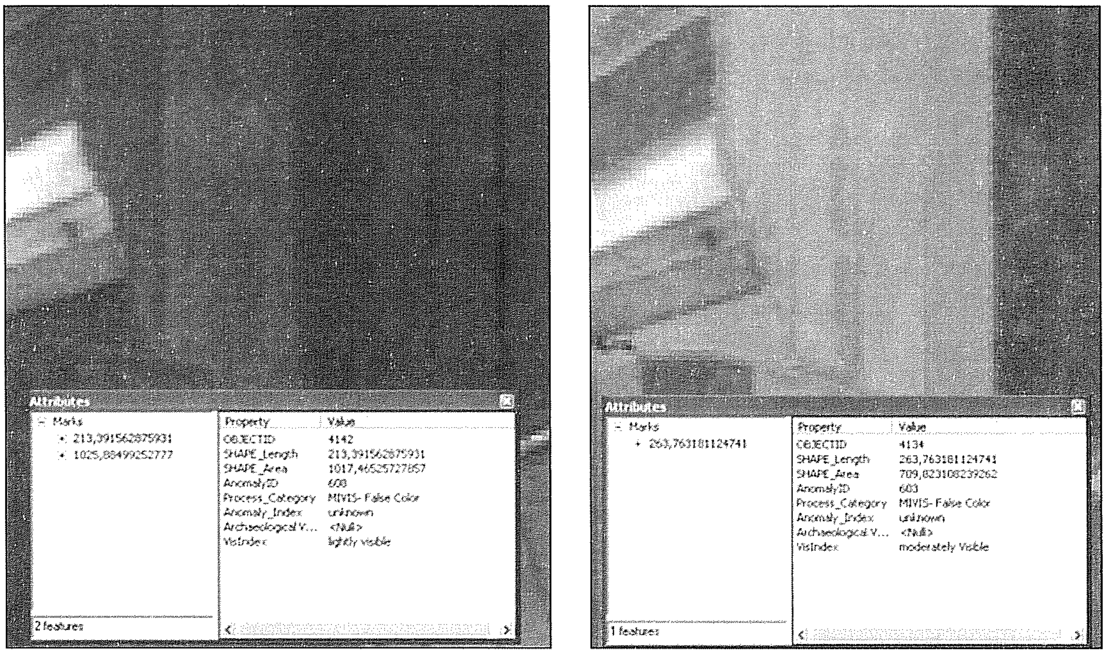

FIG 13. 1. Trace with low level of visibility; (FIG 13. 2.) same trace with higher level of visibility as result of a False Color dispay.

curred in the modern times, the percentage will be low. The values are decreased from the recognition of the presence of modern objects or changes arisen on the landscape (see FIG. 12).

The 'Index of Visibility' of the anomalies is an index of the quality of visual appearance of the traces (see FIG. 13); it is evaluated through a scale of values from 1 to 5, where 1 indicates slight possibility to identify the trace and 5 means that the trace is extremely visible, independent of the type of surface materials surrounding the trace (bare soil or vegetation).

It must be stressed that an attribution of a value (no matter which value) is a subjective process based on comparing surface traces with known features (results of archaeological remains under the surface): this process is largely affected by the archaeologist's background.

7. 1. GIS *overview*

The GIS designed for the evaluation of the landscape features merged different kinds of data that can be organized into three macro-groups, each including one or more themes belonging to the same context:

– cartography, divided in five typologies: base, thematic, thematic generated during the research activities (georeferenced archaeological data), utility and historical maps;

– different kind of remotely sensed images, in their original look (or format) and their transformations;

– digital terrain model providing a 3D vision of the landscape.

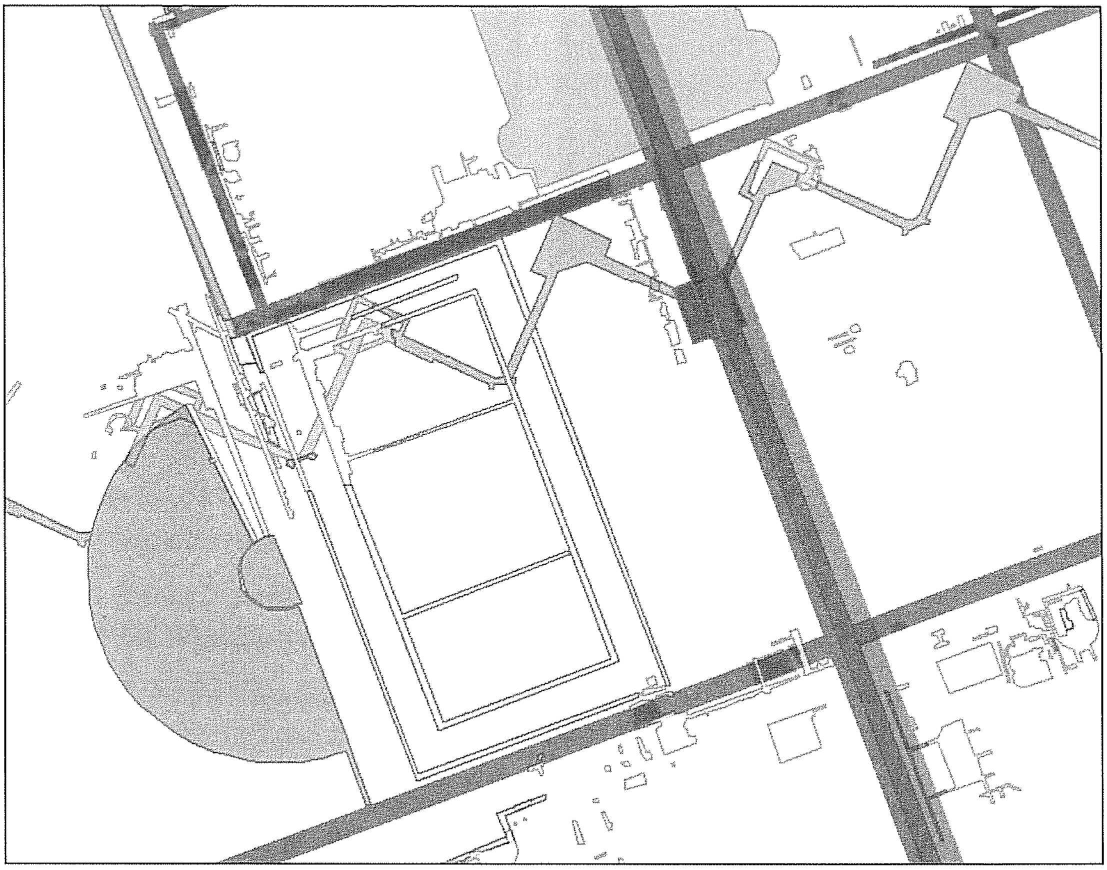

FIG. 14. Different archaeological objects on the archeological thematic map layer (when semi-translucent, track or location are hypothetical).

As regards the cartography, the base, thematic and historical cartography used to setup the system have been already presented; now it will be presented the new thematic and utility cartography that were created during the research activities through the arrangement of different layers. The archaeological data, collected from the literature on the topic, were transferred in thematic maps, each of them corresponding to different layers of the GIS (see FIG. 14). A primary division was performed between the known archaeological sites and archaeological areas hypothesized on the base of the previous ones. The first layer includes the published data about Aquileia's urban and suburban area archaeological monuments and comprises most of the archaeological excavated sites inside the urban perimeter of the town and in a short tract of the suburban area.[1] The second layer provides data about hypothetic archaeological site based on information related to location of existing archaeological sites made known from excavations, surveys, oral tradition. As previously exposed, while performing or after the completion of the photo-observation and interpretation, also the traces recognized in each image inserted in the GIS (MIVIS images – original bands, processes or composites –, orthophotos and historical photos) have been recorded in a dedi-

[1] Primarily based on BERTACCHI 2003.

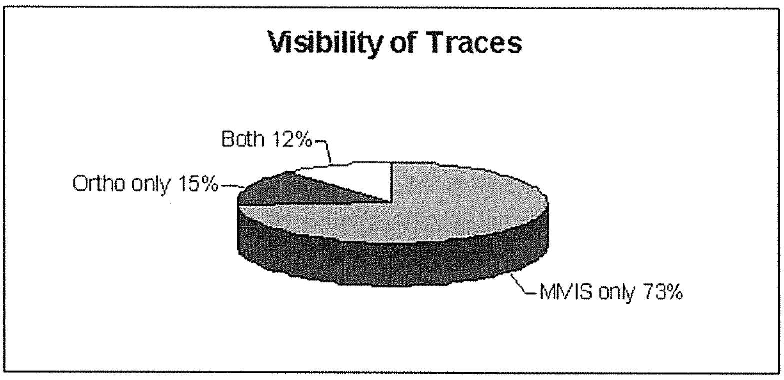

CHART 1. Comparison of the visible traces in Orthophotos and MIVIS true color images.

cated layer where the features that are possible to recognize in a specific band, process or composite are drawn and labeled. This layer includes also the information related to each feature about the above stated process categories, the Anomaly index and the Archaeological reliability and Visibility index. Finally, the utility layer consists of the drawing of aerial tracks and photographic shoots of the area captured through MIVIS.

In the first step of the evaluation of the many processes performed over the MIVIS images, various tests have been executed to identify the processes most successful in the detection of the landscape features; the selection was made through an empirical comparison of some sample traces. At the end of the selection process, a group of them was chosen in order to be imported in the GIS while the others were excluded, having proved to provide redundant information.

As exposed, remotely sensed data other than MIVIS images were used and imported in the GIS with the aim to aid in the evaluation of the airborne spectral sensor's images by comparison. The aerial pictures can be in fact estimated as the terms of comparison for the evaluation of MIVIS images: they help to define which is the level of growth in the possibility of identify features on the studied surfaces. The Orthophotos related to the target area have been composed to create a mosaic. No special image process has been applied to them, but some enhancements by contrast stretches (linear, gaussian and piecewise stretches) have been used to accentuate some features and make them more visible. The traces identified in the Orthophoto have been recorded in the general anomalies layer.

As part of the understanding of the landscape and of the interactions of the anomalies on it, a D.T.M. was created through a Triangulated Irregular Network (T.I.N.) and used to represent the studied surface. The T.I.N. was generated by the spot heights of the Regional Technical map scale 1:5.000 (average distance 5 m). Obviously, in the case of the Aquileia plain, the view of the landscape is not so impressive in visualizing it, because the countryside is pretty much flat with slight variation of altitude from -3.76 m below the sea level to 10.6 m above. However the model is interesting to better understand and evaluate the scenery and to identify the areas corresponding to morphologically 'lowlands' or 'highlands' relatively intended.

7. 2. GIS *based interpretation*

The G.I.S., as it is structured for combining and managing the information from base and thematic maps, digital elevation model, remotely-sensed data, performs a guided analysis to identify the anomalies that can have an archaeological origin among the many provided by the remotely sensed images and their processing. In order to select, among the others, the anomalies that can be considered to have a high probability to be connected with archaeological remains, this analysis has been performed in two different levels: intra-site and inter-site analysis.

In the first stage of analysis (intra-site) the remotely sensed data have to be combined with the other information at disposal for that specific location on the landscape (proximity or coincidence with other hypothetical or real archaeological sites, overlay with areas of scattered lateritious or fictile material, proximity to the infrastructures etc.) and then reinterpreted. The archaeological interpretation of the combined data was done directly on-screen, through the overlaying of different forms of imagery, along with relevant geographical and archaeological information. When an understanding of each site individually has been reached, inter-site relationships started to be analyzed. Once also this step was performed, it was possible to give to each trace a percentage attribute of archaeological 'reliability' or certainty factor of archaeological site.

The traces with a sufficient level of archaeological reliability found in Orthophotos and MIVIS True color images have been also compared numerically. From the comparison of their number, it would seem demonstrated that through MIVIS it is possible to recognize many features that are not identifiable in the Orthophotos. However, the MIVIS images and the Orthophotos, for being fully comparable, should have been shot in the same day, at the same time of the day in the same light conditions, or at least in the same period of the year. Unfortunately, this is not the case, since the MIVIS images were taken in October while the Orthophoto had been taken in May of the same year. For this reason, in comparing the True color MIVIS images to the Orthophoto, it must be kept in mind that the better results gained through MIVIS could be not entirely due to the higher sensitivity and computer enhancement capabilities of the MIVIS data and instead to the moments in which the photographs were taken. Nevertheless some kind of comparison can be done. May is supposed to be still a good period for archaeological survey's images at least for gathering traces over the vegetation, which in that period has not reached the maximum development yet; consequently, if an anomaly on the plant canopy is not visible in the Orthophoto, at its best as regards canopy quality's display, but is visible in the MIVIS image it is likely that it can not be seen any better in a Orthophoto taken in October.

The results of the comparison between MIVIS and Orthophoto's analysis results, however, are encouraging, showing a large increment in the detectability of traces through the hyperspectral sensor (see *Chart 1*), another confirmation of the validity of the hyperspectral instrument for detection of unknown archaeological sites. Orthophotos anyway have proved at the same time to be fundamental for guiding the process of interpretation of the surface features in any processed image because of their better spatial resolution.

8. Conclusions

At the beginning of the research, some issues have been presented in order to find an answer or at least an indication of research through the MIVIS images. It can be said that, at the end of the work, at least part of them have been partially solved, while new issues, not estimated at the beginning, appeared.

One of the first issues was to investigate the archaeological objects that MIVIS could theoretically identify on the ground due to its intrinsic characteristics. It has been proved that the level of detail provided by MIVIS images can be useful for archaeological interpretation and that it allows the identification of a large range of objects' areas: not only roads or other large objects could be detected, but MIVIS images proved to be efficient in recognizing small features that could be identified as probable built structures, canals or narrow road networks. It must be clearly stated, however, that in the case of identification of very small objects, they were, most of the times, found on the base of other indications offered from other processes where they were visible in larger shape and from advises from the archaeological layers, again emphasizing the need for a multi-temporal and multi-scale search process. It must also be stressed as a further prosecution of the research, that, in order to define the typology of the detected objects, it would be necessary for a project to include field-walking survey: only a collection of the surface materials can in fact provide indication of the typological, functional and chronological nature of the object itself, while very few can be said using only the remotely sensed images, unless the archaeological objects are roads or ancient palaeo-riverbeds, easy to recognize for the unmistakable shape.

MIVIS images have proved to be able to detect variations in the surface texture also in proximity of very disturbed areas. Moreover Aquileia territory, for a long time subjected to intense agricultural exploitation, is potentially suitable to recognition of traces of the past occupation, even if some areas of the ancient suburban belt have been strongly modified and covered by the modern expansion and some portions of the territory in the North-East part of the town were subjected to phenomena of elevation of the current soil level because of flooded sedimentation (Maggi, Oriolo 1999, p. 104).

One of the other issues posed at the beginning was to understand when and why the use of hyperspectral sensors imagery can be helpful. MIVIS proved to be able to provide a unique contribution for identification of archaeological targets and settlement dynamics that could not be provided by aerial photographs: the increment of recognizeability compared with Orthophoto was greater than 2 to 1. The hyperspectral tool provides information like the infrared and the thermal wavelength, which, both singularly or combined with other bands, allow to see features not otherwise visible. The MIVIS imagery was helpful also in the detection of variations in the growth of the vegetation and in the state of soil. It demonstrated to be effective especially in the case of areas of uniform vegetation or cultivations, when it makes possible the determination of the level of the stress of the plants and, if the 'stressed' area has a regular shape and matches with other requirements, it is possible to form the hypothesis that it can be an archaeological feature. Equally, hyperspectral imagery showed its potential also in the case of bare soil, where specific bands or processes allowed the discrimination of the humidity or the dryness of the soil.

It is concluded that MIVIS imagery represents a very important complementary source of information when prospecting for archaeological features. Exploiting the elevated spatial and spectral resolutions of the MIVIS data, it was possible to identify probable buried archaeological structures in a more accurate and definite way compared to traditional analysis methods based on aerial pictures. However it is important to stress that an approach of integration of multiple tools and data has shown to be fundamental for a correct interpretation of the detected features and should be strongly supported in every further phase of the research. A really effective investigating strategy in a macro context has in fact to be oriented to the combined use of different remote sensing products managed in G.I.S. environments and to merge them with other information layers in order to obtain results that can not be differently reached and that constitute an important point of reference for the planning of future archaeological excavations.

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