Landscape Archaeology in Tuscany: Cultural resource management, remotely sensed techniques, GIS based data integration and interpretation

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Abstract. The Department of Medieval Archaeology at the University of Siena has long been engaged in the study of the ancient landscape, essentially through intensive field survey and surface collection from agricultural surfaces, the analysis of vertical aerial photographs and the stratigraphical interpretation of monuments. In the last ten years the Laboratory of Information Technology Applied to Medieval Archaeology (LIAAM) has directed its work towards the development and application of global management systems for archaeological documentation. This work has involved not only archaeological excavation but also the preparation and publication of archaeological cartography through the development of GIS dedicated systems. This type of solution allows the realization of three main objectives: acceleration of investigative times, sophisticated elaboration of “intra” and “inter” site data, and real possibilities for tutelage. In particular, we can now for the first time produce efficient instruments for integrating archaeology into the politics of teaching and for achieving a fuller appreciation of the landscape around us. In the past, there have been in essence two fundamental problems: insufficient precision in describing the location of discoveries and the absence of efficient instruments for processing the resulting data. Now, with the georeferenced definition of site boundaries, based on differential GPS technology managed using Geographic Information System, this gap has been conclusively filled. In recent years we have been working towards the integration into the GIS base of a remote sensing module able to process, integrate and maximise the data received from various sources: vertical and oblique aerial photography, high-resolution satellite imagery, geophysical surveying and micro-digital terrain modelling using differential GPS. Basically, this work is aimed at the creation of an interconnected series of databases composed of alphanumeric archives (features, images, the results of ground-truthing exercises and dGPS surveys) along with the essential tools for processing the images in georeferential environments in which it is possible to define surfaces and to correctly calculate dimensions, distances and possible relationships between anomalies. This organization of the data greatly assists the potentially difficult task of surface ground-truthing, allowing anomalies to be located quickly and easily on the ground through a dGPS system and facilitating the subsequent management of the site documentation. The prototype system has been developed in two sample areas, chosen for their differing geo-morphological characteristics, landscape and cultural complexity. These lie in the southern and southeastern part of the province of Siena and along the coastal strip in the province of Livorno between Populonia and San Vincenzo. They have a combined extent of about 470 sq. km. In recent years both areas have been subject to intensive surveys and the multi-temporal analysis of vertical aerial photographs. They therefore present an excellent opportunity for testing the potential of multistage remote sensing in combination with conventional methodologies for landscape analysis.

1 Introduction

The Department of Medieval Archaeology at the University of Siena has been actively engaged in programmes of landscape archaeology for over twenty-five years. The current research projects fall into two categories: the creation of diachronic archaeological maps, and the thematic cataloguing of individual sites. The archaeological maps now cover the provinces of Siena, Grosseto, and various communities around Livorno, taking in a total area of about 9000 sq km. Lately we have carried out systematic field survey within sample areas totaling 800 sq km and have located a total of about 6000 new archaeological sites. The processes of archaeological cartography are for the most part based on three methods of investigation: systematic field survey in sample areas (20-30% of the total landscape); analysis of vertical air photos combined with selective ground-truthing; and field examination to assess the significance of individual monuments[1]. The second category of projects concentrates on thematic research such as that leading to the *Atlas of Tuscany Hill Forts,* which includes more than 4500 anomalies identified on vertical aerial photographs, 1500 of them attributable to medieval castles[2].

We take the view that the creation of archaeological maps has two main objectives, one scientific, the other politico-administrative. The combination of these two objectives facilitates on the one hand the study of the socio-economic and settlement patterns of the region, and on the other gives us access to public administration processes concerned with development and conservation.

To achieve this last objective it is necessary to raise our instrumentation and functionality to the level demanded by the responsible public authorities. New digital technology, in addition to offering powerful tools for the cataloguing, storage, and analysis of archaeological data, has become the new common language for the communication of information. For example, in Tuscany one only has to look at the widespread use of GIS, now present in every local authority office. In addition to traditional methods, archaeologists must use the power of technology to facilitate the dialogue with public authorities that is vital for truly co-operative work. The revolution in technology has opened up new prospects for the public application of archaeology[3].

Our chosen solution is directed towards two fundamental requirements: firstly, the education of professionals who are able to respond to, improve and promote new standards of production; and secondly, communication with different kinds of users through the multi-media presentation of archaeological information.

For at least the last ten years we have been working on the training of archaeologists in computer sciences. This puts a group of people in the position to be educated working, experimenting, and sharing their most valuable experiences for activate new teaching. Presently, we are working with various technologies and applications, including image processing of remotely-sensed data, GIS management of excavations and landscapes, multimedia cataloguing of archaeological resources, 3D modeling, photo-quality rendering and animation, morphing of excavated structures, electronic video documentation, organization and CAD management of sites, QuickTime Virtual Reality setting, video/film editing and management, and the creation of Internet sites and pages concerning research and archaeological parks. Communication with the general public, as well as with private individuals and institutions, is enhanced by multimedia support and educational Internet sites, which are quickly becoming the gateway to Medieval Archaeology in Italy. By including archaeological sites and information in digitally-available cartography we are increasing the value and impact of our research while at the same time satisfying the needs of public authorities for the protection and management of archaeological sites, and the desire of the general public for cultural enrichment[4]. The principal scientific objective has been achieved through the construction of a management system for all of the information gathered in the research programmes of the Department of Medieval Archaeology. Archiving this information in the most comprehensive way allows us to bring together a vast amount of digital data, alphanumeric, graphical and moving images. It also speeds the processing time and significantly reduces the loss of data. Ultimately, it means that the research results become available to the whole scientific community. Digital archiving, along with the Internet availability of research data, opens up our laboratories and secures the public use of archaeological information. Our chosen solution combines the use of data-management packages (ArcView GIS, MacMap, FileMaker Pro, Canto Cumulus etc) in combination with the design and implementation of an application which we have called Open-Archeo. This application, through a simple user interface, compares and creates multi-directional dialogue between the basic data and the many different applications in use at any one time. Essentially, it permits optimal access to the archaeological data[5].

Riccardo Francovich

[1] We note here only the last few in a long series of papers on the methodology used in the Siena Province Archaeological Map Project: VALENTI 1999, pp.10-14; FRANCOVICH-VALENTI 2001, pp.83-116; CAMPANA 2001, pp. 47-71. A detailed introduction on this subject can also be found on the Siena University Internet Site (Webmaster: L. Isabella, A. Mignani):<archeologiamedievale.unisi.it>.
[2] FRANCOVICH-GINATEMPO 2000.
[3] FRANCOVICH-VALENTI 2001, pp.83-116.
[4] FRANCOVICH-ZIFFERERO 1999.
[5] FRONZA *et al.* 2001, pp.173-177; ISABELLA *et al.* 2001, pp.31-64.

2 Research methods

In the last few years we have turned our attention to the development of remotely sensed techniques[6]. Within the Department, the Laboratory of Aerial Photographic Interpretation has been active since 1984. In addition to teaching, the Laboratory has carried out numerous research projects, leading to the identification of over 5000 air-photo anomalies in Tuscany alone[7]. The laboratory is dedicated to the stereoscopic examination of vertical aerial photographs. The photographs at our disposal belong to Regional Mapping Office or to Military Institute for Cartography. They are taken as a matter of routine, every ten years between August and September, to generate maps. Despite good archaeological results, we have been conscious throughout of the inherent limitations of this method of survey. The main problem is the cartographic nature of the data and the impossibility of planning the flights to coincide with times when conditions for the detection of archaeological features are at their best. In addition, there are other problems with vertical photographs, such as the inherent inflexibility of paper documents, the difficulties of magnifying details, and the limited capacity to distinguish between tones of grey, etc.

To try and overcome these limitations in pursuit of our own objectives we have changed our focus to the experimental application and evaluation of new techniques in the study of the Tuscan landscape. After looking at experience elsewhere, we realized that there was not an ideal technique capable to exclude all the others. Each data source has its imperfections. In short we started from known concepts summarized by Lillesand and Kiefer as “more information is obtained by analysing multiple views of the terrain than by analysis of any single view” and that “successful application of remote sensing is premised on the integration of multiple, interrelated data sources and analysis procedures”[8]. This is the reason why we turned to oblique aerial photography, to the latest generation of multi-spectral high-resolution satellite imagery, to geophysical survey and to micro-digital terrain modelling using differential GPS.

Our progress in developing this approach can be highlighted by looking at two sample areas, representative of the landscape complexities and settlement patterns of Tuscany.

The first, consisting of primarily flat land, is situated in the province of Livorno and includes the coastal strip between Populonia, Campiglia Marittima and Donoratico (Fig.1). The second area is situated in the province of Siena. This geo-morphologically hilly countryside, as well as its known archaeology, is representative of considerable stretches of Siena province (Fig.2)

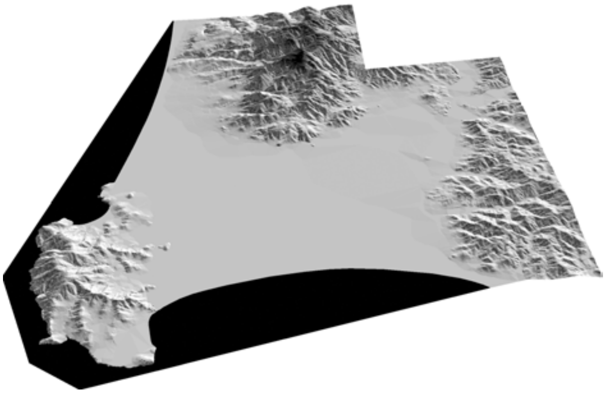

Fig.1 – DEM of coastal strip between Populonia, Campiglia Marittima and Donoratico (sample area 1)

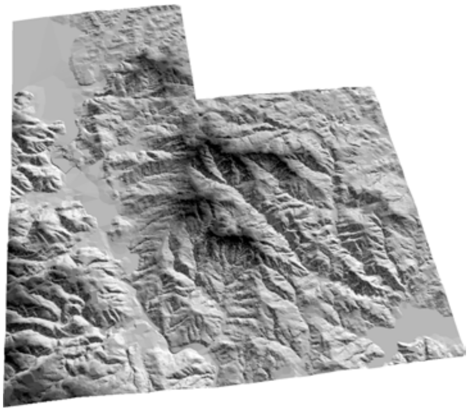

Fig.2 – DEM of the typical hilly countryside of Siena Province (sample area 2)

The total extent of these sample areas is around 470 sq km. Both areas have recently been the subject of numerous socio-archaeological studies, field-walking surveys, excavations, vertical air-photo interpretation and geological and geomorphological analyses. Presently there are in our DBMS more than 1800 archaeological sites, from Palaeolithic to Late Medieval[9]. When setting up the research project we paid particularly close attention to the systematic collection of data. The first objective of the operation was to acquire as many individual pieces of information as possible for comparison between oblique aerial photography and satellite imagery. The second stage will aim to integrate and reinterpret the whole body of information using GIS based technology, and from this to postulate new settlement patterns. To manage all of the related documentation we have designed an archaeological GIS system using a data model which combines alphanumeric and multimedia databases, basemaps (topographic raster and vector data), remotely-sensed data, Triangulated Irregular Network (TIN) objects, differential GPS data and a variety of derived datasets.

It is possible to divide the graphical information into three categories: technical, thematic and historical. The maps can be presented in raster and/or vector format with Gauss-Boaga geographical coordinates. The availability of source

[6] CAMPANA-FORTE 2001.
[7] COSCI 2001, pp.55-64.
[8] LILLESAND-KIEFER 1994.

[9] CORTEMIGLIA *et al.* 1983, pp. 148-173; FEDELI *et al.* 1993; MAZZANTI 1995; CECCARELLI LEMUT-GARZELLA 1996; BIANCHI *et al.* 1997; COSCI 2001, pp.55-64.

maps has increased during the project, the material now at our disposal being shown in Table-1. At the same time, we have designed an ArcView GIS extension for the better management of the raster and vector data[10]. The basic concept of the extension is to use a friendly wizard to select the source-material that we want to present visually - Ikonos-2 MS, vertical photographs from 1954, vector data, TIN data, or any other kind of data - and then to add automatically the data corresponding to the area that we are looking at on-screen. This utility allows us to organise and manage - without the need for grids or other reference tools – very large numbers of datasets, thereby reducing dead time and giving other researchers easy access to the data[11]. The DBMS was developed by the Laboratory of Information Technology Applied to Medieval Archaeology (Siena University). We have extended it with the addition of new modules for remotely sensed data, GPS data and ground-truth check data[12].

2.1 Vertical aerial photographs

Despite their inherent limitations, vertical aerial photographs, with their wide temporal range, represent an irreplaceable source for the analysis of the Tuscan landscape. Anyone interpreting the photographs used in our own study will see a 3D replica of the whole landscape as it was in 1938, 1954, 1976 and 1994. In addition to their historical content, vertical photographs are of course an important source for the conduct of "aerial reconnaissance". Our way of working can be defined as hybrid, based on analog and digital analysis of every frame. All the photographs at our disposal have an overlap of 65%, providing stereoscopic views. Firstly the whole of each photograph is examined thoroughly using a stereoscope. In a second phase each frame is scanned and orthorectified. Because this process is very time-consuming it has been applied only to recent research projects (Fig.3). In the case of the 5000 anomalies detected in earlier studies we have not orthorectified the entire frame but only the areas of the already-identified archaeological features[13]. It would have been more interesting, of course, to make GIS-ready mosaics of all of the photographs, suitable for image processing, interpretation and reinterpretation, and for comparison with other archaeological layers within the GIS. But by mapping only the anomalies we were able, in a relatively short time, to obtain data for "intra" and "inter" site analyses. At the moment we are working in collaboration with the Remote Sensing Laboratory of the University of Florence to achieve desk-top management of the whole process through the use of ERDAS Imagine® software[14].

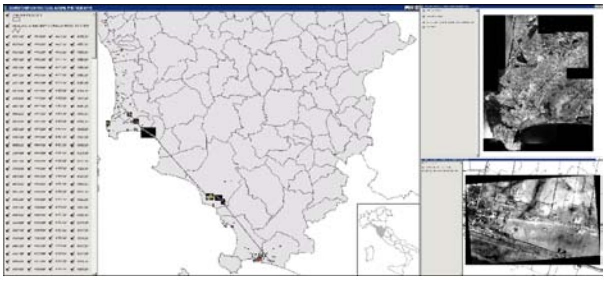

Fig.3 – Example of GIS management of vertical aerial photographs and mosaic

2.2 Oblique aerial photography

The opportunity to develop a programme of oblique air-photography for landscape investigation first presented itself in 1999 during the University of Siena's XIth International School in Archaeology. In anticipation of imminent changes in Italian law on aerial photography, the possibility of organizing an air survey training course in Siena was discussed with two colleagues from Britain, firstly Chris Musson, from Wales, and then Robert Bewley, Head of Aerial Survey at English Heritage[15]. Depending on the weather conditions during the spring, our reconnaissance season usually runs from the middle of May to the middle of June. In the spring of 2000 we carried out preliminary aerial reconnaissance to check at first hand the potential and limitations of oblique air-photography in the landscape of Tuscany. Then, at the end of May 2001, twenty-one post-graduate students engaged in the areas of research and heritage conservation took part in the first Aerial Archaeology Research School to be held in Italy. In addition to instruction, the objective of the school was to start building up an archive of oblique air photographs for the recording of the archaeological resource throughout Tuscany. Over a week of aerial photography we completed 127 hours of flying, took 5500 air photographs and made three hours of video film.

At the moment all the images have been scanned and, along with the video-film, have been imported into a multimedia database. The chosen software, Canto Cumulus, is of some interest[16]. It permits the creation of extensive catalogues of images and other media data, apparently without record limits. This software allows the building of a system of hierarchical and thematic categories that allows us to order the various items according to their intrinsic archaeological content. The pictures can be presented on-screen at various scales, from thumbnail to screen-size or greater, with related space for descriptive text (Fig.4). Following generation of the catalogue the next stage was to map all the sites that had been photographed.

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[10] Lorenzo Bianchini, of the Department of Engineering at the University of Florence, wrote the programme for the extension in ESRI AVENUE language.

[11] We are now developing the extension for use on an intranet network.

[12] For the characteristics of the DBMS see FRONZA 2000, pp. 125-137; for the new modules see CAMPANA 2001, pp.61-63.

[13] After pre-processing, the images are geo-referenced, generally using at least four ground control points on the regional technical map at a scale of 1:10.000.

[14] The Remote Sensing Laboratory of Florence University is directed by Prof. Enzo Pranzini.

[15] DRIVER-MUSSON 2000, pp. 51-54.

[16] See <http://www.canto.com>

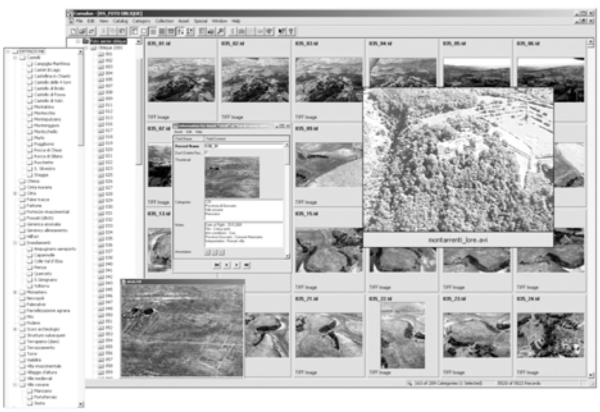

Fig.4 – Canto Cumulus media catalogue: pictures, movies and thematic categories

At this stage of the work each sequence of frames defining a site, tied to the GPS data-points acquired during flight, was placed into the GIS environment. In this phase the availability of detailed topographical maps represented the main pre-requisite for the correct siting of each sequence of frames and thence of the sites themselves[17]. Altogether, we acquired 616 GPS data-points, corresponding to approximately 281 air photo anomalies within Tuscany and a still-unidentified number in various parts of Lazio, Abruzzo and Umbria. For working in these latter regions there is a typically Italian problem - the bureaucratic difficulty of obtaining technical cartography. Moreover, the absence of comprehensive archaeological maps for these areas prevents a rapid comparison between known sites and those represented in the photographs.
Within Tuscany, by contrast, the situation is more favourable. The comparison between the known archaeological data and the oblique air photographs was carried out within the archaeological GIS, by checking the correspondence between the images and the known and mapped sites. To do this, we first concentrated on locating the images on a points layer within the GIS system. At the moment we are still working on the rectification and mapping of the photographs[18]. Considering the high number of photograph, our strategy for mapping has been to use only the most representative images, limiting ourselves in most cases to a single photo per site. This was the only way that we could hope within a reasonable time to integrate the aerial information into the GIS system and to compare it with other layers of information at our disposal. In addition, we will create a thematic vector layer showing the anomalies or the perimeters of the monuments which they represent.

During the Research School we recorded approximately 281 sites in Tuscany, the great majority being castles, medieval settlements, monasteries, old field boundaries, archaeological excavations, Roman villas and ancient roads (Fig. 5). About 37% of the sites, identified simply as 'crop marks', 'soil marks' or 'unidentified anomalies', await allocation where possible to a more precise site type. Upon first examination the comparison with the archaeological GIS of the Department of Archaeology suggests that of the 281 sites catalogued 132 are new to the record. This preliminary interpretation of the sites has made a significant contribution to our search for understanding of settlement patterns and road systems in the region. We can perhaps see this as a growing trend, even though 66% of the new sites are for the moment only generically defined, as crop marks, soil marks and unidentified anomalies.

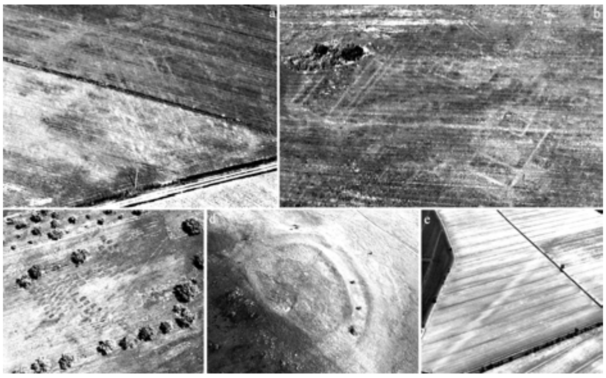

Fig.5 – Examples of anomalies recorded during the Aerial Archaeology Research School; a-b) roman villas; c) necropolis; d) hill fort; e) road

Granted that our work with oblique photography has only just begun, and that individual anomalies still need to be confirmed in the field (at least on a sample basis), our first experience of active aerial survey has been on the whole positive. Among the objectives that we would like to achieve in the rest of 2002 and the early part of 2003 is the publication of the whole photographic archive on the Internet. Altogether, the results of the Research School are of considerable significance, permitting the identification of a large number of new sites, the monitoring of well-known sites and, last but not least, the acquisition by the Department of the knowledge and experience to continue the work independently. In this last respect another goal that we are working towards is the development of a systematic programme of aerial photography and air photo mapping in Tuscany.

2.3 High-resolution satellite imagery (HRSI)

It was only in February 2001 that we begun to build up our experience in the use of HRSI. The aim is the evaluation of multispectral data for archaeological research, firstly using Ikonos-2 imagery and then from June 2002 working on QuikBird-2 imagery.

The central question was to see whether Ikonos-2 imagery could be useful in the identification of archaeological sites and heritage resources in an area like Tuscany. In the past the successes achieved through the use of satellite imagery have usually been obtained in desert landscapes or in areas where such imagery represents the only available source of

[17] DOLATOWSKA-GOLIASZ 1999, pp.41-42.
[18] For the mapping techniques used see DONEUS 2001, pp.17-27.

remotely sensed data[19]. In Italy, for instance, there have been relatively few studies using satellite imagery, and these have been mainly restricted to Roman centuriation and geomorphological or paleoenvironmental analyses[20]. Two factors have been in operation here: on the one side the low resolution of Landsat and Spot imagery, on the other the principal advantages of satellite imagery, its capacity to capture large section of the landscape and to record these at a number of different wavelengths in the visible, reflected or emitted infrared parts of the electromagnetic spectrum. In addition, computer enhancement of the digital data places less dependence on the time of year for revealing archaeological features. It is possible to identify the main differences between Landsat and Ikonos-2 as being that Ikonos-2 imagery has a higher ground resolution but a lower number of bands, including the complete absence of medium and thermal infrared.

The continuing improvement in the resolving power of the new generation of satellites is changing the possible uses of satellite imagery so that in the right circumstances the information drawn from Ikonos-2 imagery is beginning to stand comparison with that of vertical air photography[21]. Theoretically the level of detail visible in Ikonos-2 imagery allows the identification of line features 3-4 meters in width and of area features within the range of 1000-2500 sq m. In archaeological terms, Etruscan-Hellenistic *oppida*, Roman villas, churches, monasteries, medieval castles and villages are all types of remains that would potentially be visible on the new generation of satellite imagery.

The two images used in our study were captured on 10th July 2000 at 10.05 in the morning by the Ikonos-2 satellite. The first, on the Livorno coastline, is characterised by excellent quality, very good visibility and a total absence of cloud and haze (Fig.6). The second, in the province of Siena, is of low quality, showing evidence of clouds and of degradation by haze (Fig.7).

Our methodological approach to Ikonos-2 imagery has been focused on 2D visual interpretation and the exploration of 3D representations[22].

The procedure followed in processing the Ikonos-2 imagery falls into two main phases.

Fig.6 – Ikonos multispectral imagery of sample area 1

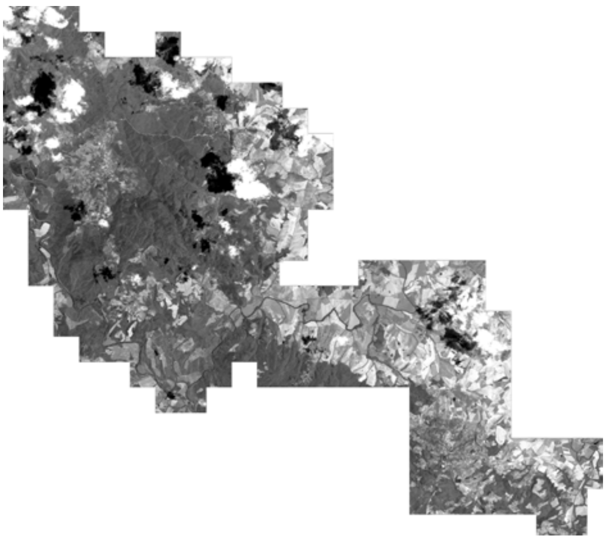

Fig.7 – Ikonos multispectral imagery of sample area 2

[19] We are thinking for instance of the pioneering work of the NASA Space Centre in south America, see <http://www.ghcc.msfc.nasa.gov/archeology/ archeology.html>.

[20] In particular we would point to the experience of MARCOLONGO - MASCELLARI 1978, pp. 131 ss.; BARISANO *et al.* 1984 ; PIERI-PRANZINI 1989, pp.1385-1388; ALESSANDRO *et al.* 1992, pp.547-551; COSTI *et al.* 1992; DICEGLIE 1992, pp.421-439; COLOSI *et al.* 1996 ; BAGGIO *et al.* 1998; FORTE *et al.* 1998, pp. 291-304; CREMASCHI-FORTE 1999, pp.207-226; PRANZINI-SANTINI 1999, pp. 283-291; MARCHISIO et *et al.* 2000; PASQUNUCCI-TRÉMENT 2000.

[21] Even if their geometric resolution is still somewhat lower than that of vertical aerial photographs, the high quality of Ikonos images, due to their digital nature and their eleven-bit radiometric resolution, overcomes this problem, making it possible to achieve a real comparison between the two different sources of information.

[22] For software we used mainly ERMAPPER, ERDAS Imagine, ArcView 3D analyst (ESRI) and ENVI.

The first consists of a series of standard transformations of the whole image. In this stage of the processing some of the most commonly used techniques have been contrast stretching, density slicing, RGB colour composites of the original bands (3-2-1; 4-3-2; 4-2-1; 3-4-1) and arithmetic manipulation, in particular averaging (to reduce the noise component) and rationing (NDVI). This phase plays a central role in the identification of archaeological features.

Between the first and second phase of processing and visual interpretation we use the GIS system to make comparisons with the features identified in the various GIS layers that mentioned above. This step has been useful in preventing other kinds of misidentification, for instance of non-archaeological features. In all, we have recognized in our satellite imagery 104 anomalies, of which 45 had already been identified through the analysis of air photography. Comparison in the GIS reduced the number of probable archaeological features to eighty-four.

At a later stage (second phase of image processing), the focus of view was narrowed in order to isolate homogeneous textures around individual anomalies. The processing was carried out using Principle Component Analysis (PCA), Tasselled Cap Transformation (TCT), Decorrelation Stretch (DS) and RGB colour composites of the results of the various transformations. The filters, when applied - whether in the first or second phase - were primarily constituted of 3 by 3 matrices, for the most part confined to sharpening, smoothing, and edge enhancement[23].
On completion of the image processing we are able to recognize some trends. As we expected, all of the best results come from transformations in which the near infrared band plays a primary role, especially in NDVI, first Principal Component, brightness and Wetness Transformation and relative colour composites[24]. Certainly there is no single ideal technique, but rather a spectrum of techniques producing variable results[25].

Altogether, our present processing of the Ikonos-2 imagery has allowed us to identify 84 archaeological features. Firstly, we may note that 82% of these are in the coastal strip (sample area 1). In the first stage of analysis we interpreted features as settlements, hill forts, mounds, roads, ancient riverbeds and some not-identified (Fig.8). During the winter of 2001/2002 we checked on the ground, mainly through traditional field survey, a sample of 40% of the features. The results confirmed the presence of archaeological finds or features in 59% of the cases. In the 18% anomalies were the consequence of modern activities. In the 23% where we found no archaeological artefacts or structural remains there was also no modern activity that might have revealed such evidence.

Although this work is still in progress, with 60% of the features still to be confirmed in the field, our experience working with Ikonos-2 imagery has been, as a whole, positive. We think that multispectral imagery has characteristics which are entirely compatible with the needs of archaeological landscape investigation. The resolving power of the images allows us to identify a large range of archaeological sites. At the best, archaeological features are distinguishable at a size of 20 to 30 m across, and more commonly in the order of 50 to 60 m across.

Fig.8 – Examples of anomalies identified analysing Ikonos-2 data; a) Mound (RGB colour composite of bands 4-3-2); b) road and ditch (true colour composite); c) ancient riverbed (RGB Colour composite of bands 4-3-2); d) Etruscan settlement(RGB colour composite of BGW derived from TCT); e) medieval village (Second Principal Component); f) medieval village (RGB colour composite of bands 3-4-2); g) hillfort (NDVI); h) not identified (RGB colour composite of bands 4-3-2); i) medieval castle (true colour composite)

In summary, the particular contribution of Ikonos-2 imagery should be recognized as lying in its multispectral properties, in the near infrared band and in the possibility of recording the whole of the landscape at times when crop marks or soil marks are at their best. Unfavourable aspects of recent satellite imagery remain substantially the same as for the preceding generation of satellites, in particular the impact of unfavourable morphology, the need for excellent atmospheric conditions, and the relatively high cost.

3 Linking real landscape and GIS environment: the GPS technology

Looking at poor archaeological literature produced in Italy about use of GPS for archaeological research, the general idea that emerged it is that GPS is rarely used and the real potential of this tool has been underestimated and in a certain way misunderstood. Moreover paradoxical is the widespread use in landscape studies of GIS technology in

[23] CAMPANA-PRANZINI 2001, pp.17-62.
[24] On account of the very similar spectral ranges of bands 1-2-3-4 of Ikonos with Landsat TM in the first approximation we used the algorithm developed by Crist-Cicone, 1984.
[25] An approach based on visual detection is affected by subjectivity, and the perception of anomalies varies from individual to individual.

comparison with the low diffusion of handheld GPS data collection system.

In the 1999 we bought our first handheld GPS, a Trimble GeoExplorer2. At the beginning the main use we did of GPS was strictly related with mapping operations of artefact scatters and monumental structures during field survey. Soon we realized that GPS technology could be applied on the field or during aerial survey for numerous tasks as to map particular finds, photographs (ground and aerial) or Quick Time Virtual Reality movie, shovel test and ground control point for photogrammetry and geophysics prospection; to monitor the movement of artefacts scatters; to record aerial tracks and the true surveyed areas**;** to generate micro-digital terrain modelling, etc. Furthermore GPS not only may map point, line and area but allow us to navigate on site exporting geographic coordinates from GIS. Navigating with the support of the GPS is not only extremely useful in many situations, but also easy, quickly and accurate. For instance in relationship with anomalies a methodological problem we had before the introduction of GPS technology was to identify with accuracy features on the ground previously identified on the imagery. This is true above all in situation of scarce visibility (wood areas) or absence of artefacts or structures. In short, GPS is fast, easy to use and very accurate for land survey mapping and navigation[26]. That's why we improved this sector buying two others handheld Trimble GeoExplorer3 and a Trimble 5700 reference station for the differential correction of rover data. Using these GPS system very intensively we collected autonomously a wide quantity of topographic data in the main with an error of ±1 m.

In our experience we believe that a significant peculiarity of GPS system it the reduction of the distance between real world and his digital representation. GPS data collection system let us move from an approximate representation of reality (our archaeological GIS and more generally digital data) to the real world and vice versa making easier to link and tie drastically the two environments: reality and its GIS abstraction. On this topic it is already possible to do more using handhelds Pocket PC. During 2002-beguinning of 2003 we will flank to Geoexplorer3 an iPAQ Pocket PC with a Trimble GPS module (the mapping precision is ±2 m). The difference between the devices is easy to understand. Geoexplore3 is "only" a handheld GPS data collection system, iPAQ is a GPS and a small computer too. We believe that this device will allows us to bring an important part of our laboratories directly on the field or better in the landscape in order to build the documentation - GIS, DBMS, media catalogues, GPS and most of digital data - directly on the field. We trust applying this technology to increase the typology and improve the quality of data avoiding any kind of intermediation. Furthermore the information will be available and manageable during every phase of the research reducing work time and lose of data[27].

4 GIS based interpretation of remotely sensed data and their integration with other data sources

It could be argued that it is possible to interpret remotely sensed data quite effectively without mapping. This may sometimes be true but to understand landscapes fully, and to combine multi-source data, there is no alternative to mapping and to management of the related documentation through GIS technology.

As has been recently noted, the archaeological interpretation of remotely sensed data is not simply the identification of anomalous features but the non-destructive recovery of archaeological information by producing accurate maps and completing entries for a descriptive DBMS. Only an experienced archaeologist can carry out this process in its entirety[28]. Moreover, archaeological interpretation in terms of detecting, accurate mapping and writing archaeological descriptions of relevant features is a dynamic process based on mental comparison of the detected features with known structures or landforms, a process driven by archaeological feedback. The interpretation of archaeological survey data, as of any other source material, represents the first stage of in the research process, but in contrast to excavation it is in this case a repeatable and non-destructive process.

As in every form of landscape analysis it is possible to distinguish two different levels of analysis: intra-site and inter-site analysis. For both kinds of analysis GIS represents the appropriate environment for the complex processes of interpretation and integration between different sources. Our approach has been based on 2D visual interpretation and the exploration of 3D representations.

In the first stage of analysis (intra-site) the remotely sensed data has to be combined and reinterpreted together if we are to retrieve the maximum information. The archaeological interpretation of the combined prospection data is done directly on-screen, through the overlaying of different forms of imagery, along with relevant geographical information (technical, thematic and historical maps) and known archaeological data. The archaeological features have been drawn onto different thematic layers (every individual element as a polyline and polygon)[29] and the alphanumeric information stored in a relational database linked to the graphical interpretation.

[26] For an exhaustive description of our experience using GPS see CAMPANA 2001, pp. 47-71.

[27] In general on handhelds Pocket PC see, WILSON, 2001, pp.40-45; COOPER, 2001, 29-32. For archaeological application POWLESLAND in the CAA Conference proceedings of 2002 (in press).

[28] DONEUS *et al*. 2001, p.31.

[29] It is possible to distinguish at least two groups of individual elements detected by the processing of imagery, area features and line features, the latter having length but no "shape" or breadth.

The quantitative results of our archaeological interpretations are summarised in Table-2. This shows clearly how every remotely sensed technique that we adopted increased the archaeological record. As expected, the vertical aerial photographs from 1938 and 1954 made a profound contribution to the study of the landscape. In Tuscany, and more generally in Italy, after the Second World War the landscape underwent great transformations. Mechanized agriculture, building operations, provincial road schemes, highways, aqueducts, pipeline, power lines and the like destroyed numerous archaeological sites. Only the appropriate use of historical air photo sorties can now show us these sites. Moreover, this source allows us to visualize the whole landscape as it was before such these destructive human interventions, giving a reasonably realistic idea of how it appeared in 'pre-industrial' times.

The differing returns, in our area of study, from vertical aerial photographs taken in 1976, 1994 and 1996, compared with those from the historical flights, has to be measured against the sometimes inappropriate "time-window" in which they were taken, as well as the loss of many sites because of recent changes in the landscape.

As regards the utility of oblique aerial photographs in the sample areas it is difficult to draw up a balance at this stage. The fourteen sites identified in these areas could seem a low number in comparison with the returns from other sources. It should be remembered, however, that the amount of flying undertaken in the sample areas during the Aerial Archaeology School provided only very partial coverage of the area. On the basis of the results achieved, and in the light of evidence from elsewhere, we feel that the high value of the oblique technique is undeniable. We recognise that it is too early to form a judgement for our own area and that we need to fly again and again, year after year in the right "time-windows". However, oblique aerial photography has already permitted us to recognize fourteen sites within our sample areas, three of them never identified before, while in four other cases we added to the existing archaeological information.

Positive results have been obtained using Ikonos-2 multispectral imagery, with the recording of 84 features in the sample areas, of which 39 are new sites. In fourteen cases where anomalies were identified previously through vertical or oblique photographs it was possible to add to the existing information. We should perhaps note one peculiarity of Ikonos-2 imagery. Through Ikonos-2 we can recognise many features that were visible in the early air photographs but which are no longer identifiable in those taken between 1976 and 1996. This situation perhaps derives from the inappropriate "time-window" in which the later photographs were taken, or alternatively from the higher sensitivity and computer enhancement capabilities of the Ikonos-2 data. If confirmed, however, this trend will indicate HRSI as an important tool for monitoring and exploration of the archaeological heritage.

In conclusion, we believe that most of the results obtained from analysis of the Ikonos-2 imagery depend very much upon the multispectral properties of the sensor. The Ikonos-2 scanner has four bands that range from 450 to 880 nanometers, although not all are equally useful. In our study we concluded that bands 2 (green), but above all 3 (red) and 4 (near infrared), show the most potential for the identification of archaeological features. Band 1, blue, suffers from atmospheric attenuation and scattering that degrades its definition. Red and near infrared images are less affected by haze and provide good definition for soil marks and crop marks. Above all the near infrared represents the most powerful band. This band is particularly sensitive to plant health and can often detect water stress in vegetation before it can be seen by the naked eye. Despite these promising early results the true potential of this type of imagery is still not fully clear and needs to be further evaluated to test its responsiveness under a broad range of environmental conditions.

Once we have reached an understanding of each site individually it is possible to proceed to the analysis of inter-site relationships. The GIS environment allows us to interpret sites in the landscapes not simply as a distribution of points but rather as real objects possessing shape, surface modulation, length and orientation. For instance using statistical tools and spatial analysis it is possible to classify orientations and compare the results for settlements, cemeteries, roads etc of the same or of different chronological periods.

It has to be admitted, however, that we have still a lot of work to do in terms of developing archaeological interpretation tools based on GIS technology for exploiting the full possibilities presented by this form of prospection.

5 Conclusions

In any approach to applying remote sensing to landscapes or to an individual site, it is necessary not only to choose the right mix of systems for data acquisition and data interpretation, but also to identify the right combination of remote sensing and "traditional" methods.

The evaluation and use of Ikonos-2 imagery, oblique aerial photography and geophysics forms part of a wider strategy aimed at understanding the peculiarity of every single source so that we can on each occasion employ the appropriate combination of remote sensing techniques to maximize our understanding of the ancient landscape.

By applying multistage sensing techniques to our landscape projects we are beginning to develop a system of modular prospecting. Starting from a broad over-view of the survey area, we move through a series of steps, ultimately to a level of detailed definition. The use of different data-sources allows us to work at a variety of spatial resolutions. But it also introduces two other key factors: spectral and temporal resolution. "Spectral resolution" refers to those parts of the electromagnetic spectrum that are employed in each technique: black-and-white panchromatic for vertical photography, colour or near infrared for oblique photography, and blue/green/red/near-infrared for Ikonos-2 satellite imagery. "Temporal resolution" refers to the frequency and length of time over which the images have been collected for the same area. The vertical photographs at our disposal have a wide temporal range, between 1938 and 1998. The oblique photographs and Ikonos-2 satellite imagery have been collected only since 2000.

Even at this early stage we can say that the introduction of this approach to landscape analysis, running hand in hand with continuing programmes of field-walking, has transformed both our way of working and our understanding of the ancient landscape.

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Table 1 *– GIS data entry and derived data*

		Raster	Vector	GPS	Derived Datasets
Basemaps	**Technical**	***regional maps 1:10.000***	***regional maps 1:10.000***	***micro-digital terrain modelling using differential GPS***	***TIN of sample areas***
		regional maps 1:5.000	***regional maps 1:2.000***		***TIN of Populonia area (1:2.000)***
		cadastral maps 1:5.000	***cadastral maps 1:5.000***		
	Thematic		published archaeological sites; administrative boundaries; technical reference grids, etc.; wetlands areas (1:10.000); vegetative surface cover (1:25.000); non-vegetative surface cover (1:25.000); regional geology, hydrography, transportation, climate, precipitation, mean annual temperature 1:100.000.		vector overlay of : land units and field-survey sample areas; texture mapping of vector overlays on the TIN.
	Historical	***various maps dating from between 1779 and 1830***	***1830 historical cadastral maps***		***1830 vegetative surface cover***
		1940 (Military Institute for Cartography - 1:25,000)	***1940 map of settlement (Military Institute for Cartography - 1:25.000)***		***1940 Thiessen poligon of settlement***
			old mineral-prospecting permissions (1900-1970)		
Remotely Sensed Data	**Satellite**	***landsatTM (summer-winter 1995); Ikonos MS (spring 2000)***	***line and area features***	***ground survey data: mapping and waypoints***	***texture mapping on TIN***
	Vertical photograph	***Fights of years: 1938, 1940, 1954, 1976, 1994, 1996, 1998***	***line and area features***	***ground survey data: mapping and waypoints***	***texture mapping on TIN***
	Oblique photograph	***Aerial survey of years: 2000 and 2001***	***line and area features***	***aerial tracks and positioning of photographs; ground survey data: mapping and waypoints***	***texture mapping on TIN***
	Geophisics	***magnetometry survey of years: 2001 and 2002***	***line and area features***	***ground survey data: mapping and waypoints***	***texture mapping on TIN***
Field survey		***geocoded photographs, QTVR and movies***	***point, line and area of: artefact scatters, archaeological sites divided up so as to show settlement patterns at different periods***	***Mapping of: artefact scatter areas, perimeter of monuments***	***texture mapping on TIN***

Table 2 *– Relationship between remotely sensed techniques*

	Features in the two sample areas	Features visible only through a single source	Increased information for features visible from two or more source
Vertical aerial photographs 1938-1954	92	36	32
Vertical aerial photographs 1970-1996	22	6	2
Oblique aerial photographs 2001	14	3	4
Ikonos multispectral imagery July 2000	84	39	14