HIGH RESOLUTION SATELLITE IMAGERY: A NEW SOURCE OF INFORMATION TO THE ARCHAEOLOGICAL STUDY OF ITALIAN LANDSCAPES? CASE STUDY OF TUSCANY

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ABSTRACT

The experience of the Department of Medieval Archaeology at the University of Siena in high resolution satellite imagery (HRSI) has concentrated on five sample areas, chosen for their differing geo-morphological characteristics, landscapes and cultural complexity. They have a combined extent of about 670 km^2. In recent years all five areas have been subjected to multi-temporal analysis of vertical aerial photographs, to intensive field survey and to aerial survey. They therefore present an excellent opportunity for testing the potential of HSRI in comparison with "traditional" methodologies for landscape analysis. Ikonos-2 imagery has proved interesting in allowing us to identify features in the order of 40-50 m in diameter, along with alignments relating to ancient road systems. The work with Quickbird-2 imagery has only just begun but the higher ground resolution and above all the possibility for the first time of choosing the capture time make us optimistic about a variety of possible applications in Tuscany and more generally in Italian landscape archaeology.

1. INTRODUCTION

In the recent past most successful applications of satellite imagery have been involved with the reconstruction of past environments. The detection of archaeological features has been restricted to large structures such as cities, funeral monuments or road systems, usually situated in desert landscapes or in areas where satellite imagery represents the only available source of remotely sensed data. In Italy, for instance, there have been relatively few studies in archaeology using satellite imagery, and these have been mainly restricted to Roman centuriation and geomorphological or paleoenvironmental analyses [1]. Two factors have been in operation here, on the one hand the relatively low resolution of Landsat and Spot imagery, on the other hand the principal advantages of satellite imagery - its capacity to capture large sections 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.

Since 1999 the Ikonos-2 satellite has been available, with high resolution and multispectral band sets. In autumn 2001 the limit of spatial resolution was reduced to as little as 0.70-0.61 m with the successful placing in orbit of Qickbird-2. The continuing improvement in the resolving power of this last generation of satellites is changing the possible uses of the imagery so that in the right circumstances the information drawn from Ikonos-2, or even better from Quickbird-2, imagery can stand comparison with that of medium altitude vertical air photography. Theoretically the level of detail visible in Ikonos-2 or Quickbird-2 imagery allows the identification of quite narrow linear features (between 1-2 meters in width) and of medium sized area features (within the range of 200-1000 m^2). In Tuscany the archaeological features characterized by such sizes include Etruscan castles, Roman villas, churches, monasteries, medieval castles and villages, etc.

2. THE BACKGROUND

The use of remote sensing in archaeology at the University of Siena dates back as early as 1984. Within the Department of Medieval Archaeology, the Laboratory of Aerial Photographic Interpretation has been dedicated to the interpretation of vertical aerial photographs. In the last twenty years it has carried out numerous research projects, leading to the identification of over five thousand air-photo anomalies in Tuscany [2]. The photographs at our disposal belong to the Regional Mapping Office or to the 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 impossibility of planning the flights to coincide with times when conditions for the detection of archaeological features are at their best.

To try to overcome these limitations and to improve our approach to landscapes we turned our attention to other sources. In the last four years we have started working

with HRSI, aerial survey, geophysical survey and micro-digital terrain modeling using differential GPS. It is probably clear that the evaluation and use of HRSI, like that of 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. Certainly in the next few years we will consider other sources of remote information to improve the range of techniques at our disposal. For the moment, our experience with satellite imagery began in 2000 with a research project aimed at testing the particular contribution of HRSI to the study of Tuscan landscapes. The first part of the project was focused on two sample areas, using the Ikonos-2 multispectral product. The second part, just started, deals with Quickbird-2 data in three new sample areas of southern Tuscany.

3. THE PROJECT

The central question was to establish whether high resolution satellite imagery could be useful in the identification of archaeological sites and heritage resources in an area like Tuscany. In archaeological terms Tuscany is similar to the rest of Italy and many other areas in the northern basin of the Mediterranean. These landscapes are characterized by high population density, a huge number of archaeological studies (resulting in a great number of known sites) and - above all - a good availability of vertical aerial photographs (mostly from the second half of the XXth century), along with historical, technical and thematic maps, etc. Against this background we feel it is necessary to find a special role for HRSI, not duplicated by the existing techniques of investigation.

Before starting the evaluation of HRSI we identified a number of questions that we wanted to understand and that we thought capable of a partial resolution. Overall, we wanted to comprehend:

1. Firstly, why should we use high-cost satellite imagery, in Tuscany or elsewhere, if other sources such as multi-temporal vertical aerial photographs and oblique photographs are already available or can be obtained at lower cost?
2. Is the level of detail available on satellite imagery really useful for archaeological interpretation?
3. What kinds of archaeological features can we perceive, and by what means?
4. What are the relationships and the possible benefits of integration between aerial photographs and high-resolution multispectral satellite imagery?
5. When is the use of multispectral satellite imagery helpful?
6. Finally, what is the particular contribution of multi-spectral data to the discovery of archaeological sites and the better understanding of the ancient landscape?

When setting up the research project we paid particularly close attention to the systematic collection of data. We acquired as many individual pieces of information as possible for comparison and for evaluation of the Ikonos-2 and Quickbird-2 imagery. At a second stage we will aim to integrate and reinterpret the whole body of information using GIS based technology. To manage all of the related documentation we have designed an archaeological GIS system using a data model which combines base maps, digital elevation models, remotely-sensed data, and alphanumeric and multimedia spatial databases.

3.1.1 Part I: Ikonos-2 imagery

The first sample area is situated in the south of Siena province. This geo-morphologically hilly countryside is representative of considerable stretches of Siena province (Fig.1). The second area, 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 total extent of these sample areas is around 470 km^2. 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

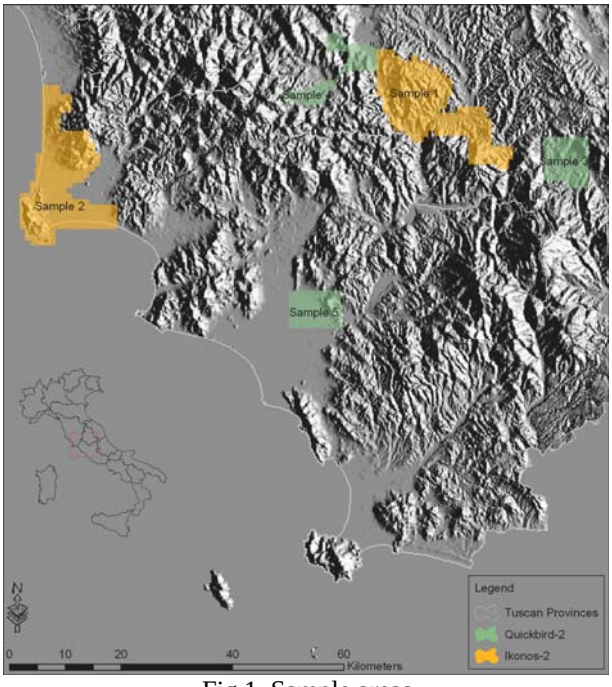

Fig.1. Sample areas

there are in our DBMS more than 1800 archaeological sites, from the Palaeolithic to the Middle Ages.

3.1.2 Image processing and visual interpretation of archaeological features

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

Our methodological approach to Ikonos-2 imagery has been focused on visual interpretation. The procedure followed in processing the Ikonos-2 imagery falls into two main phases, both taking into consideration existing remote sensing techniques.

The first phase 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 (especially Normalized Difference Vegetation Index). This phase plays a central role in the identification of archaeological features.

At the moment there is relatively little useful literature on the archaeological interpretation of Ikonos-2 imagery. It is widely recognized that the successful interpretation of aerial photographs is based on twin foundations, a good understanding of the mechanisms whereby archaeological sites are made visible and a detailed familiarity with the traces created by archaeological and other features [3]. Visual analysis of Ikonos-2 imagery has much in common with the analysis of aerial photographs. The ground resolution of the Ikonos-2 multispectral imagery is adequate to distinguish features, though sometimes small shapes can be misinterpreted. Bearing in mind these problems, the first phase of our approach has been to note any suspected feature. Between the first and second phase of processing and visual interpretation we use the GIS system to make comparisons with the various layers of archaeological information already existing within the GIS system. This step has been extremely useful in preventing other kinds of misidentification of non-archaeological features. In the second phase, the focus of view was narrowed in order to isolate homogeneous textures around individual features. 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. With TCT, on account of the very similar spectral ranges of bands 1-2-3-4 of Ikonos-2 with Landsat TM in the first approximation, we used the algorithm developed by Crist and Cicone [4]. 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, edge enhancement [5].

3.1.3 Ground-truth reconnaissance and results

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 2). We think that the reasons for this situation are to be found in the different qualities of imagery in the two sample areas, and above all in the differences of ground cover, geology and morphology. In the first stage of analysis we interpreted features as settlements, hill forts, mounds, roads, ancient riverbeds and some 'not-identified'. Aware of the need of ground truthing for validating remote observations, during the winter of 2001/2002 we checked in the field, 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.

The anomalies varied widely in size, from 200 m^2 to 100.000 m^2 (Fig.2). Clearly, Ikonos-2 imagery allows us to recognize quite small objects, beginning from 200 m^2. In figure 3 an example is shown from the Necropolis of San Cerbone (sample area 2), which has been well known since the end of the XIXth century.

Even without the aid of special processing, using only the true colour composite, we can easily make out on

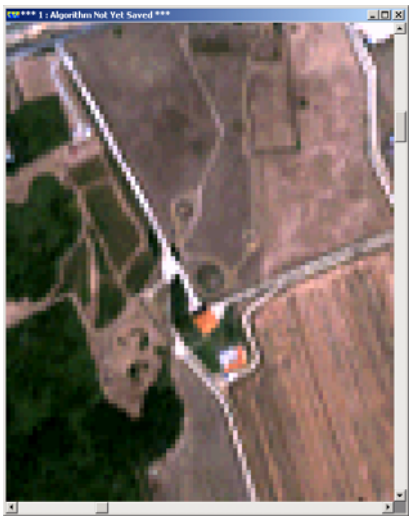

Fig.3. True colour composite of the Etruscan necropolis of San Cerbone (Baratti - sample area 2)

the satellite imagery the burial mounds of “Flabelli di Bronzo” and “Letti funebri”, circular features with a diameter of 30 and 20 m respectively. The principal component analysis, especially PC1-PC2-PC3, and the related colour composite also enable us to identify another funeral monument, the “tomba delle pissidi

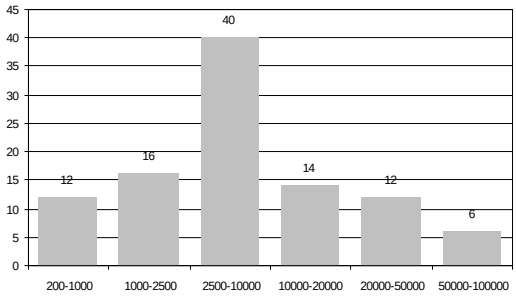

Fig.2. Trend of size range of archaeological features (x = m^2; y = %)

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From the point of view of geometric resolution, the Ikonos-2 imagery can therefore clearly show structures with surface areas about 20 to 30 m across. Of course we have to acknowledge that the identification is aided in this case by the presence around the mounds of stone pathways that emphasize the different spectral responses of the various surfaces. However, cases like this must be considered rare (only 12% in our sample), being related to particular situations on the ground. Most of the archaeological sites which we detected (70%) had a bigger surface area, between 1,000 and 20,000 m^2.

A typical anomaly is represented for instance by Montegemoli in sample area 2 (Fig.4). The Ikonos-2 satellite imagery enables us to recognise a circular anomaly on the western side of the area in question. This anomaly can be detected in a colour composite 4-3-2 and is very clear in the first principal component. This anomaly was not seen during vertical air photo

Fig.4. First principal component of the Montegemoli hill-country (Piombino - sample area 2)

interpretation, and the three photographs that we used for comparative purposes - an excellent frame from a flight of 1938, a low-class photograph from 1954 and a recent ortho-photo map of good quality with 1m resolution - in no case show this anomaly. The generation of a DTM enables us to relate the anomaly to the morphology, and to recognize the existence of a ditch surrounding the hilltop. This feature was not detected in any earlier researches but recent

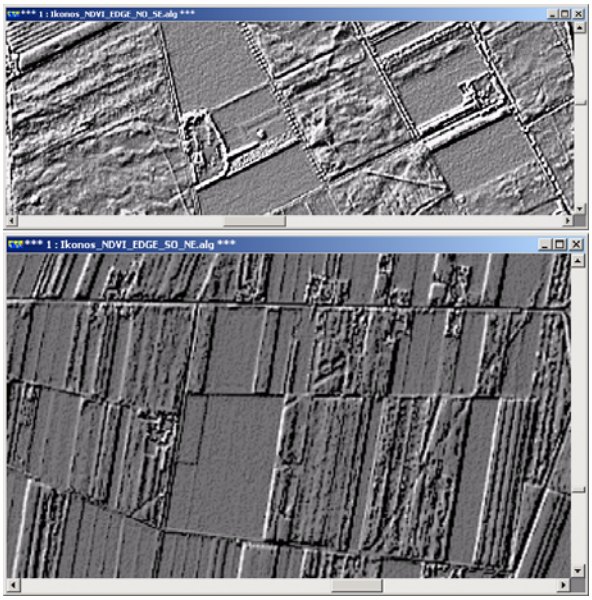

Fig.5. NDVI and Edge enhancement of zones showing linear features (sample area 1) interpreted in relationship to the Aurelia road system

examination on the ground attests to the occupation of the area from Late Antiquity to the late Middle Ages. For the detection of linear features Ikonos-2 imagery is very effective, with a minimum range between 2-4 m. The most distinguishing characteristic, however, is the straightness or linearity of these features and their orientation, parallel or perpendicular to one another. The topography of the landscape of sample area 2 also reveals linear geological faults and fractures that could perhaps be confused with the causeways of ancient roads. Despite this, a successful example is represented by the identification of a number of linear features which we have interpreted as parts of the road system of the ancient Via Consolare Aurelia. In the imagery it is possible to recognize several wide-spaced parallel segments that in one case lead from the main road to the swamp area and then on to Populonia. Other anomalies appear to be related to the Via Aurelia but have still to be checked on the ground (Fig.5).

Turning attention now to the near infrared wavelength and multispectral imagery, the next example highlights the possibility - not very common - of identifying features in conditions of broken morphology and heterogeneous ground cover (Fig.6). The site in this case is in the district of Montalcino (sample area 1), in a zone in which, according to documentary sources, there stood from the middle of VIIth century the medieval monastery of San Pietro ad Asso. Before our research the monastery was identified with the farm of San Pietro, which contains the still visible remains of a Romanesque building: a small church tower and several pieces of decorative stonework. All of the documentary

sources, from the second half of the XIIIth century onwards, refer of a village that must have been present in the same area. The identification of the monastery was determined through use of 3D landscape models generated from isolines drawn from differential GPS data collected during ground survey. This permitted the recognition of an abnormal hill form only 200 m from the abandoned farm of San Pietro. The ground survey produced clear evidence for shaping of the hill's profile, with terracing along the slopes as well as round the crest of the hill. In particular, on the topmost part on the northern side there is a considerable spread of walling, perhaps attributable to fortification works (Fig.6).
Analysis of the same area, carried out on panchromatic aerial photographs from 1954, 1976, 1994 and 1996, revealed numerous features while oblique photographs taken during the Research School in 2001 confirmed the presence of many anomalies. A magnetometer survey of the hilltop provided us with the possibility of mapping other archaeological features. The Ikonos-2 imagery uncovered further evidence of linear anomalies in farmland adjacent to the site, rectangular features and an anomaly on the top of a hill about a kilometer from the monastery. Some particular anomalies look very interesting (Fig.6).
These lie near the farm of San Pietro, in the area where the data from surface surveying inclines us to identify the documented late medieval village of San Pietro. In this area the air photographs show some confused trace we didn't considered before. Processing of the Ikonos-2 imagery permits the identification of two square features that ground survey allowed us to associate with buildings of the medieval village. With particular reference to the near infrared wavelength in multispectral imagery it is interesting to see how features in this case are visible only in the near infrared band (Fig.6).

Fig.6. Early medieval Monastery of San Pietro ad Asso (sample area 2). Draping of 3D model over an oblique aerial photograph, showing the morphology of site; some very clear features on the near-infrared band (invisible in all the other Ikonos bands and in the aerial photography); considerable spread of walls perhaps attributable to fortification works.

3.1.4 Discussion of Ikonos-2 results

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 recognize 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 (Tab.1).
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

Tab.1. 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

and needs to be further evaluated to test its responsiveness under a broad range of environmental conditions.

3.2.1 Part II: Quickbird-2 imagery

In the spring 2002 we bought three samples of Quickbird-2 imagery, two in the province of Siena and one near the coast in province of Grosseto for a total extent of about 200 km^2 (Fig.1). On the experience developed studying Ikonos-2 we focused our need on two main problems: the resolution and the best capture time.

Even though it has been possible to distinguish some small features through Ikonos-2 and to identify a first range of detectable site size (above) we have felt it necessary to stress that there is still some risk of misinterpretation. When we captured Quickbird-2 imagery we acquired both the multispectral and the panchromatic data. Pan-sharpening of the 4 multispectral bands using 0.70 m panchromatic image was then carried out to improve the spatial resolution. In this context it should be noted that a pixel of Ikonos-2 multispectral imagery correspond to 32.65 pixels of Quickbird-2 pan-sharpened data. Our first impression, looking at the Quickbird-2 imagery, is that most features of the landscape can be easily and unambiguously recognized. The detail allows us, for instance, to recognize the centre line of a small country road (Fig.7).

In relationship to the second problem, the Ikonos-2 imagery was captured in July, though we would have preferred the end of May. The order for Quickbird-2 data was submitted so as to coincide with a programme of aerial survey which we were carrying out with Otto Braasch and Chris Musson at the end of May 2002. The QuickBird-2 imagery was captured after a delay of "only" 15 days from our preferred time, though this was

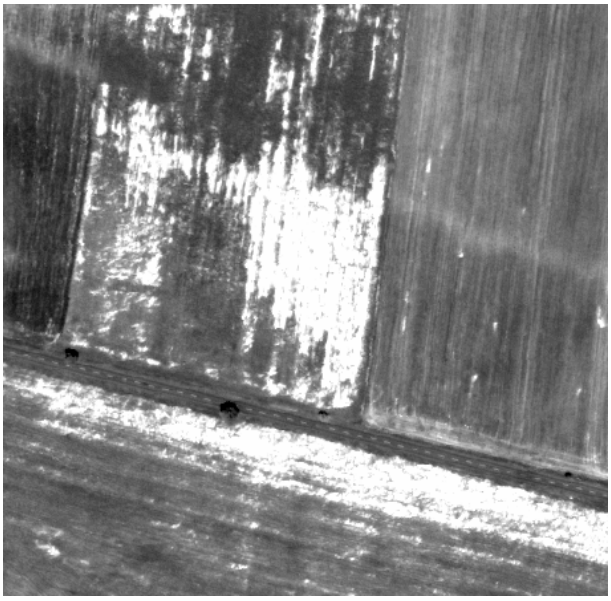

Fig.7. Detail of the centre road line. On top of the image the light trace is related to the ancient Via Cassia road.

probably enough to result in some loss of sites. There were two extenuating circumstances. Firstly, we did not consider the possibility of submitting a priority order (at a 50% increase in price) which would have given image capture within a maximum of five days from the specified date. The second was a typical problem of satellite imagery - though one not so significant in the Mediterranean region - that of poor weather conditions.

Our study of the Quickbird-2 imagery has only just begun and we do not yet feel able to present a considered report. However, our first impression is that many of the limitations that we found in using Ikonos-2 imagery will be overcome with Quickbird-2 and that we are not so far away from being able to achieve the right capture time for archaeological needs.

4. Conclusions

Although work on this project is still in progress, with 60% of the features detected by Ikonos-2 still to be confirmed in the field and with the study of Quickbird-2 data only just begun, we consider that our experience of working with HSRI has on the whole been positive. In relation to the questions that we posed at the beginning of our research we think that in general multispectral imagery has characteristics which are entirely compatible with the needs of archaeological landscape investigation. Using Ikonos-2 imagery the resolving power 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 40 to 50 m across. Moreover, the much improved resolution of the Quickbrid-2 imagery will surely result in a substantial improvement in these figures, and hence in the archaeological value of this new generation of satellite

imagery.
In saying this, however, we should point out that some unfavorable aspects of the most recent satellite imagery remain substantially the same as for the preceding generation of satellites, in particular the impact of critical morphology, the need for excellent atmospheric conditions, and the relatively high cost.
The particular contribution of HSRI to archaeology in Tuscany - should be recognized as lying in its multispectral properties, in the near infrared band, in the possibility of choosing the exact area of interest and in the opportunity of recording the whole of a chosen landscape at the time when crop marks or soil marks are at their best.

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6. REFERENCES

1. Alessandro V. and Pranzini E., Il telerilevamento nella gestione dell'ambiente tropicale, *Studi Geologici Camerati*, Special Issue, pp.9-27, 1992.
1. Baggio P., Birocco C.A., Colosi F., Piro S., Versino, L. E. and Zamboni C., Telerilevamento, ricognizioni archeologiche e prospezioni geofisiche sulla Collina Orientale di Selinunte, *Science and technology for the safeguard of cultural heritage in the Mediterranean basin*, 1st International Conference, 1998.
1. Barisano E., Bartholomes E. and Marcolongo B., Interprétation integrée de données télédetectées. HCMM, Landsat, photos aériennes, corrélée avec des aspect physiographiques et archéologiques dans la pleine vénitienne occidentale, CNRS, Paris, 1984.
1. Colosi F., Pompeo L., Sangiorgio D. and Zamboni C., Elaborazione ed interpretazione di immagini telerilevate per lo studio sistematico delle testimonianze antropiche nel territorio. I casi di Palmyra e di Selinunte, *Archeologia e Calcolatori*, 7, 1996.
1. Costi A., Lazzaro L., Marcolongo B. and Visentin J.,. *La centuriazione romana fra Sile E Piave nel suo contenuto fisiografico. Nuovi elementi di lettura*, CNR, Padova, 1992.
1. Cremaschi M. and Forte M., Reconstructing a fossil landscape by Remote Sensing and GIS applications: sites, virtual models and territory during the Middle Bronze Age in the Po Plain (Northern Italy), *Archeologia e Calcolatori*, 9, pp. 207-227, 1999.
1. Diceglie S., I "cerchi di pietra" di Lampedusa (Telerilevamento archeologico dell'Isola), *Osservazione dello spazio dell'Italia e delle sue regioni: metodo, risultati e prospettive*, proceedings of 3th AIT National Conference, Pisa, pp. 421-439, 1992.
1. Forte M., Montebelli M. and Tusa S., Il progetto valle del Belice: applicazioni GIS e di Remote Sensing su dati archeologici, *Archeologia e Calcolatori*, 9, pp. 291-304, 1998.
1. Marchisio E., Pascquinucci M., Pranzini E. and Vigna Guidi G., The Pisa territory Project, *Non-destructing techniques applied to landscape*, edited by Pasquinucci, F. Trément M., Oxford, 2000.
1. Marcolongo B. and Mascellari M., Immagini da satellite e loro elaborazioni applicate alla individuazione del reticolato romano nella pianura veneta, *Archeologia Veneta*, I, pp.131-154, 1978.
1. Pieri M. and Pranzini E., Geomorphological evolution of the Pisa plain in historic time deduced from Landsat TM data, *Global Natural Resource Monitoring and Assessment: Preparing for the 21st Century*, pp. 1385-1388, 1989.
1. Pranzini E. and Santini C., Remote Sensing for Earth Science, Ocean, and Sea Ice Applications, *EUROPTO Conference on Remote Sensing for Earth Science Application*, Florence, pp.283-29, 1999.
2. Cosci M., Il contributo della fotografia aerea allo studio e alla valorizzazione del territorio: metodi adottati e risultati conseguiti, *La gestione del territorio. Memoria, partecipazione, sviluppo della ricerca*, edited by Di Gangi, G., Lebole, C. M., Proceedings of Saluzzo National Meeting, Cuneo, pp.55-64, 2001.
3. Wilson D.R., *Air Photo Interpretation for Archaeologists*, Tempus, 2000
4. Crist E.P. and Cicone R.C., Application of the Tasseled Cup Concept to Simulated Thematic Mapper Data, *Photgrammetric Engieneering and Remote Sensing*, vol.52, no.3, pp.343-352, 1984.
5. Campana S. and Pranzini E., Telerilevamento in Archeologia, *Remote Sensing in Archaeology*, edited by Campana S. and Forte M., pp.17-62, 2001.