"Personal" Multistage Remote Sensing and Traditional Field Work to the Archaeological Analysis of Complex Landscapes: Relationships, Benefits and Actual Limitations

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Abstract. The Department of Archaeology at Siena has been engaged for several decades in the testing of new methodologies, new approaches and new instruments for construction of the archaeological record. The South Tuscan landscapes is characterized by a low level of visibility and heavy clay soils that have directed us towards those techniques of remote sensing managed directly by archaeologist and that we like to define as "personal". We are referring particularly to those techniques that leave a wide choice to the archaeologist in the periods for carrying out data capture. We have begun to work on a systematic program of aerial survey, on Ikonos-2 and QuickBird-2 satellite imagery and on micro-digital terrain modelling using digital photogrammetry. On the ground our infra-site analysis has been improved by applying extensive magnetic survey, recently integrated with GPR survey; important gains have come from the systematic use of differential GPS and PDA devices.

1. Introduction

Prior to 1999 the Department of Medieval Archaeology at the University of Siena based its work in archaeological cartography on three methods of investigation: systematic fieldwalking in sample areas aimed at representing 20–30% of the whole landscape; the analysis of historical vertical air photographs through stereo viewing and ground-truthing in the field; and detailed surveying aimed at providing high-quality understanding of particular monuments or archaeological areas (Francovich and Valenti 2001).

In this paper we will discuss in particular our experience with the progressive introduction of new methodologies and the problems of integrating different survey techniques in the archaeological mapping of South Tuscan landscapes, specifically in the administrative areas of Grosseto and Siena.

The need to test new instruments and new approaches to surveying derives from a certain dissatisfaction with the results obtained through previous methods. Our past work has allowed us to identify a large number of new sites and to collect new data about known sites. Notwithstanding this we still feel that we have not answered our questions about understanding the complexity that characterizes ancient landscapes, ancient settlement patterns and their reciprocal relationships. In particular some specific chronological periods, such as the Early Middle Ages, or some specific historical questions, such as the change in the location of settlement from Roman villa to hillfort, remain particularly hard to confront (Francovich and Hodges 2003). We focus in this paper on two main problems, the first largely qualitative, the second quantitative:

- In our previous strategy there was too large a difference between the nature of the information obtained from surface collection compared with that derived from stratigraphical excavation (which is by its nature too slow and too expensive). We clearly needed to develop our capacity to recover more detailed information without recourse to large excavation.
- The requirement to work on the basis of limited sample areas, combined with the opportunity to study our landscapes from the air only through vertical air photographs, represented a strategic shortcoming that resulted in a considerable loss of otherwise detectable sites.

It was clear to us that there was a need to improve our study of ancient landscapes in both of these respects. We therefore turned our interest firstly to remote sensing techniques, while remaining aware of the limitations that this methodology will encounter in a countryside like that of Tuscany and in particular of the Province of Siena and the northeast of Grosseto territory.

2. Tuscan Landscapes

Fifty percent of Tuscany is covered in forests and other areas characterized by a low level of visibility, whether from the ground or from the air.

The remaining landscapes consists in great part of agricultural cultivation on heavy clay soils that are known to constitute a particularly unfavourable surface for most remote sensing techniques. A second limitation introduced by heavy clay soils is that the number of years when the meteorological conditions are likely to produce good archaeological traces is even smaller than on soils above substrata such as gravel or sand (Jones, Evans 1975).

Areas with a higher level of visibility consist mainly of the alluvial plains of substantial rivers, in particular the Arno, Cecina, Ombrone, Serchio, Chiana and Orcia. In some of these areas, however, other problems arise from the great thickness of the alluvium and from the impact of modern industrial and residential development (Agnoletti 2002).

All these circumstances, as is already well known, have a direct influence on the results of research based on the use of the methods and instruments of remote and proximal sensing (Wilson 2000; Clark 1997).

This situation has directed us towards an integrated and interrelated use of those research techniques – we defined as "personal" – that leave a wide choice to the archaeologist in the periods for carrying out data capture, and in particular towards the study of parts of the electromagnetic spectrum not visible to the human eye (Donoghue 2001):

- Exploratory aerial survey and oblique air photography
- Multispectral high-resolution satellite imagery (HSRI)
- Digital photogrammetry
- dGPS survey
- Geophysical prospecting (gradiometer and GPR)

Along with the integrated development of these new approaches to the study of past landscapes we have of course continued our study of historical aerial photographs and the use of field-walking survey, both of which remain undeniably valuable sources for the archaeological study of settlement patterns (Guaitoli 2003).

3. Remote Sensing Techniques: Peculiarity and Limitation

Our Department manages regional and sub-regional landscape projects. Whatever the scale, the study area is always based on the local administrative units, which in Tuscany range in size between 40 and 450 sqkm with an average of 150 sqkm. In order to obtain a total coverage of areas of these dimensions at relatively low cost we began a project using multispectral imagery captured with the Ikonos satellite.

The results have been encouraging, within the limits of the geometric and spectral resolution of the data. We should perhaps note two peculiarities of Ikonos-2 imagery (Campana 2002a). Firstly, through Ikonos-2 we can recognise many features that were visible in early vertical air photographs but which are no longer identifiable in those taken in recent years. This situation perhaps derives from the inappropriate time of year 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 exploring the archaeological heritage (Fig.1). Secondly, we believe that most of the results obtained from analysis of the Ikonos-2 imagery depend heavily on the multispectral properties of the sensor. 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 (Donoghue 2001). 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 effectiveness under a broad range of environmental conditions.

A real limitation of the Ikonos products turned out to be the great difficulty of achieving with precision the desired capture time. The commercial strategy of the Space Imaging Corporation is to make priority ordering of images at the particular time required by the consumer extremely expensive. Since we did not have sufficient money to pay for the priority option the images ordered for the last week of May or the first week of June were not actually captured until the middle of July, a month which in our latitude corresponds to a very poor period of the year for the recording of archaeological traces.

In spring 2002 we started testing three samples of Quickbird-2 imagery, two for the province of Siena and one near the coast in the province of Grosseto, to a total extent of about 200 km^2. On the basis of our experience with Ikonos-2 we focused our attention on two main problems: geometric resolution and best capture time.

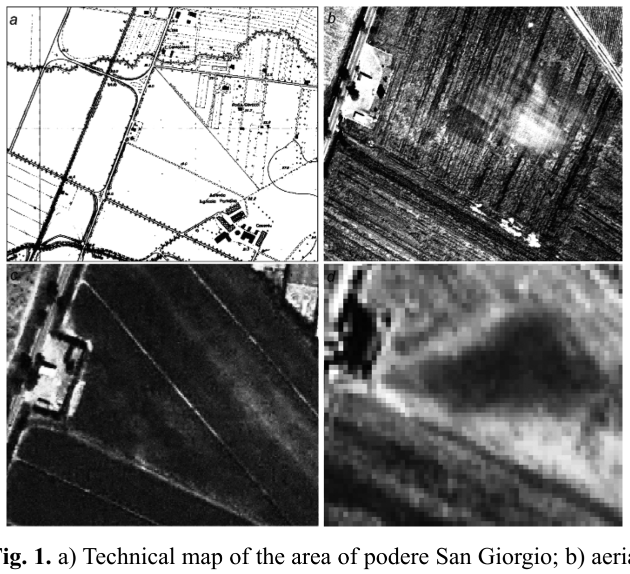

Fig. 1. a) Technical map of the area of podere San Giorgio; b) aerial photograph of the year 1954; c) aerial photograph of the year 1996; d) Ikonos satellite imagery band 4 (near infrared).

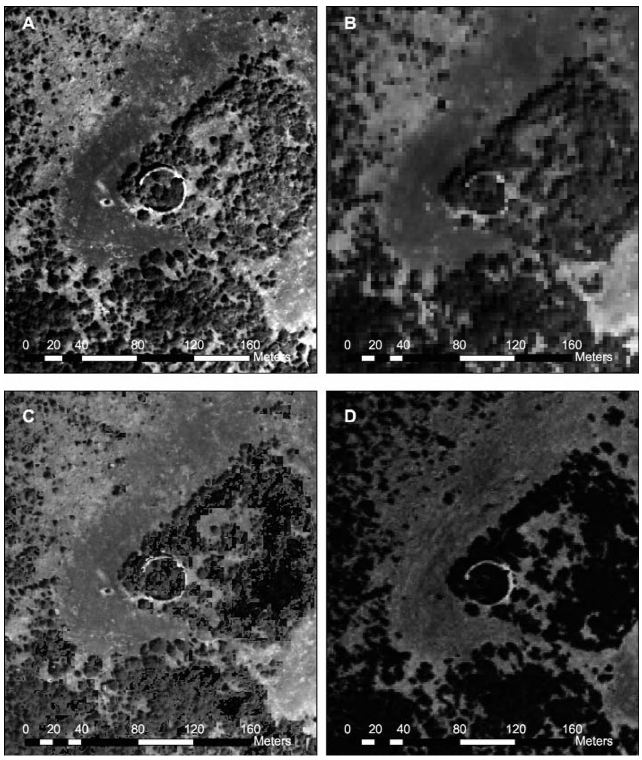

Fig. 2. Comparison of resolution capabilities of the QuickBird sensor in relationship with the castles of Moscona: a) panchromatic satellite imagery with a resolution of 0,70 m; b) color composite 4-3-2 of multispectral satellite imagery with a resolution of 2,80 m; c) pansharpened satellite imagery with a resolution of 0,70 m; d) Aerial photograph with a resolution of 1 m.

Even though it has been possible to distinguish some small features through Ikonos-2 and to identify a first range of detectable site size we feel it necessary to stress that there is still a risk of misinterpretation (Campana 2002a). When we captured Quickbird-2 imagery we acquired both the multi-spectral and the panchromatic data. Pan-sharpening of the four multispectral bands using the 0.7 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 multi-spectral imagery corresponds to 32.65 pixels of Quickbird-2 pan-sharpened data (Fig. 2).

Our first impression, looking at the Quickbird-2 imagery, is that most features of the landscape can be easily and unambiguously recognized in this more recent source of data.

In relationship to the second problem, the Ikonos-2 imagery was captured in July, though we would have preferred the end of May. The QuickBird-2 imagery was captured after a delay of "only" 15 days from our preferred time, though this was probably enough to result in some significant 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 is still in progress and we do not yet feel able to present a fully considered report. However, our impression at this stage is that many of the limitations that we found in using Ikonos-2 imagery will be overcome with Quickbird-2 and that with the priority option of QuickBird it will at last be possible to achieve the right capture time for archaeological needs (Campana 2002b).

The analysis of satellite imagery does not entirely remove uncertainty from the study of ancient landscapes and in particular of complex territories like Tuscany. For instance many of the archaeological discoveries that we made during field survey or in examining vertical air photographs are not visible on the satellite imagery.

For these reasons we started a programme of aerial survey averaging 35–45 hours of flight per year, focused on the end of May and the beginning of June (Musson et al. 2004). The use of exploratory aerial survey in Italy has only become possible in recent years following legislative changes, but in many other countries of northern Europe it is a method with a long tradition of application. In ideal conditions this technique offers, also in South Tuscany, an extraordinary contribution to the search for new sites and for the continuous monitoring of the cultural heritage (Fig.3).

From our short experience of the technique we can point to the flexibility of the method in allowing us to respond to the development of archaeological traces with extreme rapidity and therefore to be in a position to observe the landscape and document the archaeological information at the most appropriate time for each individual year and each geographical area. In the air the archaeologist is free to choose conditions of lighting that range from soon after dawn to almost sunset (Musson et al. 2004).

Fig. 3. a) settlement (roman villa); b) road system; c) square and round enclosure; d) field systems.

The detail of the acquired information is remarkable and, despite the strong distortion of oblique images, it is well known that the spatial information can be corrected using algorithms developed by Professor Irwin Scollar and can thus be mapped and integrated without difficulty into our archaeological GIS (Scollar 1998; Doneus 2001). Currently at the University of Siena we have collected an archive of about 11.000 oblique air photographs, recording just under 1000 archaeological sites of widely varying types.

We wish to emphasize here our view that oblique air photographs and satellite imagery are not in conflict with one another. Apart from the obviously varying degree of detail, the satellite images provide a total, continuous and objective view of the whole of the land surface within the chosen survey area. By contrast, every oblique aerial survey is dependent on the environmental conditions of the moment and is influenced by the experience of the individual archaeologist in choosing which parts of the landscape to document.

Along with the development of new methodologies we are continuing our study of historical aerial photographs, which have an importance which we think it unnecessary to emphasize here (Picarreta and Ceraudo 2000; Guaitoli 2003). We are thinking particularly in this regard of the photographs of the Institute of Military Survey from the 1930s to the 1950s, along with the regional coverage of the 1970s. The mapping of all the information recovered from satellite imagery and from

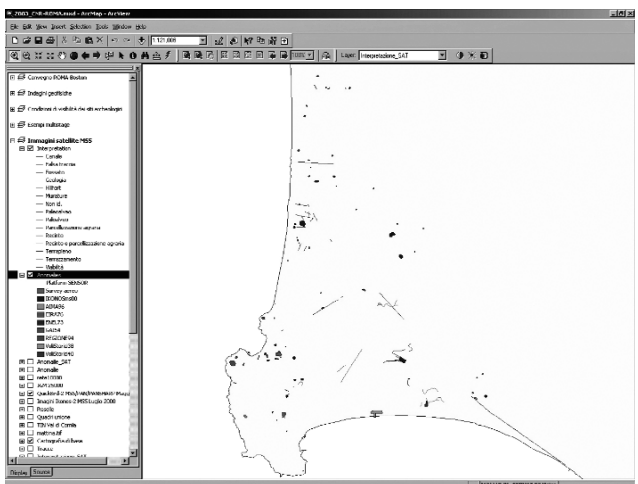

Fig. 4. Synoptic map of the whole evidences.

vertical and oblique air photographs represents the main result of this strategy (Doneus et al. 2001). This operation allows us to create detailed georeferenced layers of sub-soil features that, as we will see in the following section, greatly enrich the data at our disposal and consequently our reconstruction of the archaeological record (Fig.4).

4. Fieldwork Research Methods and Related Problems

The activities on the field are aimed at the systematic investigation of sample areas and at the verification of the remotely sensed evidence. The main methodologies involved in the process are field walking and geophysical survey.
Through field-walking survey there have so far been detected in the provinces of Siena and Grosseto about 9000 sites (Francovich and Valenti 2001; Carandini et al. 2002). This research method constitutes therefore an extremely important source for the archaeological study of settlement patterns but the collected information often turns out to be incomplete, confused and difficult to interpret because of post-depositional processes in the field (Boismier 1997).
We should take account, for instance, of the progressive degeneration of many of the surface finds due to more than half a century of intensive ploughing, vineyard and olive cultivation. Many years ago Tim Potter wrote about this subject in his The Changing Landscape of South Etruria underlining how by from the beginning of the 1970s the ideal moment for this kind of study had already passed (Potter 1979).
Our experience in South Tuscan landscapes shows that progress in the development of interpretation methods for surface evidence has given us the possibility in the last 25 years to carry out successful programmes of field-walking with an acceptable degree of uncertainly (FENTRESS 2002). In recent surveys, however, there seems to have been a progressive change in the relationship between surface and sub-surface archaeology. We have realized that it is more and more rare to achieve to satisfactory interpretation of surface remains and in some cases the process of collection within carefully predefined grids is no longer sufficient.

5. Proximal Sensing Techniques

After describing these phenomenon it will be more clear a recurrent problem we encounter in the field. Visible traces detected through the analysis of remote sensed data do not always correspond with the presence of dense or well-defined scatters of archaeological material in the field.
Considering the scale of our landscape research project we cannot hope to address the situation through systematic test excavation. Moreover we have to consider the bureaucratic difficulty of asking for permission for each excavation from the Italian Office of Heritage Conservation. In the last two years we have focused our attention on this topic in order to overcome or at least to reduce the consequences of this problem. The first attempt took the form of experiments with magnetic survey of a kind suited to our particular requirements.
In addition to the well known diagnostic characteristics of magnetic survey methods (Piro 2001) this technique satisfies one of our fundamental needs: the capacity to cover large areas in a limited time (Powlesland 2001). In a field survey carried out in Val d'Orcia we progressively tested a system of acquisition that allowed us to cover one hectare per day at a resolution 60 cm along traverses each set 1 metre apart.
So far we have acquired only 12 hectares of data but the general trend of the results seems to confirm that the degree of detail, although not very high, is sufficient to show with a good approximation the position of the main features, depending on the characteristics of the material to which the magnetometer is reacting. This pattern of acquisition will allows us to contemplate the future acquisition of approximately 20–40 hectares per year, an area perfectly compatible with our research requirements.
In several cases we were able to improve the resolution by means of a sampling interval of 25 cm along traverses set only 50 cm apart. We can take as an example the case of Pieve di Pava in the community of San Giovanni d'Asso (Province of Siena) where we acquired 2 hectares of data at a resolution of 1 metre between traverses and then reduced the resolution to 50 cm in order to make a comparison.
The results from the closer sampling interval undoubtedly show an enrichment of the data and an improvement in definition of the shapes of features. At this stage this closer resolution looks to be the best choice for medieval sites generally characterized in our region by the absence of building materials with high a magnetic susceptibility.
The site of Pieve di Pava represents for us an important case study, in particular because in July and August 2004 we will be undertaking an archaeological excavation at this site. The excavation represents for us the first chance to verify and compare the gradiometric data with the observed stratigraphy. It was for this reason that we intensified our geophysical work on the site by testing a wide range of different parameters of the gradiometer and by trying other instruments such as GPR.
In conclusion, in the immediate future our challenge will be on the one hand to enlarge the range of geophysical instruments systematically available and on the other side to make use more and more often of the practice of small test excavations on different sites so as to improve our experience.

6. Bridging Remote Sensing, Infra-Site Analysis and Artefact Scatters through Mobile Information Technology

After discussing our work in the field we should emphasise that from the second half of the 1990s, when in Siena as in the rest Italy we began to use Geographical Information Systems for the management of archaeological data, we have felt a progressive disjunction between work in the laboratory and work in the field. While the availability of advanced technologies has been rapidly growing, activities in the field have continued to make use of instruments and methodologies developed in the 1970s. The risks arising from this situation are many. Firstly, there are problems inherent in the collection of data that lack the accuracy required by GIS systems, or which rely work to a different kind of rational logic. Secondly, there is the problem that the large amount of data produced or available through GIS systems in the laboratory is available in the field only as hard copy, without the possibility of direct interaction or real-time data integration and interrogation.

To overcome this situation we systematically map the field information thought GPS device and recently, from 2002, we tested PDA computer with mobile GIS system (Fig.5).

The technological merging between PDA and GPS devices goes far beyond the level of increased fieldwork efficiency, in at last making possible the systematic application of strategies and methodologies developed in the past but applied only rarely up till now because of the excessive amount of time involved in their use (Ryan, Van Leusen, 2002; Orton 2000; Campana, Francovich in print). In general we believe that giving more attention to the process of data collection, and in particular to the contribution that technology can make in the process of fieldwork, is one of the best ways to achieve a real improvement in the acquisition of new data for our GIS systems and consequently in the type and quality of the integrated analyses which we can then carry out.

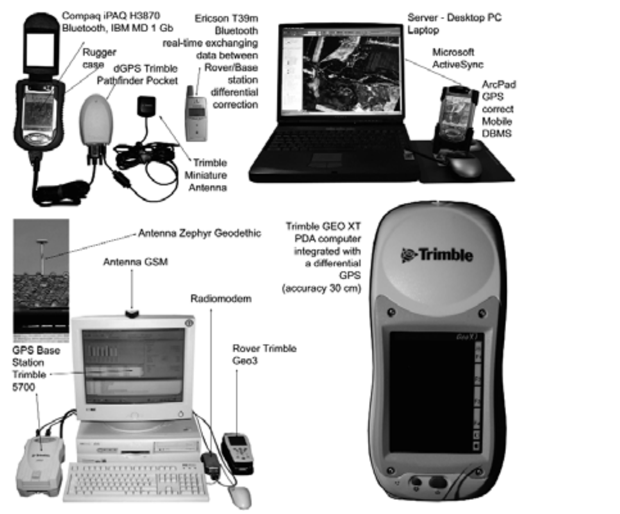

Fig. 5. PDA, mobile GIS/GPS, DBMS solution and the GPS base station tested during our landscape projects.

7. Conclusions

A common risk in archaeological research on the use of technology in the study of the cultural heritage is the obsessive pursuit of the latest technological device or software. In this short review of our work and our experience we have tried to show that the progressive integration of survey techniques directly responds to the need to answer specific historical and archaeological questions or to face specific methodological problems. In technical and methodological terms we have not yet encountered the "ideal" situation in which the increase of information recovered is directly related to the increase in the geometrical resolution of the data-capture system. The trend that has emerged from our own short experience of this area of research is that generally only one or two of the many different sensors used allows us

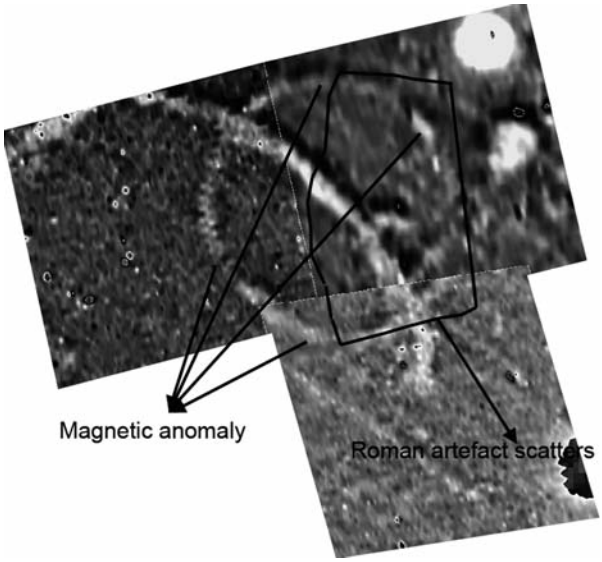

Fig. 6. Relationship between surface collection and magnetic data (the black lines delimited surface findings mapped with sub-meter GPS device).

to improve the information collected in the field, sometimes with unexpected results that introduce new problems and questions, as for instance in the case showed in the figure 5 (Romitorio – SI) where to a circular enclosure, a typical prehistoric feature, correspond on the surface only late roman pottery but not prehistoric features.

Generally we can affirm that even the success of only one or two of the remote sensing techniques employed in our project represents for us a very positive result, because in most cases we can combine the remotely-sensed data with the field-walking evidence and so substantially improve the archaeological record. We affirm, on the evidence collected so far, that geophysical survey and the use in the field of the PDA play an extremely important role in this strategy, representing for us at this moment the best way to connect remotely-sensed evidence with the results of field survey. On the basis of our present experience we are firmly convinced of the advantages of using integrated sources and technologies. Even in favourable areas such the Tavoliere in southern Italy, or in lowland Britain or parts of central and eastern Europe such as Hungary and Poland, it has been demonstrated that there are significant advantages in the use of integrated techniques (Powlesland 2001; Grosman 2000; Doneus et al. 2002). This strategy becomes even more obvious in less favourable contexts such as Tuscany, and particularly in the Province of Siena and the hill-country of Grosseto.

Without the integrated use of multi-sensor approaches and the critical application of both traditional and new methods we can rarely hope to achieve results which will have a real impact on the search for a better understanding of the development through time of regional settlement patterns.

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