REMOTE SENSING IN ARCHAEOLOGY: AN OVERVIEW

Rosa LASAPONARA[1], *Nicola MASINI*[2]

[1]IMAA-CNR, EARSeL Genel Sekreteri, , C/da S. Loya Tito Scalo 85050 (PZ) İtalya rosa.lasaponara@imaa.cnr.it
[2]CNR-IBAM C/da S. Loya Tito Scalo 85050 (PZ), n.masini@ibam.cnr.it

ABSTRACT

Recently, the importance of applying satellite remote sensing technology to archaeological research has been paid great attention worldwide, due to the following aspects:

(i) the improvement in spectral and spatial resolution reveals increasing detailed information for archaeological purposes;
(ii) the synoptic view offered by satellite data helps us to understand the complexity of archaeological investigations at a variety of different scales;
(iii) satellite-based digital elevation models (DEMs) are widely used in archaeology for several purposes to considerably improve data analysis and interpretation;
(iv) the availability of long satellite time series allows the monitoring of hazard and risk in archaeological sites;
(v) remotely sensed data enable us to carry out both inter and intra site prospection and data analysis.
(vi) satellite radar systems offer very high resolution data
(vii) the quite recent (mid-1990s availability of Airborne Light Detection and Ranging (LiDAR)) remote sensing technique with the unique capability to penetrate vegetation canopies and identify earthwork features even under dense vegetation cover.
Potential and limitation of active and passive satellite and aerial sensors will be presented along with significant test studies selected from South America (Peru, Bolivia, Europe and Turkey)
Nowadays the tremendous amount of data available from diverse remote sensing data sources can efficently support archaeological surveys providing a scalable and modular approach that can significantly improve our current knowledge on past human activities, enabling us to better understand the past and forecast the future

1. INTRODUCTION: REMOTE SENSİNG İN ARCHAEOLOGY AN OVERWİEV

Historically, since the thirties of the last century (Lasaponara and Masini, 2011), aerial photography has been the first remote sensing technique employed in detecting surface and underground archaeological information. The first applications of geophysics (in particular d.c. resistivity and magnetometry) in archaeology date back to the fifties of the 20th Century, whereas, in the following decades, there were the early applications of georadar. Beginning from the eighties, satellite data acquired from both active and passive sensors (see example of these sensors in figure 1) started to be used in palaeo-environment studies and archaeological landscapes. In the last decade, the availability of very high resolution (VHR) satellite images (Ikonos in 1999, QuickBird in 2001, WordlView1 in 2007 and GeoEye in 2008) opened new perspectives in archaeology. Finally, LiDAR (Light Detection And Ranging) has been the last important technological tool fruitfully applied in a number of applications based on the use of digital terrain models, from geomorphology to archaeology (see, for example, Lasaponara and Masini, 2009).
All these passive optical remote sensing technologies are effective tools to detect the presence of buried archaeological remains. Figure 2 shows the spectral behaviour of crop and soil marks as described in Lasaponara and Masini (2006, 2012) and Masini and Lasaponara (2007).
Optical remote sensing (traditional aerial photography, multispectral and hyperspectral airborne and satellite imagery) is particularly effective in recording damp, soil and crop marks (Lasaponara and Masini, 2006, Masini and Lasaponara 2006, 2007) due to the differences in moisture content, porosity, vegetation cover and/or status caused by the presence of buried archaeological remains. Results from remote sensing tools provide maps of archaeological features, which can enable us to identify and classify the type of the detected cultural remains (domus, urban fabric, ditch, walls) according to their spatial patterns can also to date (roman domus, medieval settlement, neolithic ditches etc..) them on the basis of field working.
The limitations of optical remote sensing are: i) the impossibility of surveying archaeological features of areas covered by dense vegetation; ii) the difficulty in detecting archaeological features related to micro-relief also in the case of bare ground surface; iii) the impossibility to characterize the anomalies in three dimensions.
The limitations listed at point i) and ii) could be overcome by using airborne laser scanning, also known as LiDAR which is an active remote sensing technique based on laser pulses. LiDAR provides direct range measurements between laser scanner and earth's topography, mapped into 3D point clouds. The range to an object is determined by measuring the time delay between the transmission of a pulse and the detection of the reflected signal, thus allowing

the production of high resolution digital terrain models (DTMs). Moreover, the penetration capabilities of the laser beam through gaps in vegetation allow us to filter it and to obtain DTMs in areas covered by dense vegetation as woods and forests (Lasaponara and Masini, 2009)

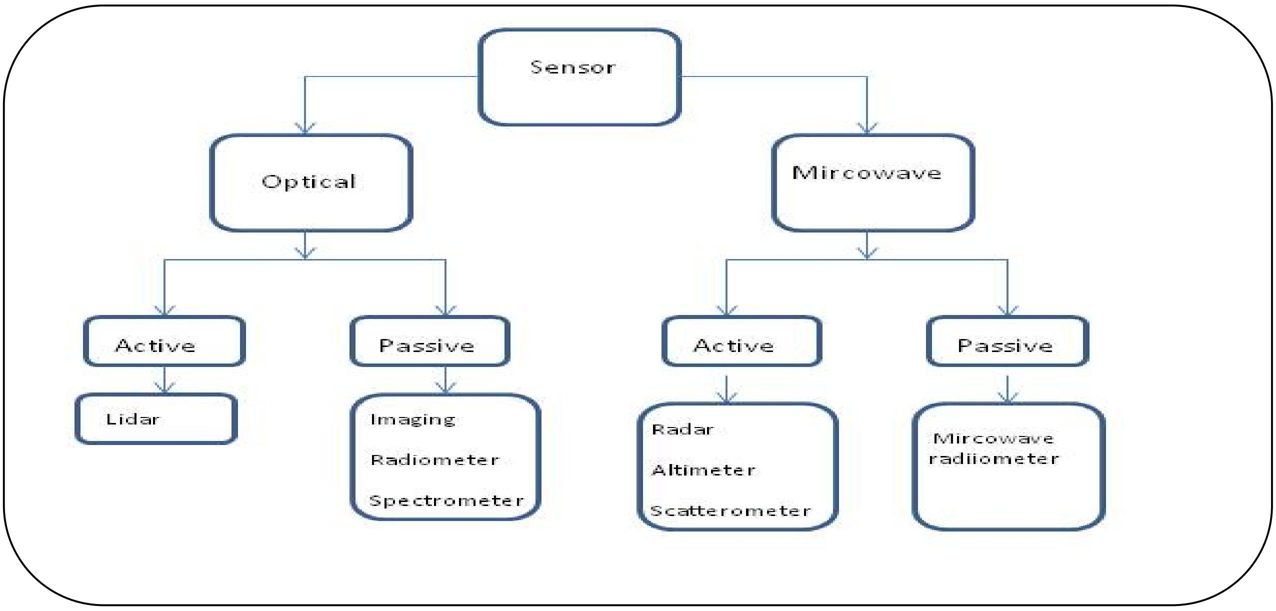

Figure 1. Passive and Active sensors.

.

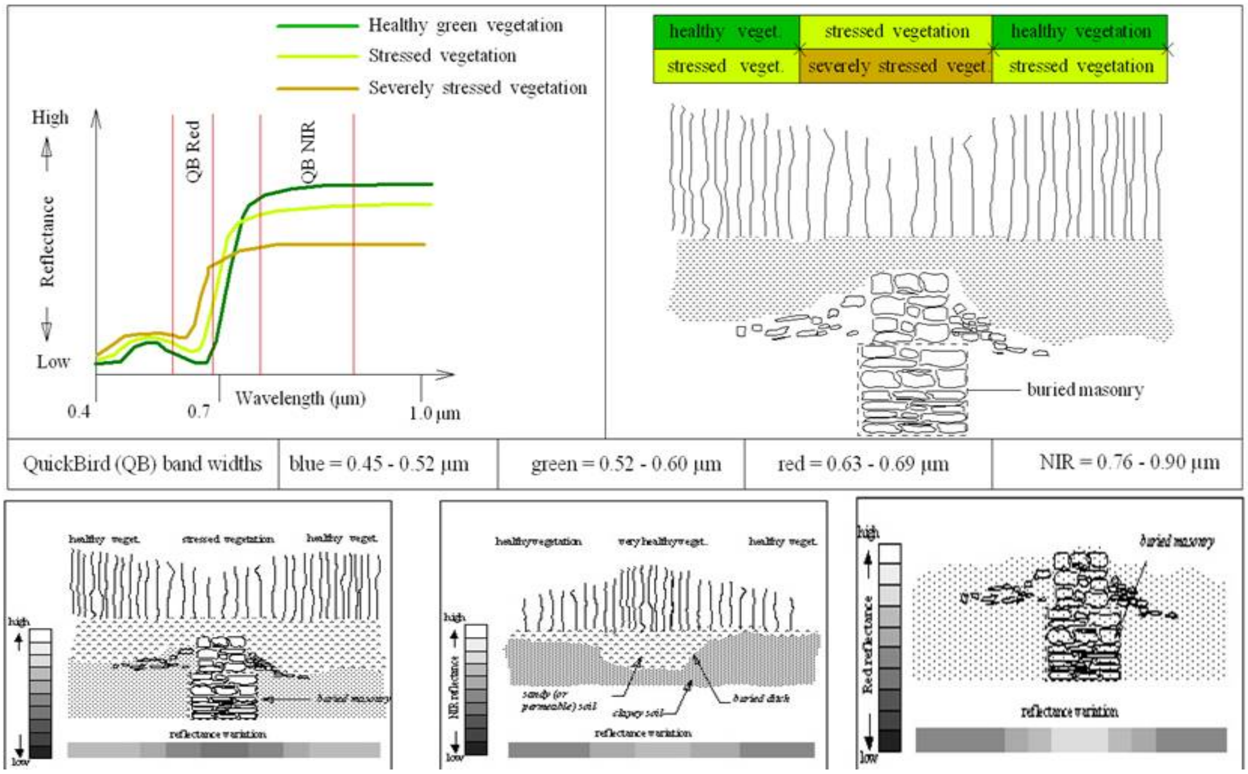

Figure 2. Spectral behaviour of crop and soil marks.

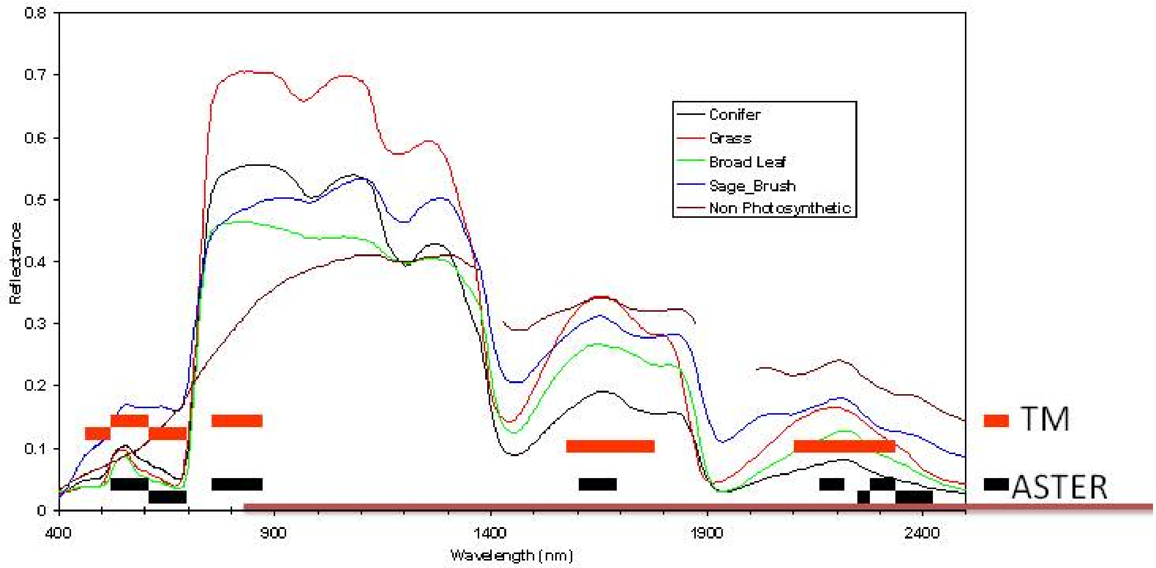

Figure 3. Spectral signatures of conifer, grass,broad leaf, sage brushand non photosintetic as obtained from hyperspectral sensor, with the indication of spectral channeles of ASTER and Landsat Temathic Mapper (TM), shown botton and up, respectively.

The limitation, listed at point (iii), in detecting archaeological buried remains in three dimensions could be overcome by geophysical methods, such as GPR (see for example Lasaponara et al. 2011) which uses microwave electromagnetic radiation to measure the reflected signals and detects potential subsurface objects (walls) or boundary (filled ditch) with different dielectric constants respect its surrounding. The currently available GPR systems presents some drawbacks, in particular: a) considerable expertise is necessary to plan, conduct, and interpret GPR surveys; b) a significant performance limitation has been observed in GPR survey conducted in high-conductivity materials such as clay soils, which usually could be found in several archaeological features (profile of a ditch) and sites. In the latter case it is preferable to use a geophysical technique for imaging sub-surface structures from electrical measurements made at the surface, such as Electrical resistivity tomography (ERT). Compared to GPR, ERT is time consuming, but it allows us to overcome the above-said limitations of GPR. Moreover, ERT provide useful correlation with the lithological characteristics and, therefore, it is particularly useful in the identification of buried archaeological remains, especially if integrated with other geophysical methods such as seismic refraction tomography. In presence of sources of magnetic anomalies, magnetometry is customarily the most effective method to be used. This method is based on the study of the anomalous contribution to the natural configuration of the Earth's magnetic field. This contribution is caused by the presence of buried structures having magnetic properties (susceptibility and/or remanent magnetization for instance) unlike respect to their surroundings. Several anthropogenic features of archaeological interest are sources of magnetic anomalies . The related values can range from hundreds of nanotesla (e.g. furnaces, kilns, ovens, etc.) to tens of nanotesla (e.g. walls, roads, ditches, pits, etc.), till thousandths of nanotesla (e.g. post-holes). The choice of the most appropriate remote sensing method depends on detail and morphology of archaeological features to be detected (site, walls, toms), characteristics of ground surface (vegetated or not vegetated), geochemical properties of soils and archaeological deposits.

2. SPACE ARCHAEOLOGY: AN OVERVIEW OF EARLY APPLİCATİONS

In 1972 the launch of the first LandSat satellite made available the 80 m resolution of the Earth Resources Technology Satellite, the multispectral scanner which started a new era for remote sensing applications, but it was not suitable for archaeological purposes. Early applications of satellite for studies on past human activities were attempted starting from the 1980s using the Thematic Mapper (TM), which was the highest (30 m) spatial resolution sensor available at that time for civilian applications.

Using TM data, some success was achieved in landscape archaeological investigations, for example, the finding of old roads, ancient land divisions, Roman centuriation, relict agricultural systems (see Lasaponara and Masini 2011,

2012 and references therein quoted). Moreover, these early studies highlighted the need to set up proper image processing techniques and modelling to predict areas of potential archaeological interest.
The subsequent availability of the 10 m resolution of the Spot imagery of French satellites was a missed opportunity for archaeological utility, because they were much more expensive than TM and offered a “coarse” spatial resolution still not enough to detect smaller features of archaeological interest.
A significant improvement was achieved later, after the end of the Cold War, when in the 1990s, Russian and American intelligence satellite photographs were made commercially available for civilian purposes. This strongly pushed archaeologists to use the extensive archive of photographs acquired by US and Russian intelligence in the 1960s and 1970s. Archaeologist used this huge data set to study ancient landscapes, to detect changes affecting regions rich in cultural resources and to discover unknown sites, mainly in regions of the Middle East where intelligence satellite photographs were available at higher spatial resolution, of around 2 m.
Russian declassified KVR-1000 imagery were exploited to detect archaeological features such as crop and soil marks, even if over the years, the American declassified KH-4B Corona has been more widely used than the Russian declassified data (see Lasaponara and Masini 2011, 2012 and references therein quoted). This was mainly because the latter were much more expensive and were available for only four years.. Before the availability of High and Very High Resolution (HR and VHR) satellite data, Corona has been the unique data source for archaeological prospection in countries where aerial photography was, and currently is, strongly limited.
Early studies based on satellite microwave radiation provided unexpected insights in archaeology. For example, they enabled the discovery of subsurface features related to dry channels and rivers in the eastern Sahara (McCauley et al. 1982) with subsequent important implications in the geo-archaeology of prehistoric environments of this region (see also El-Baz et al. 2007). The use of SIR-C data allowed to find a portion of the Great Wall of China (Xinqiao et al. 1997) under sand, and to discover the City of Ubar in the desert of Oman (http://visibleearth.nasa.gov/view_rec.php?id¼536). Other discoveries have been made in the famous site of Angkor, Cambodia. A vast water management system was identified under tropical forests using radar images taken from a NASA Space Shuttle (Moore et al. 2007). Later, other discoveries in the urban area of Angkor have been made by Evans et al. (2007), using JPL AirSAR data, along with other remote sensing data. Nevertheless, the relatively low spatial resolution of radars (in L and P bands), the complex interpretation of radar-based products, and the difficulty to access low-cost data sets (such as SIR-A, SIR-B, and SIR-C) have strongly constrained their use in archaeological studies. One of the most useful and used radar-based products is the DEM obtained from the Shuttle radar topographic mission SRTM data.
The multispectral capability of satellite images can strongly improve the identification of differences in texture, moisture content, roughness, topography, various types of terrain, vegetation cover, lithological and geological composition and other information used in archaeological studies. Nevertheless, the need of very high resolution data was and is the main issue which has strongly determined the spread of satellite data in archaeological studies, the availability of Very High Resolution (VHR) satellite data from both active and passive sensors opened new opportunities and challenges.

3. SPACE ARCHAEOLOGY: AN OVERVIEW OF RECENT APPLİCATİONS

Presently, the great amount of multispectral VHR satellite images, even available free of charge in Google Earth, opened new strategic challenges in the field of remote sensing in archaeology. The availability of VHR satellite data has determined an increasing use of satellite data in archaeology. As an example, Figure 4 shows the increasing number of papers based on the use of satellite data which were recently published in the Journal of Archaeological Science. This increasing trend can be also observed in other journals see, for example, the special issues published focused on the topic in a number of specialized peer review journals, such as Journal of Archaeological Science, (vol. 38, issue 9, 2011), Archaeological Prospection (vol. 16, issue 13, 2009), Journal of Cultural Heritage vol. 10S, 2009., Photo Interpretation European Journal of Applied Remote Sensing, vol. 46, 2010, (http://www.ibam.cnr.it/earsel/Editorial-activity.htm).
The access to VHR satellite images is different, depending on the satellites owners, in the case of private companies such as IKONOS, QuickBird and OrbView images are well distributed. A good distribution network also exists for SPOT, the Indian Satellites and EROS.

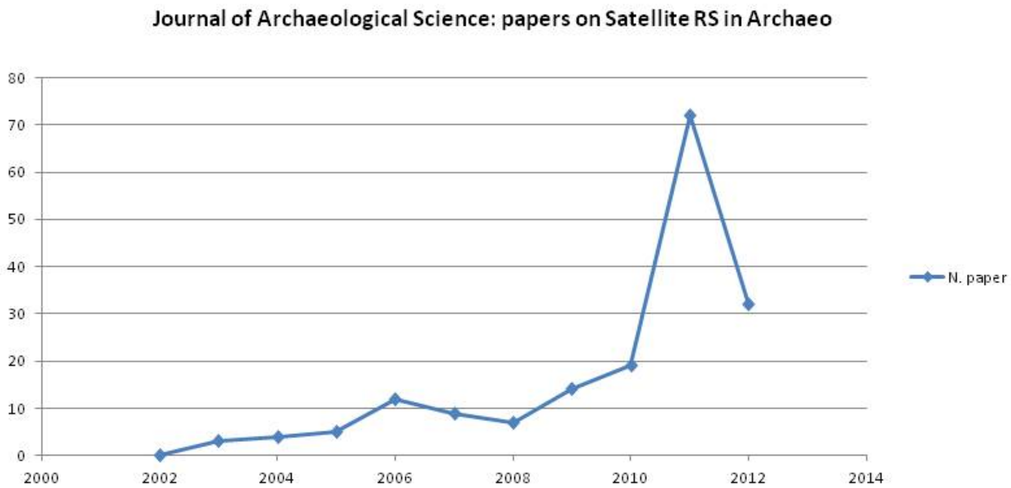

Figure 4 Number of papers based on the use of satellite data which were recently published in the Journal of Archaeological Science (the data of 2012 is updated to July)

Table 1. Examples of satellite sensors which can be fruitfully applied in archaeological investigations

	launch	country	Pan	ms
SPOT 1	1986	France	10 m	20 m
SPOT 2	1990	France	10 m	20 m
SPOT 3	1993	France	10 m	20 m
MOMS 02	1993	Germany	4.5 m	13.5 m
IRS-1C	1995	India	5.8 m	23.5 m
MOMS-2P	1996	Germany	6 m	18 m
ADEOS	1996	Japan	8 m	16 m
IRS-1D	1997	India	5.8 m	23.5 m
SPOT 4	1998	France	10 m	20 m
IKONOS 2	1999	USA	0.8 m	2.4 m
KITSAT 3	1999	S. Korea	15 m	15 m
UoSAT 12	1999	UK	10 m	30 m
Kompsat 1	1999	S. Korea	6.6 m -	
EROS A1	2001	Israel	1.8 m -	
QuickBird	2001	USA	0.6 m	2.4 m
TES	2001	India	1 m	
SPOT 5	2002	France	5 (2.5) m	10 m
OrbView 3	2003	USA	1 m	4 m
Resourcesat	2003	India	5.8 m	5.8 m
BilSat	2003	Turkey	12 m	28 m
ROCSat	2004	RO China	2 m	4 m
Cartosat 1	2005	India	1 m	2.5 m
Kompsat 2	2006	S. Korea	1 m	4 m
Topsat	2005	UK	2.5 m	5 m
ALOS	2006	Japan	2.5 m	10 m
Resurs DK2	2006	Russia	1 m	2:3 m
EROS B	2006	Israel	0.7 m	
WorldView	2007	USA	0.5 m	2 m
Cartosat 2	2007	India	0.8m	
RapidEye	2008	Germany	5 m	5 m
GeoEye-1 (Former name OrbView 5)	2008	USA	0.4 m	1.6 m
THEOS	2008	Thailand	2 m	15 m
RazakSat	2009	Malaysia	2.5 m	5 m

The huge amount of the available satellite data offers the possibility to use diverse datasets according to the specific and diverse needs ranging from small site detection to inter-site analyses and multiscale investigations. Examples of diverse pixel sizes on large features are shown in Figures 5 for Nasca line in Peru.

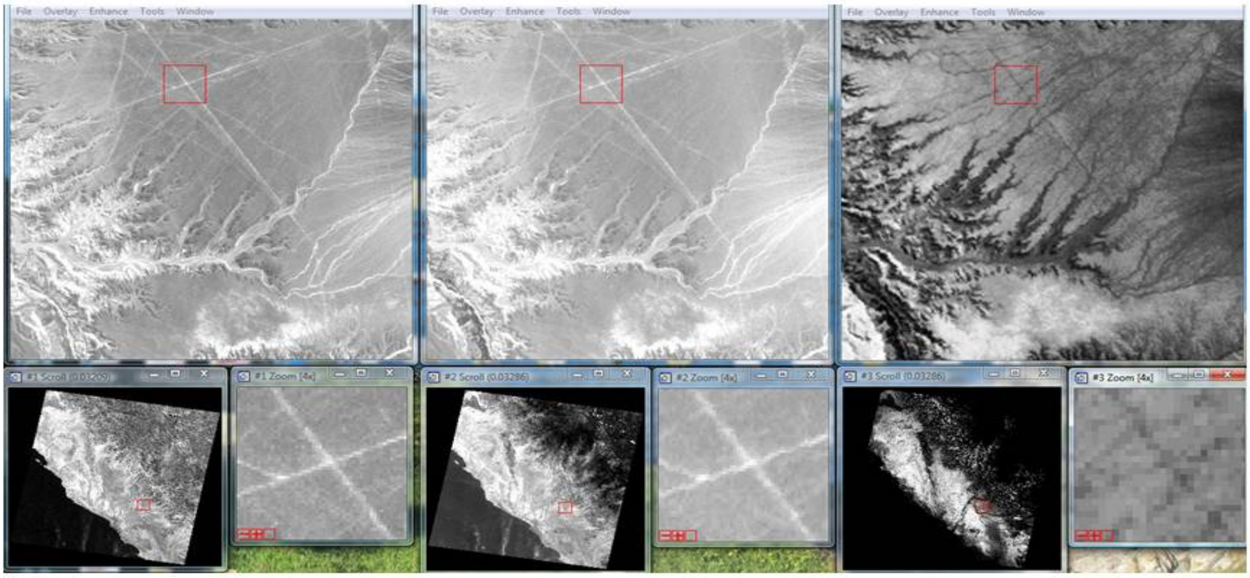

Figure 5. Examples of diverse pixel sizes on large features selected from the famous Nasca line in Peru from left to right: (i) 15 m panchromatic from ETM, (ii) 30 m (TM NIR channel) and (iii) 90 m (TM thermal channel)

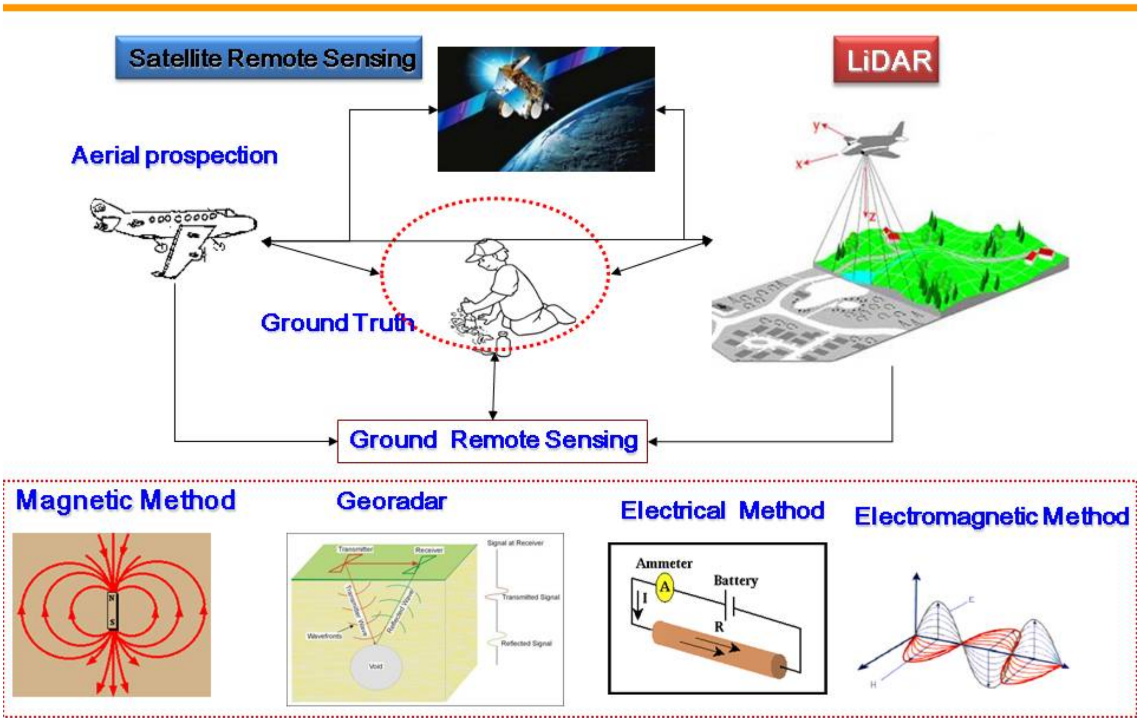

Figure 6. Example of integration of non invasive technologies.

The ROCSat images are distributed by SPOT. The advantages of VHR satellite imagery, compared to aerial photos, are the synoptic view, the multispectral properties of the data and the possibility to extract geo-referenced information which allow the extraction of valuable information from site level up to historical landscapes. The multispectral bands, available at a resolution four times lower than panchromatic channels, can be pan-sharpened using image fusion algorithms available in several image processing software routines. The pan-sharpened spectral bands emphasize moisture and vegetation changes linked to the presence of buried archaeological deposits (e.g., Lasaponara and Masini, 2007; Grøn et al., 2008).

Nowadays, the use of EO for archaeology is still an open issue and additional strategic challenges deal with the integration of remote sensing with other traditional archaeological data sources, such as surveys, trials, excavations and historical documentation.
This strategic integration requires a strong interaction among archaeologists, scientists and cultural heritage managers to improve traditional approach for archaeological investigation, protection and conservation of archaeological heritage. Data coming from diverse non-invasive remote sensing data sources can support a scalable and modular approach in the improvement of knowledge as a continuous process oriented to collect and puzzle pieces of information on past human activities, thus should enable us to better understand the past and to better manage the present.

4 SPACE ARCHAEOLOGY : FUTURE CHALLENGES

Future challenges substantially deal with the exploitation, as much as possible, of the data which are currently available from both active and passive sensors, and, in turn, with the setting up of effective and reliable automatic and/or semiautomatic data processing strategies and the integration of the traditional ground truth activity with numerical scientific testing (i.e. in-situ spectro- radiometric measurements).
Moreover, the integration of diverse data source, mainly from active and passive sensors, can strongly improve our capacity to uncover unique and invaluable information, from site discovery to studies focused on the dynamics of human frequentation in relation to environmental changes. Figure 6. Shows an example of integration of non invasive technologies.
The integration of diverse data source can strongly improve our capacity to uncover unique and invaluable information, from site discovery to studies focused on the dynamics of human frequentation in relation to environmental changesFuture challenges in the field of Space technologies substantially deal with the exploitation of the available data as much as possible, and, in turn, with the setting up of effective and reliable automatic and/or semiautomatic data processing strategies and the integration of the traditional ground survey activity with numerical scientific testing (i.e. in-situ spectro- radiometric measurements).
Next generation of satellite data for archaeological applications are expected to offer improved technical capabilities, with higher spatial and spectral resolution to support the diverse phases of archaeological research from discovery, to documentation, from preservation to valorization. This approach can effectively support a smart management of cultural heritage including the sustainable “touristic exploitation” and the educational activities to spread new technologies and “attitude” in the context of natural and cultural heritage management.
Nowadays, the preservation and enhancement of natural and cultural heritage is perceived as one of the topics of great economic and social significance. Recently, the debate on strategies for the preservation of both environmental resources and cultural heritage has seen increasing importance mainly due to the fact that:

- cultural heritage has an increasingly significant role in the context of sustainable economic development models based on local identities
- environmental heritage is regarded as a key factor in the development of local resources in a sustainable economic approach

All these aspects require the preservation and management of heritage as a resource for economic development based on the principles of sustainable use of unique non renewable resources not only for the benefit of society, but also as a useful source of human development.
Some early examples of this advanced methodological approach, adopted to improve both preservation and smart management of natural and cultural heritage, can be already found in Rosa Lasaponara (scientific coordinator of the MITRA project), among them we briefly focus on investigations (Lasaponara and Masini 2006, 2007, 2009, 2011, 2012) carried out near the medieval village of Monte Irsi or Yrsum, located in the Basilicata Region (Southern Italy).

For this test pilot area, analyses were performed using historical documentation along with data from non invasive remote sensing technologies, such as satellite imagery, aerial photos and LiDAR survey in order to detect unknown features (see figure 7), reconstruct the urban shape of the village and monitor the evolution of the palaeo-landslide (see figure 8) which can adversely affect the archaeological area. Finally, the virtual reconstruction (see figures 9) enables the valorization of the site including museum exhibition and/or touristic purposes and the educational activity.

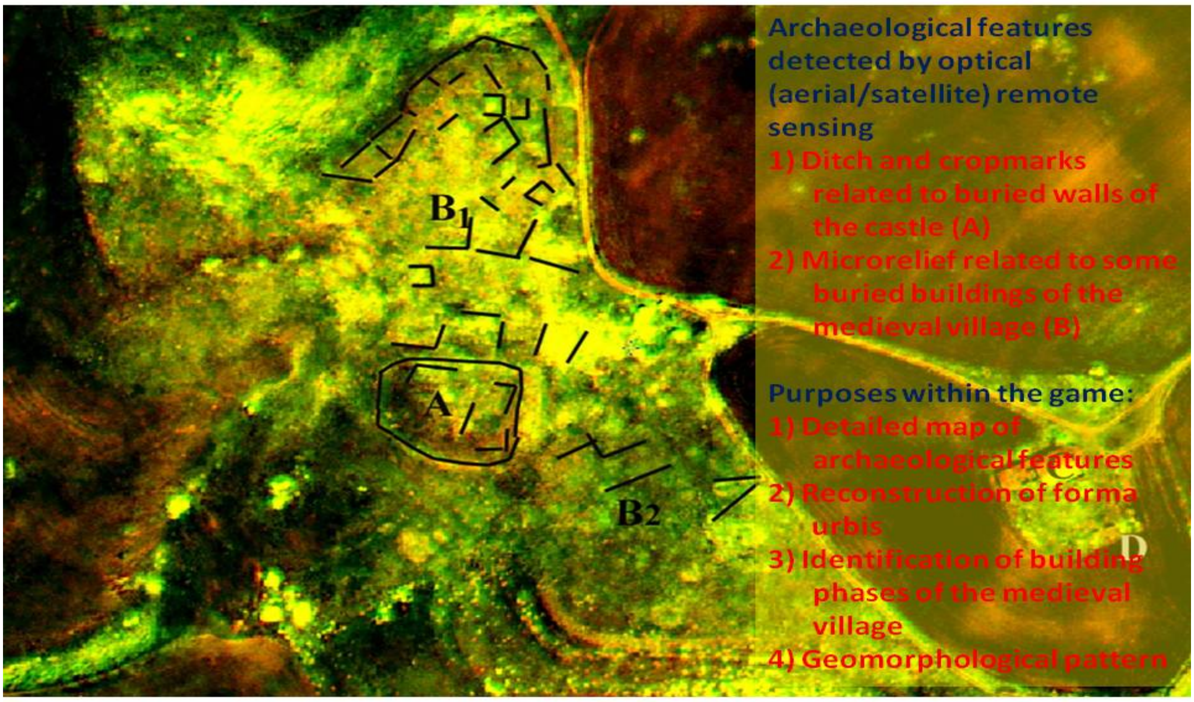

Figure 7 First approach: discovery of unknown archaeological features using VHR satellite data see detail, in Lasaponara and Masini, 2006

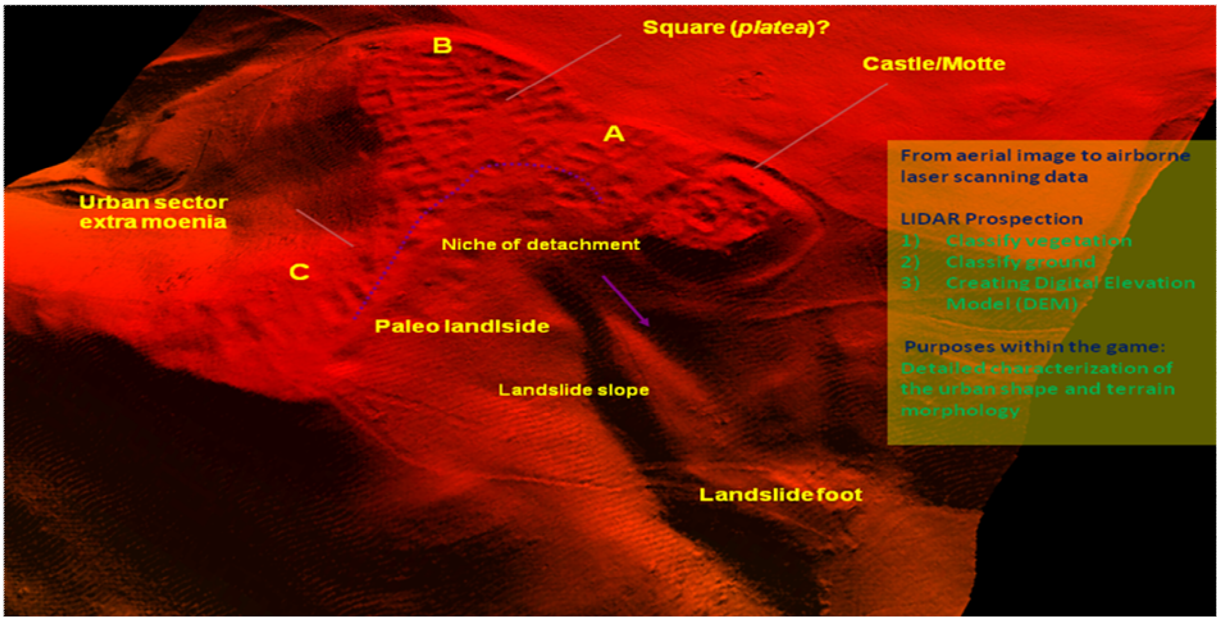

Figure 8. Identification of urban shape of the lost medieval village and palaeo-landslide in Monte Irsi (for details see Lasaponara and Masini, 2009)

Figure 9 3D virtual reconstruction based on LiDAR survey for educational activities

5. CONCLUSIONS

In this paper we provide an overview of non invasive remote sensing technologies useful for archaeological investigations.
The application of aerial photographs had been long appreciated by archaeologists. In fact, over the last century, aerial reconnaissance has been one of the most important tool which enabled the discovery of a tremendus amount of unkwon archaeological sites across the world. Later a number of new technological tools were adopted in archaeology, as follows:

- end of 19th century : first application of aerial archaeology in UK and France
- 1950s:first application of resistivity and magnetometry i
- 1970 s: first georadar application in archaeology
- 1980s medium resolution satellite data for palaeoenvironment and landscape archaeology
- 1999 :very high resolution satellite data
- 2003-2004 aerial Lidar

Nowadays, the use of EO for archaeology is still an open issue and additional strategic challenges deal with the integration of remote sensing with other traditional archaeological data sources, such as field surveys, trials, excavations and historical documentation. The integration of diverse data source can strongly improve our capacity to uncover unique and invaluable information, from site discovery to studies focused on the dynamics of human frequentation in relation to environmental changes
Data coming from diverse non-invasive remote sensing data sources can support a scalable and modular approach in the improvement of knowledge as a continuous process oriented to collect and puzzle pieces of information on past human activities, thus should enable us to better understand the past and to better manage the present.
This strategic integration requires a strong interaction among archaeologists, scientists and cultural heritage managers to improve traditional approach for archaeological investigation, protection and conservation of archaeological heritage.
Future challenges substantially deal with the exploitation, as much as possible, of the data currently available from both active and passive sensors, and, in turn, with the setting up of effective and reliable automatic and/or semiautomatic data processing strategies and the integration of the traditional ground truth activity with numerical scientific testing (i.e. in-situ spectro- radiometric measurements).
Next generation of satellite data for archaeological applications are expected to offer improved technical capabilities, with higher spatial and spectral resolution to support the diverse phases of archaeological research from discovery, to documentation, from preservation

to valorization for supporting a smart management of cultural heritage including the sustainable "touristic exploitation" of both natural resources and cultural heritage.

REFERENCE

El-Baz, F., Robinson, C.A., Al-Saud, T.S.M., 2007. Radar images in geoarchaeology of Eastern Sahara. In: Wisemann, J., El Baz, F. (Eds.), Remote Sensing in Archaeology. Springer, pp. 47–70

Evans, D., Pottier, C., Fletcher, R., Hensley, S., Tapley, I., Milne, A., Barbetti, M. 2007. A comprehensive archaeological map of the world's largest pre-industrial settlement complex at Angkor, Cambodia, Proceedings of the National Academy of Sciences of the United States of America, 104 (36): 4277-4282.

Grøn, O., Stylegar, F.-A., Palmer, S., Aase, S., Orlando, P., Esbensen, K., Kucheryavski, S., 2008. Practical use of multispectral satellite images in general Norwegian cultural heritage management and focused Viking age research. Experiences from South-western Norway. In: Lasaponara, R., Masini, N. (Eds.), Remote Sensing for Archaeology and Cultural Heritage Management. Aracne Editrice, Rome, pp. 285–288

Lasaponara R., Masini N., Satellite Remote Sensing: A New Tool for Archaeology, Springer Verlag. 360 pp, 2012.

Lasaponara R., Masini N. 2011, Satellite Remote Sensing in Archaeology : past, present and future, *Journal of Archaeological Science*, **38**, 1995–2002, doi:10.1016/j.jas.2011.02.002

Lasaponara R., Masini N. 2007, Detection of archaeological crop marks by using satellite QuickBird, *Journal of Archaeological Science*, 34, pp. 214-221 [ISSN: 0305-4403] [10.1016/j.jas.2006.04.014]

Lasaponara R., Masini N. 2006, On the potential of Quickbird data for archaeological prospection, *International Journal of Remote Sensing*, **27** (15-16), pp. 3607-3614. [ISSN: 0143-1161] [DOI: 10.1080/01431160500333983]

Lasaponara R., Masini N. 2009, Full-waveform Airborne Laser Scanning for the detection of medieval archaeological microtopographic relief, *Journal of Cultural Heritage*, 10S, pp. e78–e82 [doi:10.1016/j.culher.2009.10.004]

Lasaponara R., Masini N. 2011. On the Processing of Aerial LiDAR Data for Supporting Enhancement, Interpretation and Mapping of Archaeological Features. In B. Murgante et al. (Eds.), Computational Science and ist applications - ICCSA 2011, Part II, LNCS 6783, pp. 392–406, Springer-Verlag Berlin Heidelberg, ISBN 978-3-642-21886-6, doi 10.1007/978-3-642-21887-3

Masini N., Lasaponara R. 2007, Investigating the spectral capability of QuickBird data to detect archaeological remains buried under vegetated and not vegetated areas , *Journal of Cultural Heritage*, **8** (1), pp. 53-60. [ISSN: 1296-2074].

Masini N., Lasaponara R. 2006, Satellite-based recognition of landscape archaeological features related to ancient human transformation, *Journal of Geophysics and Engineering*, **3**, pp. 230-235. [ISSN: 1742-2132] [doi:10.1088/1742-2132/3/3/004]

McCauley, J.F., Schaber, G.G., Breed, C.S., Grolier, M.J., Haynes, C.V., Issawi, B., Elachi, C., Blom, R., 1982. Subsurface valleys and geoarchaeology of the Eastern Sahara revealed by shuttle radar. Science 218, 1004–1020.

Moore, E., Freeman, T., Hensley, S., 2007. Spaceborne and airborne radar at Angkor. Introducing new technology to the ancient site. In: Wisemann, J., El Baz, F. (Eds.), Remote Sensing in Archaeology. Springer, pp. 185–216.

Xinqiao, Lu, Huadong, Guo, Yun, Shao, 1997. Detection of the Great Wall using SIR-C data in North-Western China. Geoscience and Remote Sensing, 1997. IGARSS '97. Remote Sensing - A Scientific Vision for Sustainable Development., 1997 IEEE International , 1: 50-52.