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Satellite remote sensing in archaeology: past, present and future perspectives
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# Satellite remote sensing in archaeology: past, present and future perspectives

## 1. Remote sensing in archaeology: from aerial view to early satellite imagery applications

The application of Earth Observation (EO) techniques has exhibited great potential for archaeological investigations, even if in an experimental stage. It has accounted for a number of important archaeological discoveries and has provided manifold capabilities starting from the detection of cultural features through archaeological prospecting in regional surveys, to palaeo-ecosystem studies and paleo-landscape reconstructions.

During the last twenty years, the use of EO technologies in archaeology has been strongly increasing for several reasons: i) the improvement of spectral and spatial resolution of satellite sensors; ii) the availability of user-friendly software and routines for data processing and analysis; iii) the interests of archaeologists to study the dynamics of human frequentation in relation to environmental changes. Moreover, archaeologists are ever more aware of the benefits of remote sensing applications for their investigations, such as: i) reduction of costs, time and risk associated with archaeological excavations; ii) creation of site strategies addressed to conservation and preservation.

Satellite remote sensing technologies have triggered improvements in archaeological research and developments of new tools in archaeological prospection from discovery to monitoring, from documentation to preservation. Nevertheless, this increasing interest in remote sensing has not been accompanied by a new perspective of data processing, analyses and interpretation. Specific methodologies, developed ad hoc for archaeology, are needed in order to optimize the extraction and understanding of the information content from the numerous active and passive satellite data sets. Often also radiometric or geometric distortions, noise reduction and data integration have not been addressed at all, mainly because the adopted approach has been very close to simple photo-interpretation since, historically, aerial photography has been the first remote sensing technology extensively used in archaeology.

In fact, since the end of the nineteenth century, aerial photography has been the technological tool most widely used for surveying surface archaeological remains as well as for revealing differences and detecting underground archaeological structures through the reconnaissance of the so-called “soil” and “crop marks” (Crawford, 1929). Soil marks are changes of colour or texture due to the presence of surface and shallow remains. Crop marks frequently appear as differences in height or colour of crops which are under stress due to lack of water or deficiencies in other nutrients caused by the presence of masonry structures in the subsoil. Crop marks can also be formed above damp and nutritious soil of buried pits and ditches. Such marks are generally visible only from an aerial view, especially during the spring season.

The multispectral capability of satellite images may 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. 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 (Romano and Tolba, 1996; Clark et al.,1998; Sever, 1998), and also in palaeogeographic environment studies (Parry, 1992; Drake, 1997; White and El Asmar, 1999). 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.

## 2. From declassified satellite photo to GeoEye: archaeological applications and data processing issues

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 by Fowler (1996) to detect archaeological features such as crop and soil marks in the surrounding of Stonehenge, and by Comfort (1997) for archaeological investigations in the Greek and Roman city of Zeugma on the Euphrates in Turkey. Russian Soyuz Kate-200 images have also been explored for studying ancient irrigated and cultivated areas in Yemen (Marcolongo and Morandi Bonacossi, 1997).

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Nevertheless, over the years, the American declassified KH-4B Corona has been more widely used than the Russian declassified data, mainly because the latter were much more expensive and were available for only four years. One of the first applications of Corona images has been carried out by Kennedy (1998a, b) to investigate the Euphrates valley (Turkey). Fowler (1997) assessed the ability of images acquired by Corona KH-4B at 1.8 m resolution in detecting archaeological features near a hill fort in Hampshire, dating back to the Iron Age. 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, as in the case of the Upper Khabur basin in North-eastern Syria, where Ur (2003) identified ancient road systems dating from the Early Bronze Age.

Altaweel (2005) integrated CORONA with ASTER multispectral satellite imagery at medium spatial resolution (from VNIR at 15 m to SWIR bands at 30 m) to identify hollow ways, canals and sites in North Iraq. As Altaweel, other researchers exploited the information content of Corona photographs along with the new multispectral satellite data for site discovery. Beck et al. (2007), for instance, used Corona along with Ikonos imagery for studying tell settlements and field systems in Western Syria. Another important contribution comes from the study and documentation of the archaeology of the Altai Mountains by Goossens et al. (2006). The latter proposed a methodology able to reduce the complex problems linked to the images' geometric rectification due to the fact that Corona images were collected using a non-metric panoramic camera on a satellite with a decaying orbit. On the basis of these corrections, Goossens et al. (2006) produced a Digital Surface Model, thus showing that Corona stereoscopic viewing images can be a useful data source also for photogrammetrical techniques and digital restitution methods to map archaeological sites and historical landscapes.

In 1999 the launch of IKONOS, the first commercial VHR satellite sensor, opened new perspectives in the field of archaeo-geophysics. Since 1999 the spatial resolution has been strongly increased, thus providing also valuable support for site discovery by means of soil/crop mark detection. The "great run" of commercial satellite technology for reaching the resolution of aerial images seems to have arrived at the end with GeoEye-1 (launched in September 2008) which provides 41 cm panchromatic and 1.65 m multispectral imagery.

Today, the number of high and very high resolution satellites is growing fast (see Table 1) and most of them offer a combination between higher resolution panchromatic channel and lower resolution multispectral channels. Of course most of these systems are fore dual use – military and civilian, herein we focus on images that can be used for civilian purposes.

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. 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).

**Table 1**
High and very high resolution satellite sensors.

| | 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 | 0.8 m | |
| 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 use of effective data processing procedures, from classification methods to spectral indices, from principal component analysis to convolution, opens the possibility to set up an automatic (without human intervention), or at least semiautomatic (with human intervention), approach for the reconnaissance of archaeological features and site/landscape change detection. To reach these aims data processing focuses on feature extraction and pattern recognition, which are generally carried out through image filtering, segmentation and measurements. Image filtering reduces noise and enhances edges of objects and features; image segmentation extracts object boundaries; finally, image measurements quantitatively characterize the shape, orientation, texture, fragmentation and size of structures, useful for classification purposes.

Traditional filtering techniques, such as spatial and/or frequency filtering, are commonly applied to satellite images to reduce noise (low pass filter), or enhance borders (high pass filter) but, the problem is that filtering and processing procedures must be calibrated or developed "ad hoc" for archaeological investigations because the signals linked to cultural features are very subtle and can be easily lost. One more issue is linked to data analysis, because sometimes the outputs from data processing have not a universal meaning, but are linked to the specific data set, as in the case of Principal Component Analysis (PCA). The PCA is a transformation of the set of data which can make evident some features not distinguishable in the original variables. It is applied simultaneously to all the bands of multi- or hyperspectral images to extract a new set of non-correlated components by reducing the dimensionality of space without a significant loss of information.

Presently, no effective automatic procedures are available for archaeological purposes, but semiautomatic and/or enhancement techniques seem to work quite well, even though they can be "site specific" or "feature specific". See, for example, the application of PCA, texture segmentation, linear pattern detection and spatial filtering to Landsat 7 images, for the detection of pre-Hispanic pathways, in Aztec cities within and outside the Valley of Mexico (Argote-Espino and ChaVez, 2005). Other examples include the discrimination of surface archaeological remains in Hisar (southwest Turkey) (De Laet et al., 2007), the extraction of land patterns, useful for palaeogeographic and palaeonvironmental investigations in Metaponto on the Ionian coast of Southern Italy (Masini and Lasaponara, 2006), and the detection of change over time in Southern Peru by Masini and Lasaponara (2010). In this last case, a time series of QuickBird-2 and World-View-1 images has been exploited to monitor archaeological looting in Cahuachi (Peru), a huge and fragile Ceremonial Centre built in adobe by the Nasca Civilization. The spatial autocorrelation statistics applied to satellite images enabled the extraction of spatial anomalies linked to illegal excavations and to recognize and quantitatively characterize looting patterns over the years. Another approach to perform the detection of change for the monitoring of archaeological sites is based on image segmentation approach, which has been applied in Turkmenistan (Nisa) and in Iraq (Babylon) (Jahjah and Ulivieri, 2010). The latter was investigated with the aim to evaluate changes before and after the second gulf war.

Along with the multispectral capability, VHR satellite images also offer a stereo view, and, in turn, the possibility to extract high resolution Digital Elevation Models (DEMs) which are recognized as basic tools in the investigation of ancient landscapes and the visualization of historical sites. DEM products can be also obtained from medium and low resolution satellite images such as SPOT or ASTER. 3D-based analyses for archaeological purposes range through various scales, from building level up to a landscape perspective. A variety of applications have emerged, from virtual surveys to the reconstruction of archaeological sites and cultural landscapes, from the detection of large archaeological features (i.e. tells, mound) to the identification of potential localizations of ancient sites through modelling and GIS-based analysis. DEM obtained from optical satellite images has several advantages, including relatively low costs (compared to field GPS survey or photogrammetric campaigns), high spatial resolution, good correlation over vegetated areas, whereas, being passive sensors, the main disadvantages include mainly the potential masking by clouds.

To obtain inexpensive DEM, multi-temporal and multi-sensor satellite data can be used, since the cost for acquisition of VHR stereo data is more than double the price of two single images. Moreover, the availability of single mode images in the commercial satellite archives is much higher than that of images acquired in stereo mode. Currently the research in the field of DEM generation from optical images is quite active in the different application fields, such as city modelling and landslide monitoring, and maybe, in the near future, results from these studies will be also useful for archaeology.

The potential of satellite VHR imagery is better exploited if they are used in combination with other data sources, such as historical documentation and records, along with multi-sensor and multi-scale spatial analysis and geophysical prospection aimed to approach different fields of site investigations, from geoscience (geo-archaeology, geomorphology) to archaeology (field survey, excavations, etc.). An integrated approach provides added value and precious contribution, from site discovery to the study of historical landscapes, as in Alexakis et al. (2011), who provided valuable information for the detection of settlements, the modelling of habitation and the reconstruction of the landscape in the Neolithic age in Thessaly, by using GIS, geomorphology, remote sensing and DEM analysis. Finally, a multi-scale and multi-sensor approach has been adopted by Ciminale et al. (2009) on a Neolithic settlement in Apulia region (Southern Italy). In particular, satellite data allowed us to reconstruct the palaeoenvironmental pattern, whereas aerial images and geomagnetic maps made it possible to identify the circular ditched enclosures of the Neolithic village, and other smaller features related to circular and semi-circular compounds.

## 3. Overcoming the limits of optical satellite data in archaeology through active remotely sensed data

Notwithstanding the tremendous increase of radiometric, spectral and spatial resolution of satellite sensors, not all the possible archaeological features are visible by analysing and processing optical images. We refer to: 1) archaeological remains covered by dense vegetation (mainly forest etc.); 2) and micro-relief linked to the presence of surface and/or shallow archaeological structures, earthworks related to ancient ditches and field divisions, geomorphological patterns of palaeoenvironmental interest on bare ground areas.

In the first case, satellite imagery is only capable to detect big structures covered by forest. In this regard, we cite the identification of Maya settlements in the jungles of northeast Guatemala by Garrison et al. (2008). As concerns the second limitation, the visibility of micro-relief depends on many factors, such as off-nadir viewing angle of the collected imagery (aerial and satellite), time of image acquisition, view geometry, sun angle and surface characteristics. To overcome these limits, a major contribution can be provided by active sensors, such as spaceborne and airborne radar and laser scanners. Being active sensors, satellite radar is able to sense a target area at any time of day or night, to 'penetrate' clouds and also to 'see through' dusty conditions (Vining and Wiseman, 2006; Wisemann and Baz, 2007). Therefore, radar sensors offer a valuable data source for mapping and studying tropical and subtropical territories, where cloud cover is one of the major limitations of optical imaging. Moreover, low frequency radar (L and P bands) can penetrate the vegetation and even soil down to several metres in hyper-arid environs.

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?id=536).

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. Still today, the application of imaging radar such as the German Terra SAR-X and the Italian Cosmo-Skymed SAR-X with high spatial resolution is quite limited due to the relatively high cost of data and their limited penetration capability being acquired in the X band. Moreover, radar data processing requires sophisticated data processing, noise suppression, and other advanced data interpretation techniques.

One of the most useful and used radar-based products is the DEM obtained from the Shuttle radar topographic mission SRTM data.

Some examples related to the use of VH and VHR along with SRTM satellite images in archaeology are shown in Figs. 1–3. In particular, Fig. 1 shows results from multi-sensor and multi-scale approach adopted in the context of the ITACA-Peru project by Masini and Lasaponara for archaeological and palaeoenvironmental investigations in Southern Peru. From top to bottom: (a) 3D DTM from SRTM (90 m resolution); (b–c) ASTER DTM (30 m) and channel 1 (15 m) of the drainage basin of Nasca river (see in ASTER the famous Nasca lines); (d) 3D QuickBird panchromatic image (70 cm) of the Ceremonial Centre of Cahuachi and its surrounding: the satellite data put in evidence the excavated pyramids and several mounds; (e) orthorectified aerial image, georadar slice

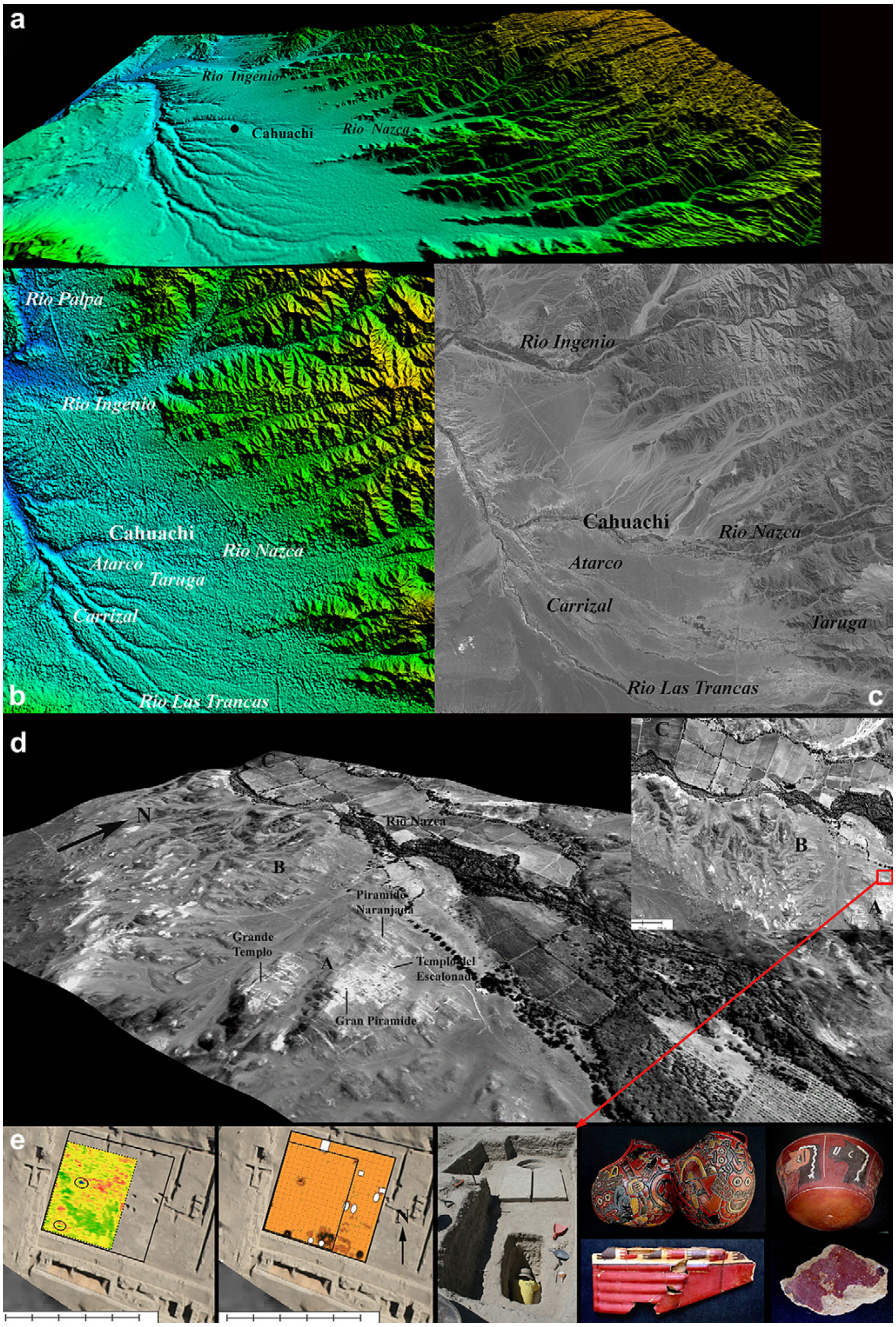


Fig. 1. Multi-sensor and multi-scale approach for archaeological and palaeoenvironmental purposes in Southern Peru. From up to bottom: (a) 3D DTM from SRTM (90 m resolution); (b–c) ASTER DTM (30 m) and channel 1 (15 m) of the drainage basin of Nasca river (see in ASTER the famous Nasca lines); (d) 3D QuickBird panchromatic image (70 cm) of the Ceremonial Centre of Cahuachi and its surrounding: the satellite data put in evidence the excavated pyramids and several mounds; (e) orthorectified aerial image, georadar slice and geomagnetic map which provided information on buried archaeological deposits, confirmed by excavations which unearthed a rich ritual offering, including ceramic, textiles, musical instruments and a trophy head.

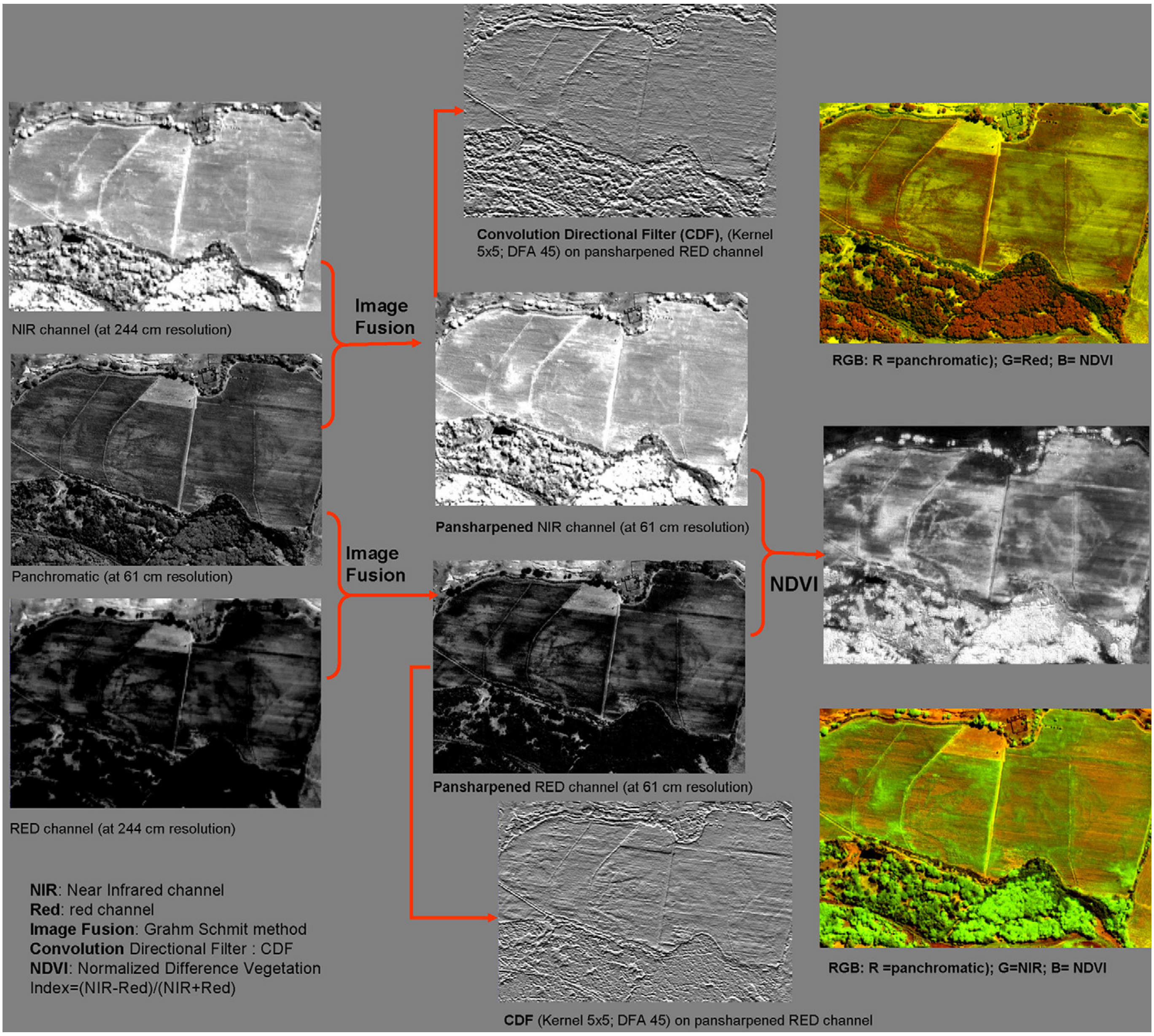


**Fig. 2.** Nasca riverbed (Peru). The satellite image processing approach allowed us to discover a huge buried settlement near the Ceremonial Centre of Cahuachi.

and geomagnetic map which provided information on buried archaeological deposits, confirmed by excavations which unearthed a rich ritual offering, including ceramic, textiles, musical instruments and a trophy head.

Fig. 2 shows the satellite image processing approach for the Nasca riverbed (Peru) which allowed the discovery of a huge buried settlement near the Ceremonial Centre of Cahuachi, in the framework of the ITACA-Peru project leaded by Masini and Lasaponara.

Finally, Fig. 3 shows results from geostatistical data analysis applied to VHR image for the desert of Nasca (Peru). The RGB composition of Moran, Getis and Geary indices applied to VHR panchromatic satellite images of 2002 (a), 2005 (b) and 2008 (c). The multi-temporal observation put in evidence the intensification of the looting phenomenon over the years (analyses carried out in the framework of the ITACA-Peru project leaded by Masini and Lasaponara).

SRTM-DEM products at 90 m resolution are available free of charge via the internet for almost 80% of the Earth's surface. The nearly global availability of the SRTM offers the archaeologists the possibility to have a prompt virtual survey of large areas for the detection and mapping of huge archaeological features, such as settlement mounds and tells. Several studies were conducted mainly in the Middle East and Near East, using also declassified satellite data (Menze and Sherratt, 2006).

The above-said restrictions of satellite optical imagery can be overcome also by Airborne Laser Scanning (ALS), also referred to as LiDAR (Light Detection And Ranging), which provides direct range measurements mapped into 3D point clouds between a laser scanner and earth's topography. ASL can penetrate vegetation canopies allowing the underlying terrain elevation to be accurately modelled. Therefore, it is a powerful tool for recognizing and investigating archaeological heritage in wooded areas, usually well preserved due to the vegetation cover which protects the sites from erosion and from possible damage by mechanical ploughing.

Currently, a LiDAR survey can be carried out by two different types of ALS sensor systems: (i) conventional scanners or discrete

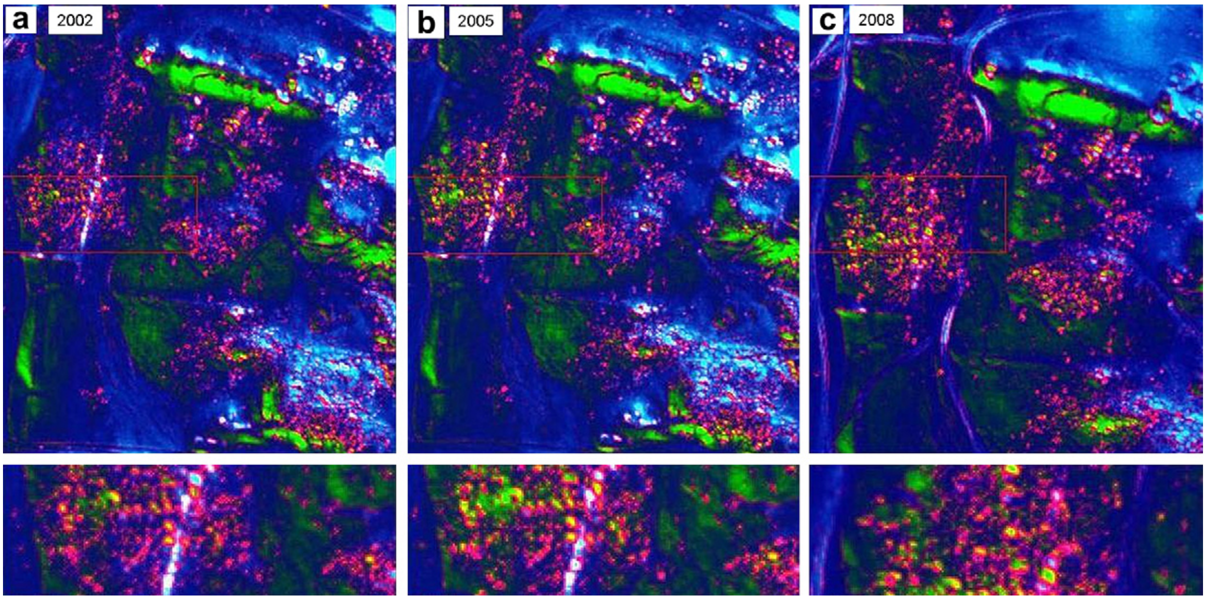


**Fig. 3.** Desert of Nasca (Peru): RGB composition of Moran, Getis and Geary indices applied to VHR panchromatic satellite images of 2002 (a), 2005 (b) and 2008 (c). The multi-temporal observation put in evidence the intensification of the looting phenomenon over the years.

echo scanners and (ii) full-waveform (FW) scanners. The first, generally, delivers only the first and last echo, thus losing many other reflections. The second is able to detect the entire echo waveform for each emitted laser beam, thus offering improved capabilities especially in areas with complex morphology and/or dense vegetation cover. Nowadays the majority of published studies are based on data collected by conventional ALS, for example for the management of archaeological monuments (Barnes, 2003), for landscape studies (Challis, 2006) and archaeological investigations to depict microtopographic earthworks in bare ground sites (Corns and Shaw, 2008) and in forested areas (Sittler, 2004; Devereux et al., 2005; Crutchley, 2009; Gallagher and Josephs, 2008).

The potential of FW LiDAR for archaeological purposes has been assessed so far only in a few studies, among which, for sake of brevity, we only cite the studies of an Iron Age hill fort covered by dense vegetation (Doneus et al., 2008) and the investigations performed on a medieval settlement, located on a bare ground hilly place (Lasaponara et al., 2010).

## 4. The special issue of the Journal of Archaeological Science

The current availability of a tremendous amount of invaluable data coming from diverse non-invasive remote sensing sources can support a scalable and modular approach to archaeological surveys in a significant improvement of knowledge as a continuous and dynamic process oriented to collect and combine pieces of information on past human activities, thus should enable us to better understand the past.

These challenges and opportunities require great efforts aimed at creating a strong interaction among archaeologists, scientists and managers interested in using remote sensing for supporting cultural heritage applications. In this cultural framework, the 1st International EARSEL Workshop “Advances in Remote Sensing for Archaeology and Cultural Heritage Management”, took place in Rome in 2008 (September 30–October 4). During the four days of the workshop more than 100 papers were presented by over 244 authors coming from 25 different countries. A fascinating and rich variety of issues, applications and study cases emerged from the discussions.

This special issue of Journal of Archaeological Science collects selected papers focused on archaeological, palaeoenvironmental and historical landscape investigations, mainly based on the use and processing of satellite images, but also integrated with additional data sources, such as LiDAR or geophysical prospection.

Giardino (2011) outlines the history of Space Archaeology with reference to the contribution of NASA for the discovery, delineation and analysis of archaeological sites worldwide. The paper focuses on passive remote sensing applied in successful projects which include the identification of ancient roads in Chaco canyon and prehistoric settlement patterns in southeast Louisiana.

Deroin et al. (2011) demonstrate the potential of a multi-scale satellite remote sensing approach for geoarchaeological purposes. The paper deals with a multidisciplinary project, including scientific disciplines traditionally related to archaeology (field and underground survey, archaeometry, study of the historical sources), for mapping the ancient Jabali silver mines in northern Yemen (7th–14th century AD).

Rajani (2011) analyses multi-sensor satellite data (from DEM SRTM to Resourcesat-1 AWiFS and IRS-1D LISS-III) using digital interpretation techniques in conjunction with Geographical Information System (GIS) to map known and hitherto unknown palaeochannels in the Indus basin (India).

Salvi et al. (2011) carried out an integrated analysis of both satellite imageries and dated aerial photos for the identification of new sites and for the assessment of landscape changes of wide archaeological areas in Ethiopia. In particular they focus on the Melka Kunture archaeological sequence, characterized by the continuous obsidian exploitation during the last 1.7 Myr. IKONOS II imageries were used to evaluate the human impact on the multi-temporal change of obsidian sources.

Grøn et al. (2011) present an overview of archaeological results obtained through the analysis of multispectral satellite images. Moreover, the paper focuses on a method of verification in-site based on the correlation between archaeological anomalies observed in spectral data and chemical variations in the sediment.

Lasaponara et al. (2011) address a strategic challenge which is the detection of buried earthen structures by using remote sensing techniques. This is an open issue, as crucial as it is complex. It is crucial because earthen archaeological remains are widely present throughout the world (in South America, Asia, Africa) and it is complex due to the subtle physical contrast between earthen remains and the surrounding subsoil. The paper presents the successful results obtained from investigations performed using an integrated approach based on VHR satellite imagery, geomagnetic surveys and Ground Probing Radar (GPR). Investigations were conducted on a mound named Piramide Naranjada, located in the ceremonial centre of Cahuachi (Nasca) in Southern Peru. Results from the analysis of satellite images allowed the identification of shallow and outcropping adobe walls, the gradiometric maps enabled the identification of tombs and ceremonial offerings, finally radargrams allowed the discovery of a rich ceremonial offering made up mainly of ceramics, textiles, and painted pumpkins.

Traviglia and Cottica (2011) show the results from investigations addressed to shed new light on early patterns of occupation in the Northern Venetian Lagoon. The authors explore the communication network between the mainland and the sea and examine the evolution of settlements along the commercial routes of the Lagoon through time. Remote sensing (RS) in this case is an important data source for investigating the extent and geomorphology of the ancient islands. Aerial photographs (both vertical and oblique) and HR satellite images are being used to identify past traces of occupation that nowadays are buried below earth surface or under the shallow waters of the Lagoon. The particular research environment of the Lagoon requires a close collaboration between archaeologists and scientists of differing expertise.

Di Giacomo et al. (2011) explore methods and issues connected with the elaboration of Ikonos stereo satellite images to create large scale cartography for archaeological research. The paper highlights the case of Hierapolis in Phrygia (Turkey), where archaeological surveys, developed by the Italian Archaeological Expedition, are in progress. In particular, this methodology has been used on an area of the ancient territory of Hierapolis for which neither cartographic material suitable for ground surveys nor aerophotogrammetrical covers were available. The satellite images were the only recent data source available. They were exploited to map and extract vectorial thematic elements (modern topography, hydrology, archaeological remains and traces, etc.) for the production of maps for archaeological research in a 1:10,000 scale.

Finally, Lasaponara et al. (2011) focus on Airborne Light Detection and Ranging (LiDAR) as a quite recent (mid-1990s) remote sensing technique with the unique capability to penetrate vegetation canopies and identify earthwork features even under dense vegetation cover. The use of ALS data in archaeology encounters serious challenges mainly linked to data filtering and processing as well as to pattern extraction and classification. The paper presents the data processing chain along with the threshold-based algorithm devised for the detection of archaeological remains. Algorithm performance was tested on some sample areas, characterized by different morphological features and cover types, from low and heterogeneous herbaceous cover to dense forests.

## 5. Outlook and conclusion

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 ways in which new archaeological sites have been discovered through the world. The advantages of aerial photographs are manifold: they can be taken vertically or obliquely, easily interpreted, used for photogrammetric application and also to provide a three-dimensional view.

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. These challenges substantially deal with the exploitation of such 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 truthing activity with numerical scientific testing (i.e. in-situ spectro-radiometric measurements).

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

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.

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