Chapter 1
Remote Sensing in Archaeology: From Visual Data Interpretation to Digital Data Manipulation

Rosa Lasaponara and Nicola Masini

Abstract 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 of cultural resources. Nevertheless, this increasing interest in remote sensing has not been accompanied by new perspectives in data processing, analysis and interpretation. Specific methodologies must be developed ad hoc for archaeology in order to optimize the extraction and understanding of the information content from the numerous active and passive satellite data sets. This chapter provides a brief overview on qualitative and quantitative data analysis from visual interpretation to digital manipulation.

Keywords Visual interpretation • Digital processing • Archaeological-marks • History of satellite remote sensing

1.1 Introduction

The importance of applying space 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;

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(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.

The availability of high resolution satellite data has been so rapidly growing that new problems have arisen mainly linked with methodological aspects of data analyses. In this context, the main concern is the lack of correspondence between the great amount of remote sensing image and effective data processing methods not only for archaeology but also for different field of applications.

This is particularly pressing in archaeology and palaeo-environmental studies, for which the data processing currently applied need to be adjusted and adapted for archaeological purposes.

The starting point is that ordinary data processing routines may provide outputs without any relevant information for archaeology. The traces of ancient human transformations of landscape create very subtle spatial features, namely surface anomalies, that are only visible from a bird view. The characteristics of these archaeological features strongly depend on vegetation cover and phenology, pedology, soil types and topography. These features are generally named soil, shadow and crop marks. Soil-marks can appear on bare soil as changes of color or texture. Shadow marks can be seen in presence of variations of micro-topographic relief visible by shadowing. Crop marks can be evident for vegetated areas, covered by crops or weeds. They can appear as differences in height or color in crops which are under stress due to lack of water or deficiencies in nutrients. Crop marks can be formed as *negative* marks above wall foundations as well as *positive* marks above pits and ditches (Crawford 1929; Adamesteanu 1973; Dassie 1978; Wilson 1982; Masini 1998; Piccarreta and Ceraudo 2000; see Fig. 1.1).

So, the possibility of locating unknown small sites as well as large scale cultural features from an aerial or space view is highly dependent on the image spatial resolution, extension of buried sites, ground characteristics, illumination conditions, view geometry etc.

The practical potential of satellite in archaeology needs to be tested in relation to the local specific different surface conditions, sites (extension, building materials), expected features (soil, shadow, crop marks), and environmental setting (Grøn et al. 2011). Early investigations, based on the use of satellite VHR data for archaeological studies in different environmental conditions (see state of art in Wiseman and El-Baz 2008; Parcak 2009; Lasaponara and Masini 2011) clearly pointed out that the subtle signals of archaeological features pose a serious challenge for digital image processing, so that satellite-based identification of archaeological features is recognized as one of the most complex tasks faced by computer vision and photogrammetry communities.

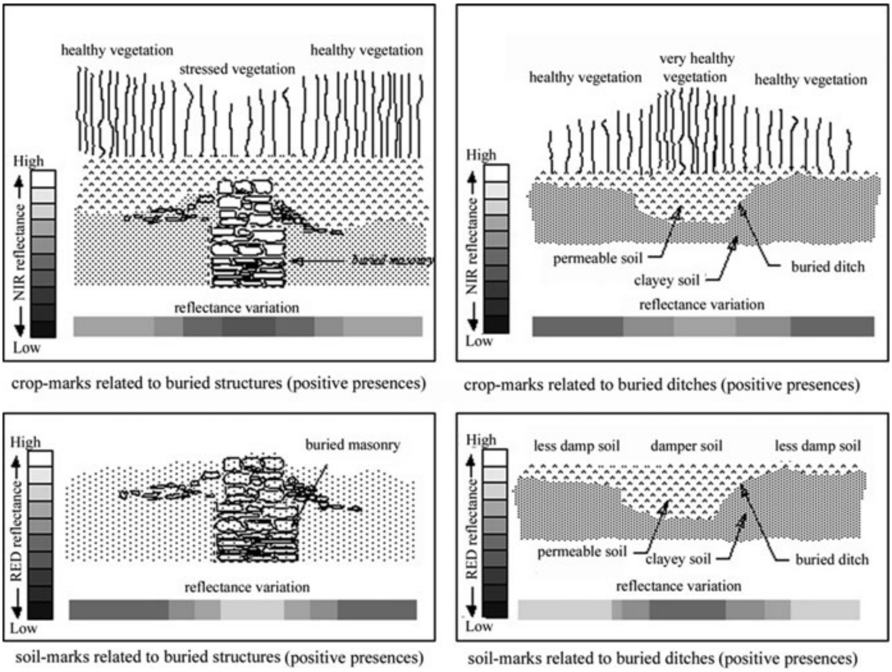

Fig. 1.1 Reflectance variation in presence of crop marks, caused by buried structures (*upper left*) and ditches (*upper right*) and soil marks (*lower left* and *right*, referable to shallow masonry structures and ditches, respectively)

Moreover, the integration of satellite data with traditional data sources, such as historical documentation and data collected on field at various scales, inevitably involves new challenges to be addressed and ad hoc processing strategies (see, for example, Fig. 1.2), such as:

(i) data fusion;
(ii) image enhancement, edge detection and pattern recognition;
(iii) spatial and spectral analysis that combines the advantages of two approaches based on spectral information and contextual information from a given pixel and its neighboring (geospatial data analysis);
(iv) image segmentation and classification, correlation between spectral data derived from pixel information and libraries as the basis for a new classification routine.
(v) satellite time series data analysis (temporal and spatial autocorrelation).

The listed methods are only a first step towards the optimization and integration of various components of data analysis (for additional details on points (i) to (v), the reader is referred to Chaps. 2, 3 and 4 of this book). Effective approaches must be devised, implemented and quantitatively evaluated to address key challenges of what can be called ‘digital light archaeology’ (namely non invasive archaeological research by digital *manipulation* of remotely sensed data).

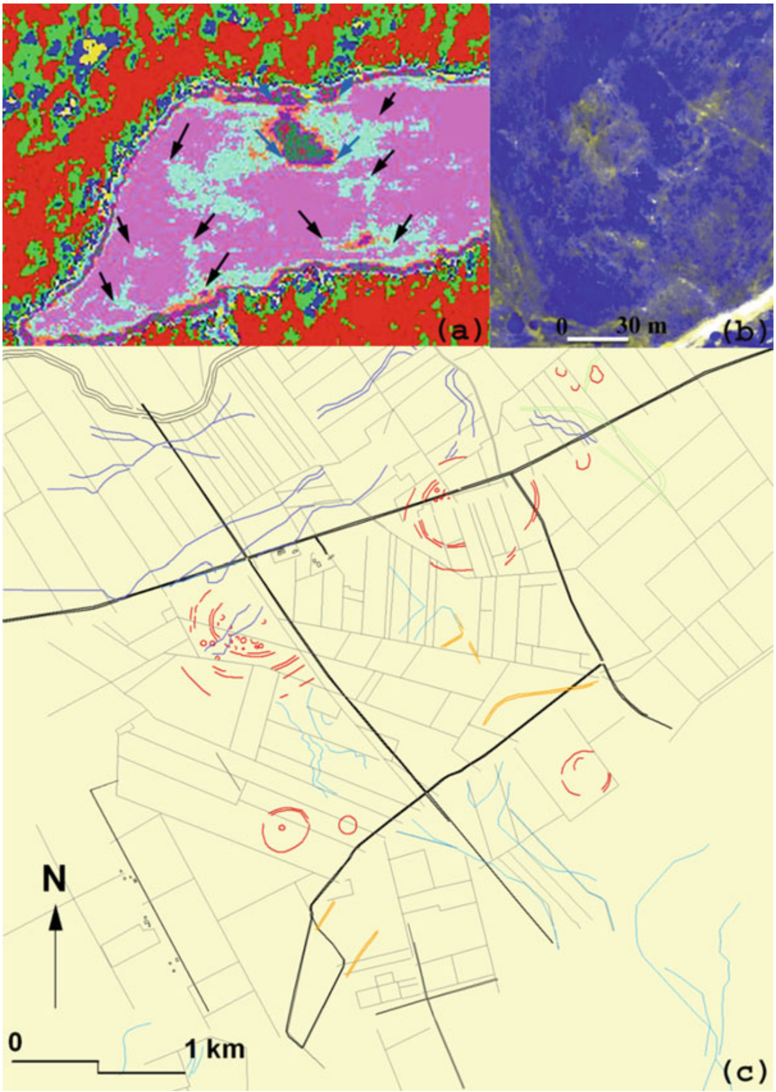

Fig. 1.2 Detection of archaeological sites by processing QuickBird imagery. (**a**) Etruscan site in San Giovenale (Viterbo, Italy): unsupervised classification to support the extraction of archaeological features; (**b**) Hierapolis (Turkey): discovery of a farm dating back between the early Imperial Roman and the proto-Byzantine age; RGB composition of red, green and NIR channel; (**c**) map of a Neolithic settlement near Foggia (Apulia region, Italy) derived from the processing of QuickBird imagery (see Backe Forsberg et al. 2008; Lasaponara et al. 2008; Ciminale et al. 2009, respectively)

The reconstruction of ancient landscape represents an important issue not only in the field of archaeology, but, also for botany, forestry, soil science and hydrology. Information on the impacts of human actions upon the environment can be widely used to address issues in human settlement, to better understand environmental interactions, climate change and the Earth's system.

1.2 Visual Data Interpretation Versus Digital Processing

Image interpretation is defined as the qualitative and quantitative examination of images recorded by various sensor systems (panchromatic, multispectral and hyperspectral cameras), in order to identify objects and evaluate their significance. The recognition of various targets can be carried out on the basis of the comparison of the visual elements which characterize them such as, tone, shape, size, pattern, texture, shadow, and spatial association, which are generally strongly dependent on the scale of observation:

(i) **Tone** denotes the relative brightness or colour of objects in an image, whose variations enable photo interpreters to well discriminate shape, texture, and patterns.
(ii) **Texture** denotes the arrangement and frequency of tonal variation and it is strongly dependent on the observation scale. For example, rough textures are related to irregular surfaces (such as a forest canopy), whereas smooth textures are linked to more uniform surfaces (such as fields, asphalt, ancient land divisions).
(iii) **Shape** denotes the general form of individual objects (for example Neolithic curvilinear ditches, square pyramids).
(iv) **Size** is a function of scale; both absolute and relative size can help in the interpretation of object/target (from buried wall structures to urban fabric).
(v) **Pattern** denotes the spatial arrangement of objects. Distinctive patterns are generally a repetition of similar tones and textures (for example, Roman centuriations).
(vi) **Shadow** provides an idea of the profile and relative height of targets which may make their identification easier (i.e. microrelief in medieval hilly settlements).
(vii) **Association** takes into account the relationship between objects or features in proximity to the target of interest (palaeoriverbeds close to ancient settlements which allow to study the relationship between environmental changes with human frequentation).

The following factors influence image quality, and therefore, object recognition:

- sensor characteristics (film types, digital systems);
- acquisition time (season of the year and time of day);
- atmospheric effects;
- resolution of the imaging system and scale;

- image motion;
- stereoscopic parallax.

In order to extract meaningful information on the basis of a visual inspection, the image interpreter has to identify and allocate objects into known categories. This implies the knowledge of local environments and a deeper understanding of the processes and phenomena under investigation. The result from recognition process is the identification of objects and features in the area as well as the delineation of areas having homogeneous patterns and characteristics.

Visual interpretation is qualitative, inexpensive and simple. Its main advantage, compared to digital data processing, is the fact that it can be carried out also when the object features are not easily distinguishable. Obviously, the main disadvantage is that visual interpretation can only be carried out for small investigation areas.

In the last decades, the advancement of technology has provided a revolution which was at the first the availability of remote sensing data in digital format and later digital processing. This requires a performing computer system, with dedicated hardware and software for image processing. The latter can be categorized into the following two groups: (1) pre-processing and (2) processing (Lillesand and Kiefer 2000).

(1) Pre-processing generally indicates radiometric or geometric corrections along with all the operations required prior to carry out the data analysis and information extraction. Radiometric corrections aim at: (i) correcting the data for sensor irregularities and reducing noise due to sensor and/or atmospheric effects, and (ii) converting the data in calibrated measurements of the reflected or emitted radiation. Geometric corrections aim at: (i) reducing geometric distortions due to view geometry, and (ii) converting data to coordinates (e.g. latitude and longitude) of a given reference system.
(2) Processing procedures assist visual interpretation and analysis, according to investigation purposes, for example, image enhancement, edge detection and extraction, pattern recognition, classification, data fusion may be applied to emphasize subtle details, etc. (see Fig. 1.3). Data processing can be automatic or semi-automatic depending on the absence or presence of human intervention, respectively. The semi-automatic data processing methods are generally more common and effective than fully-automated procedures.

Obviously, the computer cannot replace the knowledge, experience and understanding of the image interpreter (archaeologist) but can allow quantitative analysis of huge data sets and make the information extraction and interpretation easier also for large areas under investigation.

Compared to visual data inspection, digital processing offers several advantages such as, the possibility to: (i) perform repetitive and cost effective data analyses for large areas of cultural interest, (ii) obtain consistent results based on "objective" instead of subjective evaluations, (iii) facilitate the integration of imagery with other data source (archaeological record, documentary sources, etc.), (iv) explore alternative data processing methods and, (v) if required, also to apply complex algorithms to make

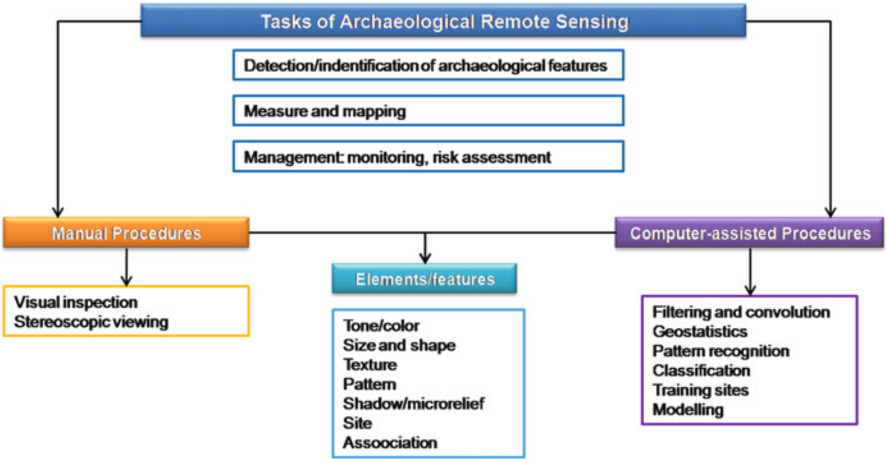

Fig. 1.3 Rational basis of archaeological remote sensing

archaeological information extraction and interpretation easier. Therefore, digital data processing and manipulation in archaeology can allow the development of effective tools for facilitating the detection of sites/features linked to past landscapes which are generally quite subtle and obscured by marks of the modern landscape. The use of digital filtering can easily enable us to leave out details of modern landscapes and enhance the subtle ones related to past human activities.

Obviously some disadvantages are present. Digital processing: may be: (i) expensive for one-time interpretation or small areas under investigation, (ii) have high start-up costs, (iii) and require elaborated and dedicated equipment systems.

1.3 Satellite Remote Sensing in Archaeology: From Early Applications to Recent Developments

Early applications of satellite for studies on past human activities were attempted starting from the 1980s using Landsat Thematic Mapper (TM), which was the highest (30 m) spatial resolution sensor available at that time for civilian applications. TM data were quite successfully used for landscape archaeological investigations, as in the case of the identification ancient field division and agricultural systems (Clark et al. 1998; Sever 1998), and also in palaeo-environmental studies (Parry 1992; Drake 1997; White and El Asmar 1999), carried out mainly based on photointerpretation.

The French Spot data (10 m) were generally not used in archaeology even if they offered higher resolution, but they were much more expensive than TM. Moreover, they still offered a spatial detail not enough to enlarge the field of application to smaller features of cultural interest.

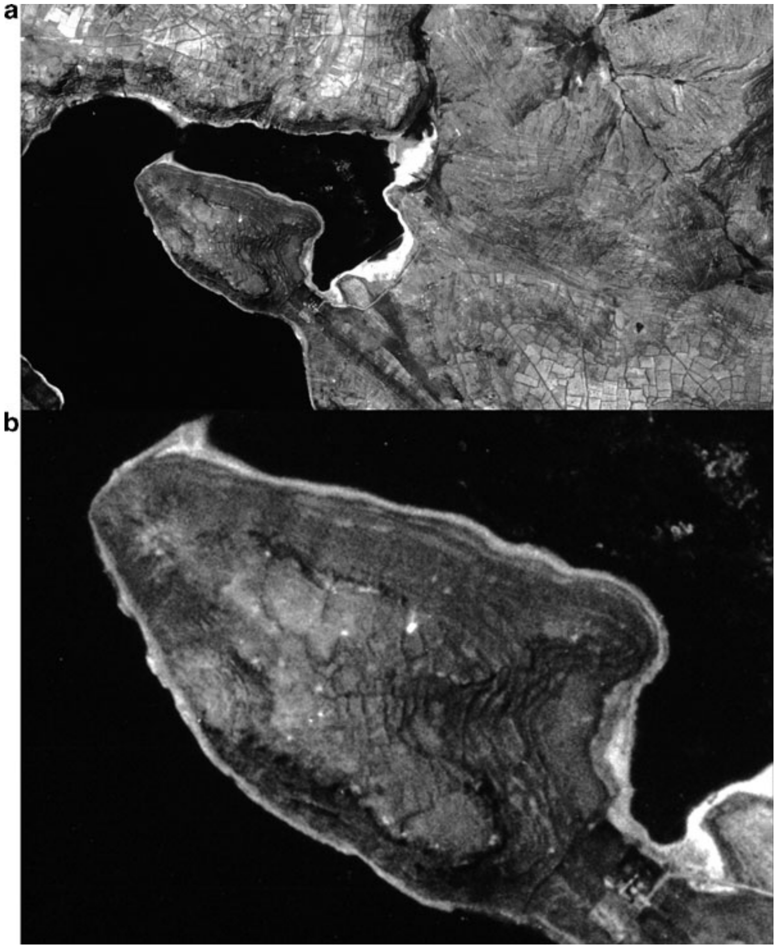

Fig. 1.4 Corona satellite image taken in 11 April 1966. (**a**) Shores of Lake Umayo near Puno in Peru; (**b**) detail of Sillustani, a burial site dating back to pre-Incas age

After the end of the Cold War, in the 1990s, Russian and American intelligence satellite photographs were made commercially available for civilian purposes. This strongly pushed archaeologists to use this extensive archive of photographs acquired in the 1960s and 1970s. For some regions of the Middle East and Southern America (see Fig. 1.4) there is a huge dataset available at a high spatial resolution (up to 2 m) which represents the unique data source useful to detect archaeological features later destroyed by mechanized agriculture and other anthropogenic activities.

Fowler (1996) exploited Russian declassified KVR-1000 imagery to identify crop and soil marks in the surrounding of Stonehenge. KVR-1000 pictures were also employed by Comfort (1997) for archaeological investigations in the Greek and Roman city of Zeugma on the Euphrates in Turkey. The study of ancient irrigated and cultivated areas was carried out in Yemen by Marcolongo and Morandi Bonacossi (1997) using Russian Soyuz Kate-200 images.

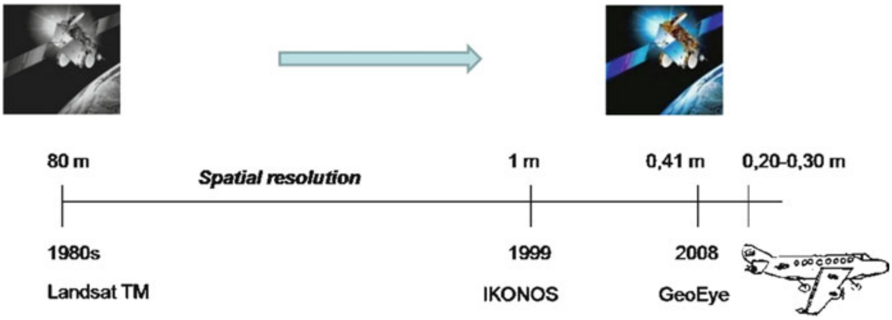

Fig. 1.5 The Great Run of satellite technology in reaching the spatial resolution of aerial images

The Russian declassified data were available for only 4 years. Therefore, the use of American declassified KH-4B Corona increased over time.

Kennedy (1998a, b) and Fowler (1997) conducted the first applications of Corona images for investigating the Euphrates valley (Turkey) and an Iron Age hill fort in Hampshire, respectively.

Even today Corona is the unique data source for archaeological prospection in countries where aerial photography is restricted for military reasons, as in the case of the Upper Khabur basin in North-eastern Syria, where Ur (2003) discovered an ancient road system dating to the Early Bronze Age.

More recently, CORONA has been integrated with ASTER multispectral satellite imagery by Altaweel (2005) to identify hollow ways, canals and sites in North Iraq. Other researchers exploited the information content of Corona photographs along with other multispectral satellite data such as IKONOS, used by Beck et al. (2007), for studying tell settlements and field systems in Western Syria.

Goossens et al. (2006) highlighted the problems linked to the geometric rectification of Corona images due to the fact that the latter were collected by a non-metric panoramic camera on board a satellite with a decaying orbit. To overcome these drawbacks, they developed a method to reduce geometric distortions, which was applied to the Altai Mountains.

The availability of the first commercial VHR satellite data (IKONOS in 1999), opened new research perspectives for archaeological applications. Later the spatial resolution has been strongly increased (see Fig. 1.5), up today with GeoEye1 which acquire 41 cm panchromatic and 1.65 m multispectral imagery (see Table 1.1).

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 the images are well distributed. A good distribution network also exists for SPOT, the Indian Satellites and EROS.

The advantages of VHR satellite imagery are not only linked to the availability of multispectral, georeferenced and very high resolution images but also to the possibility of using effective data processing for extracting valuable information from site level up to historical landscapes.

Table 1.1 List of optical VHR satellite data

Satellite data	Launch	Country	Pan	Ms
IKONOS 2	1999	USA	1 m	4 m
QuickBird	2001	USA	0.6 m	2.4 m
TES	2001	India	1 m	
OrbView 3	2003	USA	1 m	4 m
Cartosat 1	2005	India	1 m	2.5 m
Kompsat 2	2006	S. Korea	1 m	4 m
Resurs DK2	2006	Russia	1 m	2:3 m
EROS B	2006	Israel	0.7 m	
WorldView-2	2007	USA	0.5 m	2 m
Cartosat 2	2007	India	0.8 m	
RapidEye	2008	Germany	5 m	5 m
GeoEye-1[a]	2008	USA	0.41/0.5 m	1.65/2 m

[a] GeoEye1 collects images with a ground sample distance of 0.41-m or 16 inches in the panchromatic and multispectral imagery at 1.65-m resolution. Unfortunately, GeoEye's operating license from the U.S. Government requires re-sampling the imagery to 0.5-m

Nevertheless, such potential capability has not been adequately exploited due to the lack of data processing procedures developed ad hoc to address the archaeological needs. Early investigations clearly pointed out that the use of image enhancement such as pan-sharpening, edge detection, pattern recognition and classification can improve and facilitate the identification of archaeological features (e.g., Lasaponara and Masini 2007; Grøn et al. 2008).

Moreover, great effort must be devoted to set up automatic and/or semi automatic approaches for archaeology.

Presently, no effective automatic procedures are available for archaeological purposes for both VHR and medium/high resolution satellite images. Semiautomatic approaches work quite well, but their performance are "site specific". For example, pre-Hispanic pathways, in Aztec cities within and outside the Valley of Mexico have been identified by Principal Components Analysis (PCA), texture segmentation, linear pattern detection and spatial filtering applied to Landsat 7 data (Argote-Espino and Chavez 2005). Other examples include the discrimination of surface archaeological remains in Hisar (southwest Turkey) using supervised classifications (De Laet et al. 2007), the extraction of land patterns, useful for palaeo-geographic and palaeo-environmental investigations in Metaponto (Ionian coast of Southern Italy) using edge enhancement techniques (Masini and Lasaponara 2006), and the detection of change over time in Southern Peru by Lasaponara and Masini (2010) using spatial autocorrelation statistics for looting monitoring (see Chap. 8). Another approach, mainly based on e-cognition and mathematical morphology, has been applied to evaluate changes in archaeological excavated sites of Nisa (Turkmenistan) and Babylon (Iraq) (Jahjah and Ulivieri 2010). The latter was investigated with the aim to evaluate changes before and after the second gulf war.

VHR satellite images also offer a stereo view, and, therefore, the possibility to extract high resolution Digital Elevation Models (DEMs) useful for studying

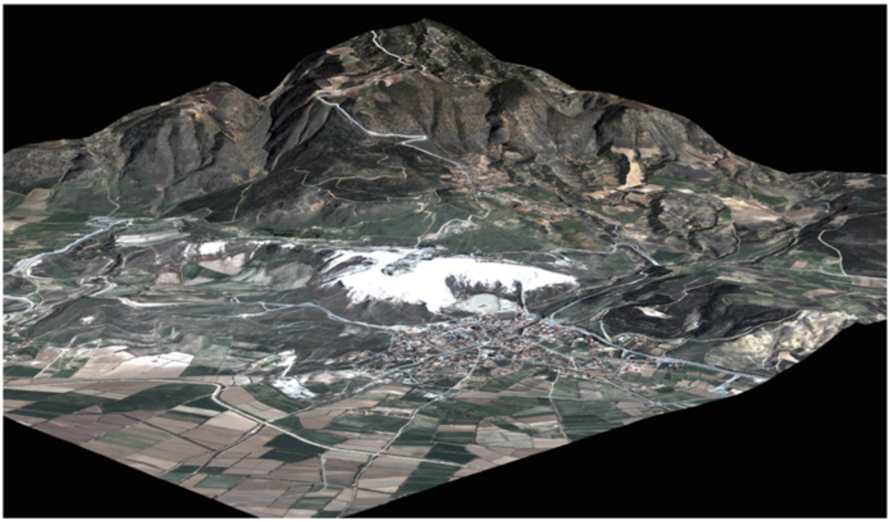

Fig. 1.6 Territory of Hierapolis (Turkey): 3d pan-sharpened QuickBird multispectral image (courtesy of Giuseppe Scardozzi)

ancient landscapes (see Fig. 1.6). DEM products can be also obtained from high to medium resolution satellite images (SPOT, ASTER). 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.

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. To obtain improved and inexpensive DEM from ASTER images, multi-temporal and multi- sensor satellite data can be used. By contrast it should be noted that the cost for acquisition of VHR stereo images is more than double and therefore, also the availability of stereo mode acquisition from the archive is much lower than the single mode acquisition.

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 geophysical prospection aimed to approach different fields of site investigations, from geosciences (geoarchaeology, geomorphology) to archaeology (field survey, excavations, etc.).

An integrated approach, based on GIS and remote sensing for geomorphology and DEM analysis, provides added value and precious contribution, from site discovery to historical landscape analyses. This was adopted by Alexakis et al. (2011), for locating settlements, modelling habitation and reconstructing landscape of the Neolithic age in Thessaly.

Finally, a multi-scale and multi-sensor data integration has been adopted by Ciminale et al. (2009) for a Neolithic settlement in Apulia region (Southern Italy). In particular, satellite data allowed the reconstruction of palaeo-environmental pattern, whereas aerial images and geomagnetic maps were used to identify the circular ditched enclosures of the Neolithic village, and other smaller features related to circular and semi-circular compounds.

1.4 Conclusion and Outlook

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 substantial 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 deals 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 investigations focused on 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, manage the present and support modelling for future forecasting.

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