THE PROGRESS IN SATELLITE IMAGING AND ITS APPLICATION TO ARCHAEOLOGICAL DOCUMENTATION DURING THE LAST DECADE

Wolfgang Boehler¹, Guido Heinz², Gong Qiming³, Yin Shenping⁴

¹i3mainz, Institute for Spatial Information and Surveying Techniques, FH Mainz, University of Applied Sciences, Holzstrasse 36, 55116 Mainz, Germany.
boehler@geoinform.fh-mainz.de

²Römisch-Germanisches Zentralmuseum, Ernst-Ludwig-Platz 2, 55116 Mainz, Germany
heinz@rgzm.de

³Shaanxi Archaeological Institute, 3 Leyou Lou, Xi’an, PR China

KEY WORDS: Documentation, Archaeology, Remote Sensing, Satellite Images, Cultural Landscapes.

ABSTRACT:

Satellite imaging systems with spatial resolutions of one meter and less for panchromatic, and 2.5 to 4 m for multispectral images have become available in the recent years. Their images can match the quality of small scale aerial photogrammetry. This is of special importance to archaeology and cultural heritage documentation since it is often difficult to acquire suitable aerial photographs. Within an archaeological documentation project (the Tang Emperors’ Mausoleums) in Shaanxi Province in the PR China, the authors used originally SPOT and LANDSAT images. During the last decade, satellite images of higher spatial resolutions (IRS-1C, KVR-1000, IKONOS) from the region concerned could be evaluated and used for the documentation project. Examining the appearance of typical topographical details, it could be ascertained that the new products show a high potential for documentation purposes. The combination of local surveys with a background from satellite images and digital elevation models leads to a powerful documentation and visualization tool showing locations of artifacts and their relation to topography and geography. The use of GIS technology offers improved data access and query tools for the documentation of extensive archaeological sites.

1. Introduction

When satellite images are used, landscapes can be documented quickly and easily. This is important to archaeology since the significance of archaeological sites, findings, and monuments can only be fully explained when their relation to the geographic environment is understood. Also, it is important to know their present relation to infrastructure and land use in order to plan their conservation and to organize the access for interested visitors.

In most cases, archaeologists must be lucky to have the resources to document an archaeological site itself and its immediate surroundings. Therefore, it is impossible to map the extended neighborhood in the field. Topographic maps can be used for this task; in many cases they are not sufficiently updated, however. Recent aerial photographs are very helpful if available in suitable scales. Unfortunately, many governments still classify aerial photographs and even maps because of military reasons. On the other hand, satellite images from sensors in the visible, infrared and microwave spectrums are readily available on the market.

In a joint project between the Shaanxi Archaeological Institute in Xi’an, PR China, Roemisch-Germanisches Zentralmuseum and the University of Applied Sciences, both in Mainz, Germany, the documentation of the mausoleums of the Tang dynasty was initiated more than ten years ago. Soon, the value of satellite images data was recognized for documentation and visualization purposes. During the following years, data in various improved spatial and radiometric resolutions from different sensors could be obtained and the potential for archaeological documentation could be investigated.
2. Surveying Methods for Archaeological Documentation

Archaeological research and documentation covers many different activities. In this paper we shall concentrate on metric surveys and their representation in graphical form. This task cannot be standardized since a large variety of objects and object sizes is encountered.

In figure 1, possible techniques for surveying are arranged according to the scale of the final document which in turn is a function of object size and achievable representation of details. If the object is small and not very complex, simple hand measurements or tactile methods (where the position of a probe touching the object is recorded) are sufficient. If points are further apart, tacheometers or GPS methods will be more suitable. Whereas these methods record point after point, scanning techniques, photogrammetry (close range or aerial) and remote sensing can record surfaces with even millions of points in a very short time. Often, a major reason for neglecting these modern methods is the fact that specially trained personnel and costly technical equipment are needed. Nevertheless, the renunciation of modern surveying possibilities may result in an unnecessary high expenditure of time and money.

Simple measurement methods will most likely not be sufficient if the objects have rather complicated shapes, if time is an important factor on site and/or if the objects are very large. In these cases, surveying specialists should join the archaeological teams and put their knowledge into practice. The Tang project has shown that a combined approach yields good results for moderate cost and within a reasonable amount of time.

![Figure 1: Surveying methods for archaeological documentation](image)

As can be seen in figure 1, remote sensing techniques are suitable for large areas, i.e. topography and landscapes. Thus, before the technical aspects of remote sensing are discussed, it seems appropriate to consider the role of landscapes in archaeology and cultural heritage.

3. The Role of Landscapes in Cultural Heritage

3.1 Natural Features, Formations and Sites

UNESCO (1972) uses the term 'Natural Heritage' for physical, biological, geological and physiographical features, formations and sites of outstanding value from an aesthetic or scientific point of view. From a conservationist's point of view, it would be desirable to keep human interference completely away from these areas. Since, on the other hand, many visitors are attracted, management guidelines have to be prepared and enforced and a monitoring process is needed to detect and prevent unwanted changes.
3.2 Cultural Heritage Objects and Landscape

Meanwhile, hundreds of objects of 'Cultural Heritage' are designated by UNESCO as World Heritage sites. This is just a choice selection of a heritage comprising innumerable single monuments, groups of buildings or historical and archaeological sites of outstanding value for historical, artistic or scientific reasons. Although cultural objects are man-made, UNESCO in its Convention mentions landscape in this context, too ("buildings because of their ... place in the landscape", "combined works of nature and man").

In fact, no cultural heritage object can be understood without taking the surrounding landscape into account. Human dwellings have to use geographical sites where an optimal protection from natural forces (weather, flooding) and enemy attacks is possible, and the supply of essentials (food, water, kindling) is assured as well. Special topographic features are chosen in all religions as places of worship or as sites for the location of divine buildings. Geomancy (feng shui) in the Chinese culture is a very special example. Sovereigns chose special places to erect their palaces and mausoleums. Cities developed along trade roads or close to bridges and fords. And even when a small arrow tip is found somewhere in the fields, it should be studied why it was lost here and not somewhere else in the landscape.

The location of all those objects in a landscape was a result of practical or metaphysical considerations and rules. Thus, it is not sufficient to examine and document the object itself. Far more often than presently done, the landscape surrounding a cultural heritage object should be considered, studied and documented, too. If the present topography is surveyed, mapped and visualized, historic evidence may be used to reconstruct landscape development from ancient to present times. At the same time, conservational hazards originating from the present topography (erosion, slides, flooding) or land use (agriculture, industry, traffic) can be foreseen and possibly prevented.

3.3 Cultural Landscapes

There are cases where natural and cultural criteria of a landscape cannot be separated. There are landscapes intentionally designed and created by man such as garden and parkland landscapes. Often, but not always, buildings and ensembles are part of those landscapes.

Organically evolved landscapes originate from an initial imperative (social, economic, administrative, religious) and have developed their present form in an evolutionary process in close interdependence with the natural environment. This evolutionary process may have come to an end in the past ('relict' or 'fossil landscape') or it is still continuing ('continuing landscape').

Associative cultural Landscapes may show no man-made evidence at all (thus, from a materialistic point of view just being natural landscapes), but powerful religious, artistic or cultural associations of the natural element attach special importance to those landscapes.

3.4 Monitoring Landscape Changes

Especially in the case of 'continuing landscapes', where a large number of authorities and private owners may have to coordinate their actions and where political decisions have to be prepared and mediated, planning and modeling future developments is of utmost importance. Changes within the landscape or in its neighborhood may impair or even destroy its cultural value. This is why UNESCO demands 'reactive monitoring' and periodic reporting to ensure that World Heritage Sites remain undestroyed and can be kept on the World Heritage List. With time-enabled GIS systems, the development in the past can be shown as well as planning alternatives for the future.

3.5 Virtual Representations of Landscapes

A landscape can only be experienced in all aspects when visited at its original location. Obviously, no virtual landscape can match reality. It should be noted, however, that not everybody is physically or financially able to visit any landscape of interest. Many landscapes can only be reached after a strenuous journey. Other places are located within areas of war or turmoil and - unfortunately - one has to be prepared that this may happen to places that have been safe so far, too. In these cases, a virtual trip through a digitally created landscape can be the only way to explore an area.

A person, moving on the surface of a landscape, can overlook only a very limited part of this landscape. Many impressive landscapes can only be observed in total from locations far above the ground. Even when such viewpoints can be reached by airborne vehicles, the vision will be limited by the vehicle's structures as well as atmospheric effects. Virtual landscapes do not impose any limits on the observer in this respect because any observation point can be reached to have a look at the scene and virtual trips through and around the place at a
course of one's own choice can be undertaken. These are reasons why a virtual representation is of much more importance for the documentation of landscapes as compared to virtual images of other objects of cultural heritage.

4. Available Satellite Imagery

4.1 The Situation around 1994

Ten years ago, only few satellites for earth observation were in operation for users outside the military authorities (tables 1 and 2). LANDSAT in the US had started its service in 1972 and supplied multispectral 30 m pixel data in the visible and infrared bands with its Thematic Mapper sensor since 1982. The highest resolution on the market, 10 m pixels, came from the panchromatic sensor aboard the French SPOT satellites, available since 1986. SPOT also supplied 20 m pixels in the green, red and near infrared bands. Japan operated its JERS-1 with similar characteristics since 1992. 30 m pixels resulting from imaging in the microwave C band could be obtained from the European ERS-1 satellite since 1991.

<table>
<thead>
<tr>
<th>Satellite, Sensor</th>
<th>Available since</th>
<th>Operating since</th>
<th>Pixel size (m)</th>
<th>Stereo</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOT 1/2/3, HRV</td>
<td>1986</td>
<td>1986</td>
<td>10</td>
<td>Across-track</td>
</tr>
<tr>
<td>ERS-1, AMI</td>
<td>1991</td>
<td>1991</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>JERS-1, SAR</td>
<td>1992</td>
<td>1992</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Satellite imagery (single band, pixel size < 30 m) available before 1994. Shaded lines indicate data used in the Tang mausoleum documentation (see section 6).

4.2 Progress during the Last Decade

For nearly ten years the SPOT PAN images with 10 m pixels had been the best source for images showing the surface of the earth from space. In 1995 India’s IRS-1C satellite appeared with pixels of 5.8 m, offering more than three pixels for an area covered by one SPOT pixel. The improvement was considerable (figs. 2, 6, 7). The real breakthrough came in 1999 when IKONOS succeeded to supply 1 m pixels from space which was followed by other commercial systems such as Quickbird (0.61 m in 2001) and OrbView (1 m in 2003). This pushed the limits towards resolutions formerly only known from aerial photogrammetry. At the same time, these systems supplied multispectral data with pixels between 2.5 and 4 m. SPOT and LANDSAT improved their performances, too, every time a new satellite in the programs was started. Also in the 1990s, both the US (USGS 2004) and Russia declassified older reconnaissance data, giving access to high quality information as far back as 1960 or 1970. Tables 3 and 4 as well as figures 6 and 7 show the dramatic improvements during the last 10 years. Further information about the different systems can be found in the internet; the VTT Technical Research Centre of Finland, for example, provides an excellent website about satellite remote sensing, including links to all important systems (VTT 2004).
THE PROGRESS IN SATELLITE IMAGING AND ITS APPLICATION TO ARCHAEOLOGICAL DOCUMENTATION DURING THE LAST DECADE

Figure 2: Airport in different images available around 1995.

Table 3: New satellite imagery (single band, pixel size < 30 m,) which became available between 1995 and 2003 (* declassified military systems).

<table>
<thead>
<tr>
<th>Satellite, Sensor</th>
<th>Available since</th>
<th>Operating since</th>
<th>Pixel size (m)</th>
<th>Stereo</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADARSAT 1, SAR</td>
<td>1995</td>
<td>1995</td>
<td>8-100</td>
<td></td>
</tr>
<tr>
<td>IRS 1C/1D/P6, PAN</td>
<td>1995</td>
<td>1995</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>IRS-2, AMI</td>
<td>1995</td>
<td>1995</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>CORONA KH-1/2/3/4, film</td>
<td>1995</td>
<td>1959 *</td>
<td>10</td>
<td>In-track (KH-4)</td>
</tr>
<tr>
<td>LANYARD, KH-6, film</td>
<td>1995</td>
<td>1963 *</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>KVR1000/KFA3000, film</td>
<td>1990s</td>
<td>1970s*</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>ADEOS, AVNIR</td>
<td>1996</td>
<td>1996</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>SPOT 4, HRVIR</td>
<td>1998</td>
<td>1998</td>
<td>10</td>
<td>Across-track</td>
</tr>
<tr>
<td>LANDSAT 7, ETM</td>
<td>1999</td>
<td>1999</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>SPACE IMAGING, IKONOS 1</td>
<td>1999</td>
<td>1999</td>
<td>1</td>
<td>In-track</td>
</tr>
<tr>
<td>EROS A, EROS A1</td>
<td>2000</td>
<td>2000</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>DIGITALGLOBE, QuickBird 2</td>
<td>2001</td>
<td>2001</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>SPOT 5, HRG</td>
<td>2002</td>
<td>2002</td>
<td>2.5/5</td>
<td>Across-track</td>
</tr>
<tr>
<td>ENVISAT, ASAR</td>
<td>2002</td>
<td>2002</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>ORBIMAGE, OrbView-3</td>
<td>2003</td>
<td>2003</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Shaded lines indicate data used in the Tang mausoleum documentation (see section 6).
**Table 4:** New satellite imagery (multi-band, pixel size > 30 m) which became available between 1995 and 2003 (* declassified military systems).

Shaded lines indicate data used in the Tang mausoleum documentation (see section 6).

### 5. Technical Aspects in Satellite Image Processing

#### 5.1 Image Enhancement

Often, the images contain the relevant information, but it is not clearly visible. Image enhancement procedures, available with digital image processing software, can emphasize certain gray values or colors, whereas less relevant information is toned down. If color images are produced, usually adjustments have to be made to achieve an agreeable result.

#### 5.2 Interpretation, Segmentation and Classification

As compared to maps, images have the advantage that every observer can undertake an own and unbiased interpretation. If the requested topographic or archaeological features possess known spatial or spectral patterns, they can be detected in the images using pattern recognition, segmentation or classification algorithms. Since archaeological features vary widely in their appearance, these methods will usually not lead to definite results which can completely replace visual inspection; they can be very helpful, however, to find possible candidates for closer inspection in large data sets.

#### 5.3 Rectification and Geocoding

Unrectified vertical satellite images usually show smaller displacements as compared to images taken from airplanes. Therefore they can be used for simple visualization tasks without further rectification (see e.g. section 6.4 and fig. 3). If more geometrical accuracy and/or georeferencing is needed, a common reference coordinate system, preferably the state coordinate system, should be used for all surveying and mapping activities. This allows the relocation of any site and a correct union with former and future documentation. A common system is also required when different data sources, such as maps, remote sensing, photogrammetry and local field surveys have to be combined. GPS receivers can be used to supply coordinates for control points. When brought together within a common reference system, data can be visualized and analyzed in various combinations for use in research, publications, and museum presentations.

Different geometric transformation models can be used for the rectification and geocoding process which also includes resampling of the image data. For utmost accuracy, especially in mountainous areas, an orthoimage should be generated. This requires a digital elevation model, however (see following section).

#### 5.4 Use of Digital Elevation Models (DEM)

Digital elevation models can be derived by several different methods. For detailed DEMs, tacheometric surveys, accurate GPS, or stereophotogrammetric measurements from aerial photographs should be used. Larger areas can be surveyed using aerial photographs of smaller scale. Some earth observation satellite sensors supply images suitable for stereoscopic measurements by taking images from two different locations (see tables 1 to 4), looking forward...
and backward towards the same ground location within one orbit (in-track stereo) or by taking images from neighboring orbits (across-track stereo). These images from digital sensors or scanned photographs allow automatic DEM generation by matching techniques, thus supplying a very powerful and economic method to create DEMs for large areas. The results of the SRTM (radar interferometry) mission in 2000, where a DEM of large areas of the world with a grid of 30 m was recorded, may also be very interesting for this purpose (NASA 2004).

To supply information about the features covering the topographic surface, the satellite image can be draped over the DEM. When this is presented in vertical parallel projection, a map type 2D representation of the landscape is achieved (orthoimage). Automatic shading may help to experience the third dimension. Perspectives can give an even better impression of the landscape and its topography (figs. 4 and 5). Animations with smoothly changing relative positions of camera and landscape result in an improved three-dimensional perception and allow a good interpretation.

5.5 Multispectral Data / Image Merging

Color images are very useful for the natural appearance of a virtual landscape as they are more attractive and contain more information as compared to grayscale images. They can be produced if a red, green, and blue band (RGB) is supplied by the sensor (see tables 1 to 4). Often, color images have less spatial resolution than grayscale images. If the ration of the pixel sizes is somewhere between about 1:2 and 1:5, e.g. SPOT PAN and LANDSAT TM (1:3) or IKONOS PAN and IKONOS multispectral (1:4), very attractive images can be achieved when image merging techniques are applied. The resulting product contains the high spatial resolution of the grayscale image and the color (or multispectral) information of the multi-band image. Several different techniques are supplied by image processing software. The best results can be found by trial and error, since they depend on the specific image data. In most cases, a color adjustment (enhancement) is necessary following the merging process.

5.6 Combination of Image Data with Ground Surveys

With the aid of image processing software, different types of data can be combined to show relations between information from different sources, e.g. archaeological objects, topography, and present land use. Point, line, and area information from maps or local surveys can be visualized as vector symbols and combined with orthoimages or perspective views from satellite images. When layer techniques are used in a hybrid GIS (accepting raster and vector data), all kinds of combinations can be visualized and analyzed.

Accuracy of data can become a critical issue when different data sources are combined. As mentioned above, all data have to be georeferenced in the same coordinate system. If high resolution images are used, the information intended for combination has to be of corresponding accuracy. In the case of one meter pixels, existing DEMs, or survey data obtained using simple GPS receivers will often result in clearly visible irritating deviations.


6.1 The Project

The emperors of the Chinese Tang dynasty (A.D. 618-907) went to great expenses for the construction of their mausoleums (Asim 1993, Gong and Koch 2002). The actual funeral chamber was excavated at the end of a tunnel inside a mound or a mountain slope. It was surrounded by a large wall with towers and four gates. More than life-sized stone sculptures representing human figures and animals were erected outside the gate areas. As a rule, the procession way leading to the south gate consists of about thirty of those sculptures. Every mausoleum was equipped with several buildings.

The mausoleum wall can easily have a total circumference of 10 km. Including the stone sculptures located outside the wall region, the immediate area of one Tang mausoleum may comprise 15 km². Furthermore, attendant tombs of nobles, court officials, and generals are spread over the country in the vicinity of the mausoleums. The total number of Tang emperors’ mausoleums located in Shaanxi Province is 18. Together with many hundreds of attendant tombs they are scattered over an area of about 5.000 km² in the vicinity of Xi’an, the capital of the Province.

The ancient walls and temples, having been constructed of tamped loess, have vanished. Their location can be ascertained, however, since many of the baked roofing tiles can still be found. The ruins of the towers and gates are recognizable as mounds rising about 5 meters above the surrounding area. They have a very similar appearance as the numerous tumuli of the attendant tombs, which can reach elevations of 20 m in some cases. Many of the stone sculptures are still in situ and in good condition, others are fallen over, or broken to pieces. The funeral chambers were not yet opened in the surveys.
Since only very few mausoleums had been documented in the past, a project was initiated in 1993 with the aim of documenting all mausoleums as they appear presently. This is carried out in a joint venture between archaeologists of the Shaanxi Archaeological Institute (Xi’an, P.R. China) and Römisch-Germanisches Zentralmuseum (Mainz, Germany). The Institute for Spatial Information and Surveying Techniques (i3mainz) from FH Mainz, University of Applied Sciences, also in Mainz, joined the project being responsible for all geometric und topographic aspects of the documentation. An average of about forty plans and maps is necessary for the documentation of just one single mausoleum. Up to date, extensive surveys for the Qiaoling, Jingling, Guangling and Tailing mausoleums have been completed. The documentation results for Qiaoling Mausoleum have already been published in a copiously illustrated volume in Chinese and German (Gong and Koch 2002). Field work at the Zhaoling mausoleum has just commenced in summer 2004.

6.2 Surveying Methods Applied in the Project

Objects of various sizes had to be georeferenced and documented in the project within an area of about 5,000 km². A common equirectangular map projection with true scale along the center parallel was designed as common coordinate system for all surveys.

The large mausoleum areas can be considered as cultural landscapes which are influenced by contemporary land use, mainly agriculture. Since aerial photographs could not be made available, satellite images played an important role from the beginning of the project (see below, section 6.3). GPS measurements were used for georeferencing objects, mainly attendant tombs and isolated findings that were too far away from the actual mausoleum areas. GPS was also used for the determination of control points and training areas for the image processing procedures. All mapping inside the mausoleum areas was accomplished with the aid of an electronic total station. Plans were produced with a common CAD system. The basic set of maps for the documentation of one mausoleum consists of an overview map in a scale of 1:5,000, and numerous maps of scales between 1:1,000 and 1:100 for procession ways, gates and mounds. All maps have dense contour lines to visualize terrain irregularities that may be present. Locations of drill holes are mapped in the larger scales. All findings of significance are mapped; a special numbering system makes sure they can be connected to the photographic and text documents created by the archaeologists. The surveying methods have been described in earlier publications (e.g. Boehler and Heinz 1996). The results can be seen in the published Qiaoling documentation which also includes a large number of images produced from satellite remote sensing data (Gong and Koch 2002).

6.3 Remote Sensing Data Used in the Project

The first images acquired for the documentation project were from SPOT PAN and LANDSAT TM (Boehler et. al. 1997). As images with much better resolution became available within the ongoing project, further images were purchased (Boehler et. al. 1999, 2001). Presently, data from the following sensors is available for the area (for sensor details see tables 1 to 4):

- LANDSAT TM
- ERS microwave radar
- SPOT PAN
- SPOT PAN stereo
- SPOT XS
- IRS-1C PAN
- IRS-1C LISS III
- KVR-1000
- IKONOS PAN
- IKONOS multispectral

The quality of these images varies considerably. The radiometric resolution of the images in the visible and infrared spectrum is mostly 8 bit. The long established systems, like SPOT and LANDSAT, have a good radiometric quality. The ERS RADAR image was of no special value because of the low spatial resolution and the poor image contrast resulting from the almost complete coverage of the region’s surface with loess. The radiometric quality of the
evaluated panchromatic IRS-1C images was comparably poor which might be a result of the data acquisition with 6 bit only. The IKONOS data is recorded with a higher dynamic range at 11 bit and can be ordered as reduced 8 bit or as 16 bit data. The quality of the KVR-1000 image is not the same in all image regions. The edges show stripes of changing brightness, probably resulting from photographic copying processes prior to digital scanning.

The examples in the following sections show the dramatic improvement and the new possibilities in archaeological documentation arising from the better spatial resolution. Table 5 gives a general overview.

<table>
<thead>
<tr>
<th>Task in documentation</th>
<th>Former systems with 30 m ... 6 m pixel size</th>
<th>New sensors with 4 m ... 1 m pixel size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning and orientation</td>
<td>Well suited for overviews and planning</td>
<td>Not really necessary for planning tasks</td>
</tr>
<tr>
<td>(see section 6.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mapping topography around a site</td>
<td>Highly dependent on map scales:</td>
<td></td>
</tr>
<tr>
<td>(see section 6.5)</td>
<td>for scales up to 1 : 20.000</td>
<td>for scales up to 1 : 5.000</td>
</tr>
<tr>
<td>Mapping a site itself</td>
<td>for scales up to 1 : 10.000</td>
<td>for scales up to 1 : 2.000</td>
</tr>
<tr>
<td>(see sections 6.6 and 6.7)</td>
<td>visibility of objects down to 15 m</td>
<td>visibility of objects down to 5 m</td>
</tr>
</tbody>
</table>

Table 5: Comparison of images with different resolutions applied to different documentation tasks.

6.4 Planning and Orientation in the Field

Raw digital or film images, as supplied by the distributors, can already be very helpful as a source of information about the project site and the surrounding area. The location of findings in relation to modern infrastructure like cities and roads can roughly be measured and used to plan further field work (fig. 3).

Fig. 3: Raw data (SPOT PAN 1B, as supplied by the distributor) was used to generate this simple map.
Using image plots together with their approximate georeference as supplied by the distributor in combination with a simple handheld GPS receiver is very useful for orientation in the field and the determination of point positions in remote areas where maps are poor or not available. For this purpose, high accuracy is not essential, thus the uncertainty in the geographic position of the image and in the GPS positioning is acceptable in most cases. The combination of GIS, GPS and image data on a laptop computer can be used for on-the-fly field mapping and project planning.

6.5 Mapping Topography around the Site

Although any archaeological fact can only be explained and understood if the surrounding geographical facts are taken into account, the mapping of topography around the site is often neglected in documentation. An important reason for this is the comparatively large amount of work necessary, especially in remote areas where topographic data is not available or classified. The use of remote sensing data can be a good compromise between expenditure and benefit, especially when other data is not available.

![Perspective view of Qiaoling, Jingling and Guangling mausoleums (from left to right). Combination of the RGB bands of a LANDSAT TM scene with a DEM. The symbol overlay shows locations of objects (mounds, walls, etc.) surveyed locally with a total station.](image.png)

In the Tang project, the use of standard data like SPOT and LANDSAT was sufficient for mapping and visualization tasks of the general area. As compared to standard mapping procedures, a lot of time and work in the field could be saved. Digital elevation models derived from different sources allowed the production of impressive perspective views (fig. 4), and animations could be produced.

6.6 Mapping the Site

The advent of high resolution images made it possible to produce very detailed and meaningful documentations of landscapes. As this resolution may not be necessary for landscapes surrounding an archaeological site, it possesses a high potential for mapping the site itself. Where local topographic surveys were necessary in the past, satellite images can replace this procedure in the future. Fig. 5 gives an indication of the results that can be achieved.
If all information is available in digital form, any combination of data can be visualized in any views and scales necessary for the user. Vector maps and orthophotos can be shown separately or as a combined product (fig. 5).

6.7 Visibility of Archaeological Structures and Findings in Image Data

Sometimes remote sensing is recommended for archaeology with the promise of detecting archaeological structures in the images. This is only true for larger objects with spectral characteristics that differ clearly from the surrounding features, however. Remote sensing cannot replace archaeological field work and the associated ground surveys. The relevant objects may be too small, covered by soil or vegetation. Therefore, they have to be examined locally and their ground location has to be recorded using GPS or tacheometers. To show their location, 2D- or 3D-symbols can be generated (as in figs. 4 and 5) and stored in separate overlays. If included in a multimedia or GIS application, these symbols can be switched on and off depending on thematic attributes or historical periods, and linked with further text or graphical information.
Figure 6 shows Huiling mausoleum with a mound of about 30 m in diameter and 15 m in height in different images. It is visible only in the high resolution data due to topography and the effects of light and shadow. The visibility of the mound in the IKONOS images is here much better than in the KVR-1000 image. Only the combination of good radiometric and geometric qualities results in good image properties and allows the detection of archaeological objects.

The western gate area of Qiaoling mausoleum featuring two tower mounds of about 10 m in diameter and 4 m in height is shown in figure 7. The tower mounds can be seen in the high resolution images and detected e.g. in the IRS-1C PAN image, but only if the location is already known. Image processing routines for the localization of these structures proved promising with high resolution data. Smaller objects, like stone sculptures with a base area of about 1 m x 2 m can only be found in the high resolution images by chance when their positions are known in advance or several objects are arranged in a regular pattern.
7. The Use of GIS

In the Tang project, a desktop GIS (ArcView) was used to examine the potential of such a system (Heinz 1997). In the documentation of such extended sites enormous amounts of data and a variety of different data types have to be managed. This can sensibly be done using database and information systems. As the geographical and topographical locations of all findings are an important attribute and topographic dependencies are of importance for the relation among the findings, the use of GIS tools can improve data storage and retrieval. GISs allow the storage and combination of different data types like vector drawings, tabular data, image data, text information, maps, elevation models, photos, etc.

8. Conclusions

Satellite image data is suitable for the documentation of extensive sites. Images with a standard resolution of about 10 m can be used for visualizations in map scales up to about 1:20,000. High resolution data (1 m) is suitable for scales up to 1:5,000 and even larger. These images match the quality of small scale aerial photogrammetry.

Using image data or other remote sensing data like radar interferometry for the generation of elevation models can reduce time for recording topography considerably and thus facilitate the inclusion of the surrounding landscape into a documentation.

If multispectral data (usually with poorer spatial resolution) is available, it is of high value for visualizations and animations in natural color as well as for classification purposes.

The combination of image information and locally recorded single findings in maps helps to understand the topography of the site and its importance for the historic processes. It provides a valuable tool for the management of the site and the assessment of the impact of present land use. The amount of time necessary for the documentation in the field can be reduced considerably. The visibility of archaeological findings is obviously limited to objects larger than pixel size. Ruins of buildings or long walls can be found in high resolution data whereas single sculptures can hardly be detected.
9. Outlook

In the future the use of satellite image data and remote sensing will have its place in archaeological documentation. The following points may gain even higher importance for future projects:

- The combination of image data of different spatial resolution for smaller objects, extended sites and surrounding areas.
- The combination of various spatial data for documentation purposes, such as image data, elevation data, tacheometric and GPS surveys, existing maps, geophysical data and attribute data from different sources.
- Geographical information systems (GIS) will become a major tool for archaeologists to handle the large amounts of collected data of various types.
- Due to the variety of different sensors and techniques used as data sources for documentation projects, the interdisciplinary cooperation of specialists from different sciences will become more necessary and accepted.

10. Bibliography


