Detection of Looting Activities at Archaeological Sites in Iraq using Ikonos Imagery[1]

Margarete VAN ESS[2], Helmut BECKER[2], Jörg FASSBINDER[2], Ralf KIEFL[3], Iris LINGENFELDER[4], Gunter SCHREIER[3], Adrian ZEVENBERGEN[5]

Abstract

Uruk-Warka, situated c. 300 km south of Baghdad, is one of the oldest metropolises of the ancient world. It was inhabited from around 4000 BC to c. 400 AD and is known as the city where writing was invented, where the oldest known epic, the Epic of Gilgamesh, plays, and where early state formation and administration were developed.

Excavations by German missions, today based at the German Archaeological Institute, started in 1912. They are still on-going, but with interruptions since 2003. Up to date only 5% of the city could be uncovered. Today the city is endangered by illegal digging and destruction by looting, as are many other sites in southern Iraq. As long as the security situation in Iraq remains difficult, it is not possible to study archaeological sites in southern Iraq on the ground.

Therefore, the German Foreign Office funded a project to check the feasibility of using high resolution satellite IKONOS imagery to detect illegal digging. In addition, methodologies to support archaeologists in detecting so far unknown sites and to better map the extent of known excavations were tested. Older aerial photographs, a geographical information system (GIS) of so far unexcavated Uruk-Warka, elevation models and magnetic measurements have been used to help in estimating the state of preservation of archaeological sites and, in cases of unexcavated, destroyed sites, should deliver information about the kind of archaeological structures once present. Object oriented knowledge based software was used to fuse all available information and to assist the archaeologists in extracting the relevant information.

The pre-war – post-war comparison of IKONOS images indeed revealed looting activities at one site in the northern outskirts of Uruk. The characteristic of this known looting was used to train the semi-automated image analysis software for use in locating so far undetected looting activities.

Though limited by the amount of data and the time available for its evaluation, the study revealed that high resolution space imagery will be of great help in surveying cultural heritage sites and protecting them against damage.

[1] Published in: Angewandte Geoinformatik; Beiträge zum 18. AGIT-Symposium, Salzburg, Wiechmann-Verlag, Heidelberg, 2006 p 668-678

[2] 1. German Archaeological Institute, DAI, Berlin; 2. Bavarian State Dept. of Monuments and Sites, BLfD, Munich; 3. German Aerospace Center, DLR-DFD, Oberpfaffenhofen; 4. Definiens AG, Munich; 5. European Space Imaging, EUSI, Munich

1 Historical background and objectives of the project

The metropolis of Uruk, today named Warka and known as the biblical Erech, most probably evolved from two settlements situated on both sides of the Euphrates and which can first be attested around 4000 BC. The city rapidly grew into an integrated urban area, around 3000 BC covering its ultimately greatest expansion of 5.5 km^2. Therewith, the enclosed city of Uruk was the largest known in the ancient world, and retained that renown until the 6^{th} century BC, when the city of Babylon occupied an even larger area.

A huge sacred precinct formed the city's centre surrounded by several living quarters and gardens interconnected by canals and accessible through streets. Obviously the city played a major political role during the 4^{th} millennium BC, controlling at the end of the millennium not only its neighbouring cities and villages but showing growing influence in regions as far as northern Syria, southern Turkey and western Iran. Uruk gained its power through the specifics of southern Iraq: the extraordinary flat, sedimentary land and its extremely hot climate. Life was only possible along the rivers or with access to irrigated land. The creation of an organized water management system was therefore indispensable, and it obviously was up to the city of Uruk to develop and control it. The more complex the management of the water and, depending on this, of agriculture became, the more grew the necessity of a functioning and extensive administration. People began to specialize and some of them gained power by directing others. The society of Uruk and its neighbourhood became hierarchical to an extent unknown elsewhere. It is the major „input" of Uruk to humanity to have introduced this political structure, including at the end of this process the development of writing, which originally was used exclusively for administrative purposes.

Uruk was settled for nearly 5,000 years. It became a well-structured city with two major sanctuaries – a main sanctuary for Anu, god of heaven, and a main sanctuary for Ischtar or Inanna, goddess of love and war. From the middle of the 3rd millennium BC onwards it never again played an important political role. But the city was well-kept and famous for its knowledgeable and scientifically active priesthood. For approximately 3,000 years, the importance of early Uruk remained in the memory of all Mesopotamia. The deeds and inventions of the kings of Uruk were narrated in epics, the most prominent of which is known to us as the oldest epic of the world – the Gilgamesh epic. Through these early narratives we not only learn about some events and culture of the rulers of Uruk, but can even extract some information about the layout of the city – and today confirm it through modern survey techniques.

The systematic observation and georeferencing of all archaeological remains visible on the ground with or without excavation, the drawing up of exact, digital topographical maps and the examination of larger parts of the city by geophysical methods allowed us to develop arguments on the formation of the city, its historical changes and its internal chronologies. In addition, the analysis of historical aerial photography by modern photogrammetric methods and the growing resolution of space imagery in the meantime add a so far unknown dimension of scientific analysis.

The observation of archaeological sites using aerial photography occurred as early as aircraft have been available to fly analogue cameras. Hence aerial images for Iraq are available from German air surveys from 1917 and for Uruk Royal Air Force surveys from 1935. Precise geometric measurements in the data and connecting these with real points on the ground resulted in the engineering science of photogrammetry, i.e., making of precise maps from aerial observation.

Moving the observation point far beyond the altitude of aircraft, observation from space satellites was initially established in the mid-1960s for military purposes and in the mid-1970s for general environmental science. Whilst some research has been performed to analyse archaeological sites (SCOLAR, 1990, SIR-C, 2006), only the release of formerly classified very high resolution (e.g., better than 1 m) data obtained from spacecraft launched in the late 1990s made it possible to use satellite images for precise archaeological mapping. Systems such as the private U.S. satellites IKONOS, Quickbird and OrbView-3 yield submetric resolution for areas either not accessible for ground surveys or where even aerial surveys are not allowed. The Iraq conflict made the country and hence the archaeological site of Uruk such an inaccessible place for scientists. Moreover, reports of illegal trade in archaeological artefacts of ancient Iraqi heritage, and therewith the looting of archaeological sites in Iraq, raised serious concern that this unique site for the heritage of mankind would be damaged and its historic context lost forever. Of course directly concerned with Uruk-Warka is the German Archaeological Institute (DAI), which has worked at this site since 1953. Therefore, in 2004, a German project team under the lead of DAI gathered the expertise of archaeologists, geophysicists and space engineers to address these urgent problems related to the state of archaeological activities in Iraq. The project was funded by the German Federal Foreign Office and worked also in cooperation with UNESCO and the Iraq State Board of Antiquities and Heritage. The project was targeted to demonstrate whether:

- very high resolution optical space imagery – such as from IKONOS – when fused with traditional maps and geophysical ground surveys, can support the mapping and even detection of archaeological features,
- space images taken before and after the military conflict can be used to detect looting activities and, specifically, whether there are looting activities in Uruk,
- semi-automated image analysis software, such as the object oriented approach in *eCognition*, can support this process and even find new structures in space imagery.

2 Data and geoinformation used for the project

Due to the long tradition of fieldwork and the experience of the German Archaeological Institute at the archaeological site of Uruk-Warka a comparatively wide range of field data is available. During several field campaigns from 1982 – 1984 and 2001 – 2002 geodetic and geophysical surveys were carried out. Hence detailed reference data sets are available, including 27 permanent geodetic points, contour lines with an equidistance of 0.5 m, grids of a magnetic survey (BECKER, 1995) as well as the course and the locations of the fence poles around the archaeological site (see left side of figure 1). BIRK (1984) specified the relative accuracy of the reference points as better than 3 cm. In addition, auxiliary data such as archaeological maps with locations of excavated buildings, reconstructed walls and topographic features were provided. However, the maps were derived from archaeological field sketches and their accuracy could not be further specified.

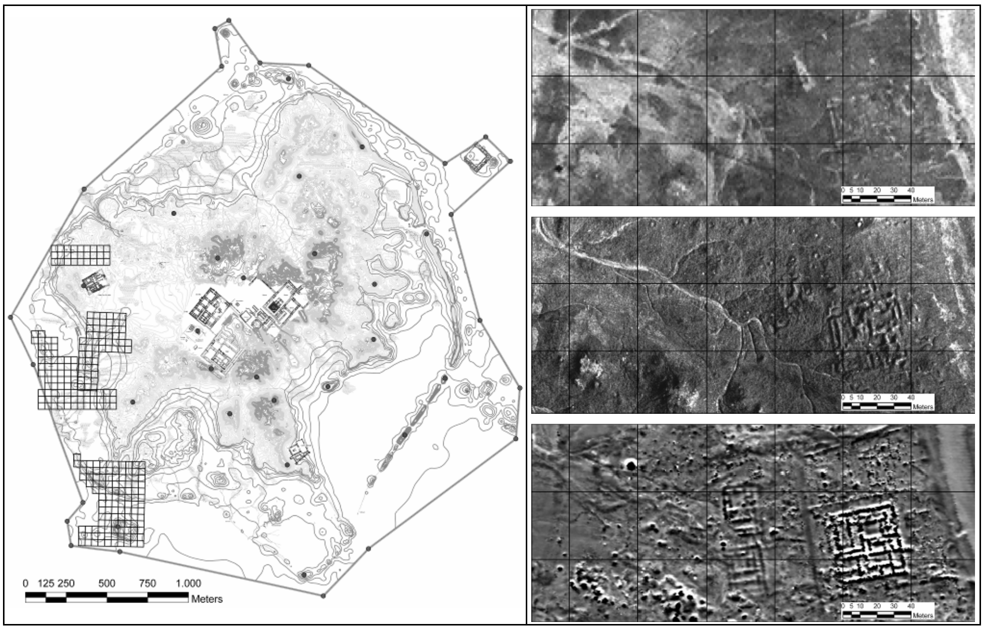

Figure 1: Available geospatial data for Uruk-Warka. Left side: Reference data (permanent geodetic points, contour lines, magnetometer grids, fence, maps).
Right side: Comparison of image examples from different sources in the northern geophysical survey area. Top: IKONOS satellite image, acquired on 07.09.2001, panchromatic band, Middle: aerial photography, Bottom: magnetometer measurement /image

Three different image sources are used for the visual and semi-automatic analysis (see right side of figure 1): Pre- and post-war IKONOS satellite imagery, acquired on September 07, 2001 and on December 12, 2005 were provided by courtesy of European Space Imaging, Munich. For each acquisition multispectral, panchromatic and pan-sharpened multispectral layers with spatial resolutions of 1 m or 4 m were used. Furthermore, scanned hard copies of very high resolution panchromatic aerial photography acquired by the Royal Air Force and archived by DAI in 1935 were available. Finally, three areas were explored with a magnetometer during geophysical surveys in 2001 and 2002. The spatial resolution of the measurements could be calculated as 12.5 cm.

3 Data preprocessing

The archaeological interpretation and the fusion of information derived from heterogeneous data sources require a common geometric reference system. During geodetic surveys between 1982 and 1984 a new local, strictly north-oriented, cartesian reference system for the archaeological site Uruk-Warka was established (BIRK 1984). Since all reference data sets are referenced to this system, it was also used in this project.

All necessary preprocessing procedures in this project were carried out using standard image processing software. In the first step a very high resolution digital elevation model (DEM) was derived from the permanent geodetic points and the contour lines using the surface tool of *ERDAS Imagine 8.7*. For the ortho-rectification of the IKONOS satellite imagery, the derived DEM, the provided RPC files (GRODECKI & DIAL, 2001) and the permanent geodetic points and fence posts were used as ground control points. Using this approach, geometric accuracies in the range of a sub-pixel could be achieved. Using the precise magnetometer grid in the next step, the images of the magnetic survey were georeferenced by creating simple world-files. No detailed information such as photo scale, focal length or flying height was available for the scanned RAF aerial photography. Furthermore, the permanent reference points were not yet installed in 1935. Hence simple image-to-image registration procedures were applied using the orthorectified panchromatic IKONOS imagery. Due to countless changes during the elapsed 70 years and the different spatial resolutions, not enough tie points could be localized. Thus the high demands of automatic procedures could not be achieved to the accuracy of co-registration. Nevertheless, the historic aerial photography is a valuable information source for visual image interpretation. All georeferenced data sets were integrated in a GIS environment for visual interpretation and semi-automatic analysis approaches.

4 Semi-automated feature detection, detection of looting

Object-based feature recognition

For the analysis of archaeological features an object based image analysis approach was applied to extract the complex information from the described image data. The approach was realized using the software *Definiens Developer* which follows the concept that important semantic information is crucial to interpret an image and that it is not represented in single pixels, but in meaningful image objects and their mutual relationships.

The main difference compared with pixel-based procedures is that an object based image analysis approach does not classify single pixels, but rather image objects which have been extracted in a previous image segmentation step. The advantage of this approach is the amount of additional information which can be derived from image objects and thus used for classification: digital values and statistics per object, shape, texture, area, context, information from, and relationships to other object layers.

All image objects are connected and the image content is represented as a network of image objects used in subsequent image analysis. Image analysis can be realized classifying the image objects on the one hand based on sample objects, on the other hand according to class descriptions or a combination of both approaches. A knowledge base using Cognition Network Language is created by means of inheritance mechanisms, concepts and methods of fuzzy logic and semantic modelling. The applied software is *Definiens Developer*, Version 5.06.

Detection of typical archaeological features

A variety of archaeological features with different properties were described in the knowledge base during the project. In the Cognition Network Language a well structured hierarchical rule based is created to extract contrasted objects, elevated areas and potential archaeological sites within the imagery. Finally ancient channels and looting are defined and extracted.

The above mentioned features were extracted using the following formulations:

- The attributes of objects including their brightness value, their homogeneity and their alignment with already found excavation edges were used to extract contrasting objects.
- The analysis of elevated areas used the advantage of a definable object neighbourhood: based on elevation information. An object is classified only if it is elevated in comparison to its surrounding. Furthermore, the mean spectral difference to neighbours, its area, and again the homogeneity criterion are used.

The extraction of potential archaeological sites was applied to areas with low contrast only, if besides this criterion the areas had a regular arrangement of low contrast edges. The ancient channels were found based on parallel lines in a typical distance from each other, fulfilling also a spectral property that the areas are brighter than their surroundings in the imagery.

Detection of looting

The first step in detecting a looting occurrence is a coarse segmentation. After that all dark areas are masked out for further processing. Because a semi-automated approach could be applied, the high variations of brightness per scene are adjusted manually to the respective scene. Once image objects are assigned to this initial class the information can be used for a finer segmentation. It is possible to split large objects, thus only the dark areas are segmented using multiresolution segmentation. Multiresolution segmentation is a bottom up region-merging technique where in numerous subsequent steps smaller image objects are merged into bigger ones, resulting in meaningful image objects. The procedure simulates an even and simultaneous growth of segments over a scene in each step. The stop-criterion for the region merging process is given by the parameter scale and can be edited by the user.

For the subsequent classification the first criteria used is the size of objects. Only small objects with a defined area are further considered. Then lengthy objects are removed if their relation of length to width is larger than 3/1. In addition the object borders must fulfil the criterion that the attribute shape index is larger than a certain threshold (> 1.3). The shape index is related to the smoothness of image object borders and is calculated based on the border length of an image object divided by the square root of its area. Finally, objects must have a high contrast to neighbouring objects to be classified as a single looting occurrence.

Based on these single looting sites the task was to find looting clusters. This was formulated based on a high density of looting (more than 60 single looted spots) within a radius of 50 m. The big advantage of the object based approach is that properties of previously defined classes can be inherited to sub-classes, and that the integration of context and expert knowledge in the rule base is possible.

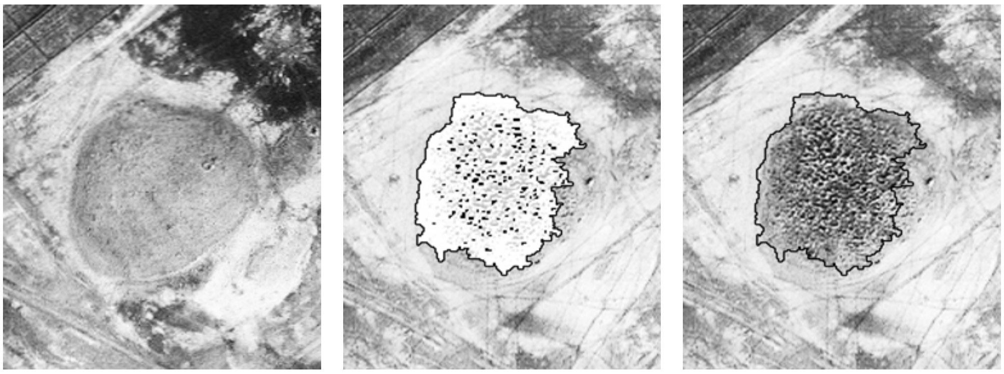

Figure 2: Archaeological site in 2001 (left) and in 2005 (middle and right) with individual looting sites and detected looting area.

5 Magnetometry results fused with satellite images

One specific characteristic of Mesopotamian archaeological sites is the lack of raw materials and especially of stone in that region, which forced people to build with sun dried bricks and in some exceptional cases with baked bricks only. Mud brick architecture is easy to destroy and highly dependant on steady maintenance. Buildings therefore were broken down and rebuilt quite often. But, usually the foundations of older construction work are kept and re-used. Archaeologists therefore do not find well-preserved and impressive architecture but foundations, and therefore the ground plans of houses, palaces, temples, complete living quarters and cities. Theses foundations are quite often preserved over thousands of years and visible at the ground and from the air under certain circumstances.

The magnetometry done by the authors (Becker, Fassbinder) at Uruk was part of a project about geophysical prospecting of mud brick architecture in archaeology. Measurements e.g. at *Troy* (Turkey), *Piramesses* (capital of Ramesses II in Egypt) and *Wah ze gang* (palace of the first Chinese Emperor *Qin ze huang di* near Xian) showed clearly that high resolution caesium magnetometry is the most suitable method.

The aim of the magnetometry at Uruk was primarily to verify features visible on the aerial photos from 1935 as water canals (see the right edge of figure 3). These canals are also very clearly visible in the satellite images, which gives the extrapolation of the limited "magnetic" area to an almost complete map of the water streets of Uruk. The very clear plan of an Ur III palace in the magnetogram of figure 3 is caused by the high magnetization of the baked bricks used for this architecture. The red colour in the multispectral satellite image also led to the conclusion that this is a building made from baked bricks. The aerial photo also shows some walls of this Ur III palace as shadow marks. Both images could be sharpened by the "magnetic" channel. Two more buildings on the other side of a street are only visible in the magnetic image.

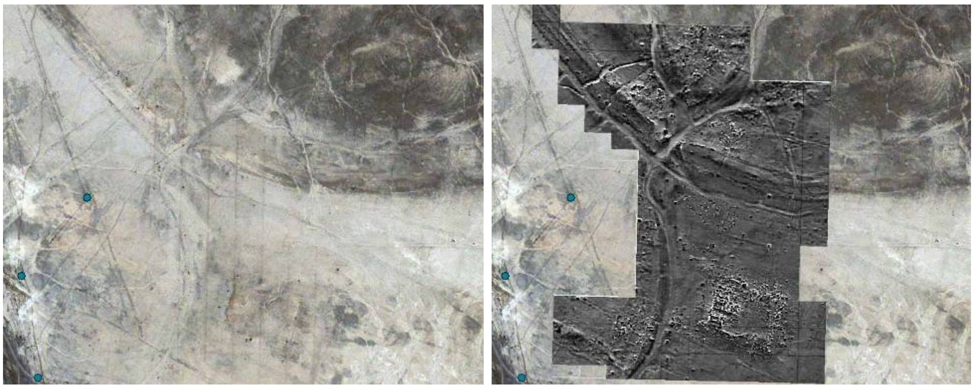

Figure 3: Left: IKONOS satellite image September 2001. Detail of the southern area. Right: Compilation of the satellite image with the magnetograms from March 2001 and 2002. Caesium magnetometry, Scintrex Smartmag SM4G-special, sensitivity 0.005 nT, dynamics –+12.00 nT in 256 grey scale (white/black), raster 0.5 x 0.1 m (interpol. 0.25 x 0.25 m), 40m grid.

Another example of a comparative archaeological interpretation between magnetic and satellite image can be made in the southern area (figure 3). There is a main gate (water gate) in the city wall for the big canal. Again the towers of this gate built from baked bricks were only detected by magnetometry. A faint red colour over a rather big building structure seen in the satellite image outside of the city wall further down to the south gives in the magnetic image the complete plan of a temple – possibly the New Year temple. In the magnetogram the ritual course of a barke coming from the city of Uruk on the main canal, turning to the left through another gate to this temple can be drawn. The extraordinary resolution of the satellite image is demonstrated by these north-south lines, which were the tracks of the two helpers walking on the base lines of the 40 m grid for magnetic prospecting – here still visible six months later from space at 681 km altitude!

6 Outlook

Further work on the mapping of archaeological features might include the improved use of the electromagnetic spectrum from space imaging sensors. Hyperspectral sensors, such as the planned German EnMAP (STUFFLER, 2005), could be a useful tool to detect the finest change in the mineralogical decomposition of especially arid surfaces. Synthetic Aperture Radar data from longer wavelength sensors (e.g., L-band) have also yielded results in mapping subsurface structures and penetration of forest foliage. The Japanese ALOS mission (ALOS, 2006) data could be used for this purpose. In addition the project has shown the potential of semi-automated detection algorithms. However, their benefit still has to be better exploited in large scale projects.

The project team discussed options for such large scale projects, e.g., the detection of looting activities for an entire country, with various stakeholders. Critical here is the availability of high resolution satellite images. Even for politically interesting areas such as Iraq, the satellite data coverage concentrates on selected "hot-spots" and gives cultural and archaeological sites no priority in mapping demands determined by military and security agencies.

On the global scale, satellite imaging technologies could be systematically used not only to observe archaeological sites but could contribute to public awareness of World Heritage Sites as well. The UNESCO World Heritage List includes 812 sites, 628 of which are cultural sites (status: April 2006). Reporting on the integrity and good maintenance of these sites is a duty of the government owning the site. As has been proven by UNESCO (HERNANDEZ, 2005), space images can help to monitor environmental pressures on historic sites caused by pollution and tourism. The commercial operators of very high resolution satellites have heritage sites such as the Gizeh pyramids and Venice on their tasking agenda (mostly for promotional reasons). Provided there is coordination of these activities by a voluntary agenda (e.g., as with the CHARTER on Space and Major Disasters), existing and future satellites can provide sufficient information to allow frequent monitoring of all world heritage sites from space.

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