

**Archaeological Prospecting Using High-Resolution Digital Satellite
Imagery: Recent Advances and Future Prospects -
A Session Held at the Computer Applications and Quantitative Methods in
Archaeology (CAA) Conference, Williamsburg, USA, March 2009**

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Introduction

Over the last few years, a new generation of satellite sensors has provided an unprecedented variety of remotely sensed imagery with a spatial resolution of 1 m and better. These images allow for the first time even small archaeological sites and features to be detected, which is a huge step forward for archaeological prospection: “*For three decades archaeologists have waited for a high-resolution satellite capability and the arrival of satellites such as Ikonos and QuickBird signals a new era in research.*” (Hung 2006: 680). Since about 2004, when the 1st International Conference on Remote Sensing Archaeology was organised by the Chinese Academy of Sciences in Beijing, specific conferences have helped to promote research in this new scientific domain. These include the 2nd and 3rd International Conferences on Remote Sensing Archaeology in Rome (2006) and Tiruchirappalli (2009), the 1st International Workshop on Advances in Remote Sensing for Archaeology and Cultural Heritage Management in Rome (October 2008), the DECARS meeting in Amsterdam in April 2009, as well as special sessions at AARG, CAA, ISPRS, CIPA, SPIE and other conferences.

Archaeologists have been quick in realizing the great potential of high-resolution digital satellite imagery for the detection and documentation of archaeological sites and features. A growing number of case studies with interesting results have evolved from ongoing archaeological field projects in recent years. While some of these projects have been limited to a visual inspection of images to aid fieldwork, others now go beyond this level by applying advanced methods of digital image analysis in order to extract archaeological information. These methods include, among others, multispectral analysis, image classification, pattern recognition, photogrammetry, and related approaches. However, a systematic evaluation of the potential of these methods, which were usually developed for different kinds of applications in the geo and bio sciences, and the potential of the new data source itself remains a desideratum. At the same time, important progress has been made in the processing and analysis of declassified high-resolution analogue photographs acquired by Corona and other spy satellites in the 1960-80s. Especially when analysed in conjunction with other images, these photographs have proven to be yet another valuable new data source for archaeological prospection.

During the 2009 CAA conference (Computer Applications and Quantitative Methods in Archaeology, see www.caa2009.org) in Williamsburg, USA (the capital of Virginia from 1699 to 1780 and today the nation’s largest outdoor living history museum), we organised a special session that aimed to explore the potential and limitations of high-resolution digital satellite imagery, and of current methods of digital image analysis with regard to the requirements of archaeological prospection. Our session was entitled *Archaeological prospecting using high-resolution digital satellite imagery: recent advances and future*

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prospects. Preference was given to papers with a methodological focus, addressing specific problems of identifying archaeological features through digital image analysis and showing recent advances and promising research strategies. Overview papers and new case studies complemented this session that brought together specialists from the fields of archaeology, remote sensing, geography, photogrammetry, digital image analysis, and related disciplines. In what follows, we will give an overview of the contents of this session along with some thoughts about the state of the art and the future of satellite remote sensing in archaeology.

Papers presented in the CAA 2009 session

The following eight papers were presented in our CAA 2009 session:

- K. Lambers (University of Konstanz) & V. De Laet (Katholieke Universiteit Leuven): *Extracting archaeological features from high resolution satellite imagery: a review of current projects, problems, and promising approaches*
- A. Traviglia (University of Sydney): *Characterizing Angkorean landscapes: RS based feature detection in tropical areas*
- V. De Laet et al. (Katholieke Universiteit Leuven): *Very high resolution satellite remote sensing as part of an integrated approach for archaeological prospection at Tepe Düzen (southwest Turkey)*
- D. Donoghue et al. (Durham University): *The Fragile Crescent Project: the rise and decline of Bronze Age urban settlements in the ancient Near East*
- D.J. Tucker (Martin Luther University Halle-Wittenberg): *Potential of simple feature signatures for mapping landscapes of mobile pastoralists*
- J. Casana (University of Arkansas): *CORONA imagery archaeological atlas of the Middle East*
- J. Cothren et al. (University of Arkansas): *Effects of ground control point accuracy on triangulation and ortho-rectification of large blocks of CORONA images*
- T. Kalayci (University of Arkansas): *Accuracy of DEM generation from CORONA stereo pair images*

A paper given by K.L. Kvamme (University of Arkansas) on *Modelling subsurface content through multidimensional remote sensing, multivariate analysis, and raster GIS* in a GIS session will also be considered here, as it was closely related to the topic of our session.

In our introductory presentation, we reviewed current projects (mainly by researchers not present in our session), problems and promising approaches of semi-automatically extracting archaeological features from high-resolution satellite imagery and determined promising starting points based on available literature. In our view, a basic research issue in satellite-based archaeological prospection is to what extent methods and algorithms from the field of digital image analysis can assist the detection and documentation of archaeological features. The fact that archaeological remains may take on a near infinite variety of formal and spectral properties complicates their extraction using rule-based algorithms. In spite of these difficulties, case studies from recent years (Altaweel 2005; Beck et al. 2007a, b; De Laet et al. 2007a, b, 2008, in press; Garrison et al. 2008; Lasaponara, Masini 2006, 2007; Lasaponara et al. 2008; Menze et al. 2007; Masini, Lasaponara 2007; Saturno et al. 2007; Schmid et al. 2008; Trier et al. 2008, 2009; Wilkinson et al. 2006) show that, if used properly, image pre-processing and enhancement, multispectral and hyperspectral analysis, photogrammetry, pattern recognition, and related methods can assist the identification of archaeological features to a considerable extent.

A case in point was the paper delivered by A. Traviglia, who applied image processing techniques like vegetation indices, vegetation suppression, and principal component analysis to multispectral and radar data in order to map unknown archaeological sites and structures (often buried or hidden under the forest canopy) of the ancient Khmer landscape in the surroundings of Angkor, such as palaeo-rivers and historical channels. These elements are crucial for a correct understanding of the extension of the Khmer settlement, the water flow system and its redirection, and of the processes which led to the site's decline and abandonment.

D.J. Tucker's paper demonstrated the potential, though not yet applied, of simple feature signatures and semi-automated pattern recognition algorithms for mapping the extensive patterns of nomadic activity in the Syrian Desert. Typical recurrent shapes, proportions, and locations of tent sites, dung patches, water retaining walls and radial animal trails provide an excellent starting point for generalised formal descriptions of archaeological features that are a prerequisite for the successful application of rule-based detection algorithms.

Image processing can aid archaeological prospection especially when digital image analysis of high resolution satellite images is combined with other data sources and prospection methods, such as aerial and satellite imagery with different spatial and spectral resolution, digital elevation models, ground-based geophysical prospection, archaeological fieldwork, etc. as shown in the presentations by V. De Laet et al. and K.L. Kvamme in Turkey and Kansas, USA, respectively (the latter in a session on *Cell-based analysis and landscape archaeology: new approaches and new applications*). V. De Laet presented a stepwise interdisciplinary integration and back-coupling of high-resolution satellite images, aerial and archaeological surveys, topographic mapping, geophysics, and excavations in order to evaluate the potential of high-resolution satellite imagery to detect unknown archaeological features and to fully understand the nature of the Tepe Düzen site. In his paper, K.L. Kvamme combined different kinds of geophysical survey data, thermal infrared aerial images and QuickBird multispectral images to predict locations likely to contain archaeological features. This fusion of geophysical and optical data provided a suitable basis for unsupervised and supervised image classification that resulted in the mapping of different elements of the historical military installations under study, such as stone and brick walls, pipes etc.

The paper by D. Donoghue et al. demonstrated the value of combining high-resolution optical images with digital terrain models derived from modern and declassified satellite imagery like Corona and Gambit to study large regions. Cold War-era Corona and Gambit photographs from the 1960s and '70s have proven to be an invaluable archaeological resource that can never be replaced by new technologies, as they predate important landscape alterations caused by urban sprawl, industrialisation, and farming mechanisation. Donoghue et al. used these multi-source, multi-resolution data to tackle the question of how the processes and patterns of Early Bronze Age urbanisation varied from region to region. The different datasets were not only used to locate features detected during previous surveys, but also to identify unknown features, to extrapolate information to larger areas and to carry out a settlement pattern analysis.

Finally, the University of Arkansas group presented three papers that combined both elements of data integration and advanced processing methods of Corona photographs (see also Casana,

Cothren 2008). The paper by J. Casana presented the general aims of a two-year NEH-funded project that utilizes newly developed methods that will efficiently and accurately orthorectify Corona photographs of the Middle East and surrounding regions. The final aim of this ambitious project is to create a user-friendly online database (“atlas”) of orthorectified Corona photographs, DEMs and stereo pairs to increase their use in archaeological projects, since the integration of these photographs into such projects has remained quite limited so far. This geo-database covering large areas of the Near and Middle East will become available in the near future at: <http://castweb.cast.uark.edu/home/research/geomatics/photogrammetry/corona-satellite-imagery-based-digital-archaeological-atlas-of-the-near-east.html>. The papers by J. Cothren et al. and Kalayci et al. discussed the automation of several photogrammetric processing steps to develop and distribute the digital Corona-based archaeological atlas of the Near East. While most previous studies presented rigorous models and methods for exploiting Corona photographs suitable for small areas or a few photographs, these studies discussed several innovative strategies to apply these rigorous methods to more than one thousand overlapping Corona photographs. Such processing is necessary because the spatial distortions produced by the fast-moving panoramic camera and the sparse metadata associated with each mission make these photographs difficult to georeference, let alone to accurately orthorectify. The main emphasis in the paper by Cothren et al. was on the effects of ground control point accuracy on triangulation and orthorectification of large blocks of Corona photographs, while in the paper by Kalayci et al. the focus was on the accuracy of DEM generation from Corona stereo pairs. The generated DEMs will have a spatial resolution of 10 m.

All these presentations clearly showed that methods and algorithms from the field of digital image analysis can assist the detection and documentation of archaeological features. Since most research projects focus on particular case studies, it is not clear, however, to what extent these promising results allow a general judgement of the applicability of digital image analysis techniques to high-resolution satellite imagery under varying environmental and archaeological conditions. A systematic evaluation of data and methods therefore is still a desideratum. In this regard, we outline below some important issues and future perspectives.

Present problems and future perspectives

The CAA 2009 session on satellite remote sensing in archaeology, the available literature on the topic and our own experiences all indicate that important progress has been made in this field in recent years. Nevertheless, some methodological as well as structural problems that hamper a sound integration of high-resolution satellite image analysis into archaeological research should not be overlooked.

Turning first to methodological issues, the technical properties of high-resolution satellite imagery determine the potential and limitations of its analysis for archaeological purposes. There is for example the limited spectral coverage of high-resolution images. The trade-off between spatial and spectral resolution means that high-resolution images usually cover only the VNIR spectrum. They are thus not regarded as truly multispectral by many remote sensing specialists. Valuable additional information from the infrared spectrum can only be obtained at the expense of a loss of spatial resolution that, in our view, is so crucial for its successful application in archaeology. The combination of satellite images of different spatial and spectral resolution with data from other sources in a multi-sensor, multi-resolution approach is probably the best answer to this problem from a methodological point of view, though practical and financial constraints may prevent such an approach. Still, the increased spectral

capabilities of high-resolution satellite images over typical aerial photographs will significantly increase the possibility to detect specific spectral signatures related to archaeological phenomena. Concerning spatial resolution, another problem that will become more acute in the future with the launch of new sensors is the current 0.5 m limit for non-US-government clients, which to the best of our knowledge will not be suspended in the near future. Finally, archaeological analysis of satellite images has so far largely focused on spectral information, whereas the potential of extracting geometric information through photogrammetry has yet to be fully tapped. Recent years have seen considerable advances in the generation of digital elevation models from high-resolution satellite images (Lambers, Remondino 2008). The resolutions and accuracies obtained are now beginning to enter the useful range for small-scale archaeological applications. This geometric information may in itself reveal the location of potential archaeological features such as earthworks, terraces, barrows and the like, or it may be analysed in conjunction with multispectral image information as an additional channel. The beauty of this approach is that the same images can be analysed twice, once for their spectral content and once for their geometric content. There is a huge potential here for archaeological prospection that is only beginning to be explored.

Concerning the detection of sites and features which is the aim of archaeological prospection, the abovementioned near infinite diversity of their shapes, proportions, locations, and contexts is a huge challenge for semi-automated detection approaches. In a sense, due to their very nature archaeological features may be regarded as “uncooperative”. While pattern recognition has made important progress in recent years in other applications such as the automatic detection of traffic signs, buildings, roads, people, cars and many other objects in different kinds of digital imagery, the intrinsic variety of all these classes of objects is usually much lower than what is observed for archaeological features. In our view, however, this does not mean that semi-automated detection approaches are doomed to fail from the outset. It is interesting to note that many successful detection algorithms in other applications rely on a surprisingly small set of carefully chosen key properties of the objects they are tailored to detect. In archaeology we are only beginning to understand and describe typical features that we encounter in given regions in such terms. There is still a lot of work to be done in the standardised formal description of archaeological features that provides useful information for the design of detection algorithms. The key question will be to what extent such formal descriptions, or models built on their basis, may be generalised in order to detect a variety of archaeological features. Carefully set thresholds concerning shapes, dimensions, spectral properties etc. will be an important aspect here. Most probably generalisation will only work to a quite limited degree, but this is a largely unexplored field that requires comparative methodological studies. In any case it is clear that semi-automated detection will mainly be useful to map typical, recurrent, well-known features (see, for example, Trier et al. 2008, 2009; this volume), whereas the detection of atypical, rare, unusual features will always remain the domain of visual image interpretation (and field observation, which is indispensable in both approaches).

Turning from data to people, there seems to be a divide between different groups within the archaeological community concerned with remote sensing applications. While archaeologists have successfully used aerial imagery for decades, surprisingly often there is little continuity or contact between experts in aerial and satellite-based archaeological prospection. It is true that many experienced aerial archaeologists have embraced the new space-borne data source and are actively engaged in the advancement of its analysis. But at the same time there seems

to be a new generation of archaeologists using satellite imagery who have little or no practical experience in aerial archaeology. There are various possible reasons for this. Aerial archaeology has always been strong in the temperate climate regions of Europe, where archaeological remains often show beautifully as crop, soil, snow or shadow marks and where large image archives exist that can be analysed for archaeological prospection. Satellite imagery, on the other hand, is available worldwide and often constitutes the only suitable image data source in countries where aerial photographs are not available or difficult to access. At the same time, crop and soil marks are of little or no use in many of these countries due to different climatic, geomorphic, vegetational and/or archaeological conditions. Faced with such a situation, it is logical to turn to the sophisticated set of digital analytical techniques associated with satellite imagery that were originally developed for the earth sciences, instead of the proved and tested toolbox of the experienced aerial archaeologist. This may in some instances lead to the proverbial reinvention of the wheel. At the same time, some aerial archaeologists have remained sceptical regarding attempts to detect archaeological features in (airborne or space-borne) digital images through the application of methods and algorithms derived from other imaging applications. While there are perfectly good reasons for this point of view, considering the great diversity of archaeological features and the contexts in which they are found, image processing can at the very least facilitate the visual identification of archaeological features in imagery, even where semi-automatic detection fails. Thus, more cooperation and exchange across the abovementioned divide would certainly be beneficial for both sides. Visual interpretation of imagery based on profound expert knowledge, and advanced digital image processing and analysis are complementary and should both be part of a carefully designed research approach.

Concerning cooperation between the disciplines involved in satellite-based remote sensing archaeology, there are gaps and problems as well. In our view, an important shortcoming of recent studies in this field is that many of them are site-oriented and only a few focus on methodology. This may partly be due to limited resources available for such studies, but, in spite of notable exceptions, a lack of communication between the disciplines seems to be involved as well. This, in consequence, leads to a lack of technological developments tailored to archaeological applications. Among the archaeological community, limited availability and knowledge of data and software is often a problem. Archaeologists therefore need to seek collaboration with remote sensing and digital image analysis specialists. Experts in these fields, on the other hand, often lack knowledge of the nature and contexts of archaeological sites and features. Distinguishing archaeology-related signatures from non-archaeological signatures requires thorough archaeological knowledge and expertise. To use this archaeological knowledge in image analysis, in turn, requires its translation into formal descriptions and models that can be used for semi-automated detection approaches. Thus, a much closer cooperation between both disciplines and some degree of familiarity with key concepts and methods of the other side is needed to foster the integration of remote sensing into archaeological research design.

It is our hope that satellite archaeology at some point will no longer remain in the domain of “technical researchers”. Ideally, remote sensing courses, not only on a theoretical but also on a practical base, should become an integral part of archaeological training, just as GIS courses already have in recent years. New study programs like the MSc in GIS and Spatial Analysis in Archaeology at the University College London, the Master of Geotechnologies for Archaeology at the University of Siena and others are very promising in this regard. To foster

communication between the disciplines, well-established forums like AARG are as important as new initiatives like the EARSel special interest group on *Remote Sensing for Archaeology and Cultural Heritage*, the ISPRS working group on *Cultural Heritage Data Acquisition and Processing*, the IAPR technical commission 19 on *Computer Vision for Cultural Heritage Applications*, and others. Additional activities such as an online database of algorithms relevant for archaeological applications, a bi-annual newsletter presenting new publications and technological developments, an online discussion forum and presentations at non-remote sensing conferences might complement and connect these activities. First steps have already been taken to create an online database, but much more work needs to be done in the near future. Also, further publications on satellite-based remote sensing archaeology like the books by Wiseman and El-Baz (2007) and Parcak (2009) would be of significant help.

Conclusions

The potential of satellite remote sensing and digital image analysis for archaeological prospection is far from exhausted. Much more testing is required, since the number and resolution of high-resolution satellites rapidly increases, and the application of digital image analysis is still in its infancy. Just as in excavation and aerial survey, remote sensing research must be well-planned and well-executed, using a comprehensive methodology. Digital image analysis can assist archaeological prospection to a considerable degree, but will never lead to a fully automatic procedure, since data manipulation will vary greatly depending on the type of data, moment of image acquisition, atmospheric conditions, type of landscape, site characteristics, and the overall research goals of the project at hand. Field observations, archaeological interpretation and human expertise remain indispensable. Satellite remote sensing projects carried out by archaeologists with backgrounds in both remote sensing and archaeology have much to offer, but satellite archaeology should not be regarded as a substitute for archaeological excavation or survey work. It is but one among a number of tools that archaeologists may want to employ in their research. Besides revealing the presence of (sub)-surface archaeological features (even in areas previously surveyed), satellite remote sensing can place archaeological sites in a much larger context, showing past social landscapes in all their complexity and helping greatly with quality assessment. As S. Parcak states in her new book entitled "Satellite Remote Sensing for Archaeology" (Parcak 2009: 3): "There is much we can miss by being on the ground and by not seeing things from an aerial perspective" (the reverse being true as well). Analysis of satellite imagery may further aid in determining where to excavate and may precede archaeological survey. Archaeologists therefore will need to rethink their surveying and excavation strategies in light of this new information, especially when sub-half meter satellite imagery will become commercially available.

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[internet links accessed 31 August 2009 – Ed]

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