3 Automated archaeological feature extraction from digital aerial photographs

J.P.M. Mathias Lemmens, Zoran Stančič & Ruud G.Verwaal

3.1 INTRODUCTION

The interpretation of aerial images has been a standard technique within archaeological survey for decades. Computer technology has also been applied within this field, especially for the rectification of oblique images (Haigh 1983, Scollar 1975). Digital image processing techniques are often used for emphasising archaeological features on aerial images (Scollar & Weidner, 1979). However, the ideal survey system would be fully automated and would enable the on–line detection of archaeological features and the determination of their position in space.

This paper investigates the possibilities of an automatic archaeological feature extraction system from digital aerial images. General techniques for digital image processing are presented and special emphasis is placed on the application of an automated system for the detection of circular archaeological features. The system presented allows the automated detection of circular features on digital images, the determination of ellipse or circle parameters and the position of such features. The results of this process are presented on the screen and the co–ordinates output to a geographic information system (GIS).

Aerial and satellite images are usually very important sources of data for archaeological databases. Satellite imagery can produce valuable information on the natural environment, definition of physiographic and other regions, but it has been proved that it has very limited potentials in actual discovery of new archaeological sites (Limp 1987). In the regions where specialised (Dassie 1978) techniques of archaeological air surveys are not normally practised, usually many vertical small scale photographs taken for other non–archaeological purposes, exist. These photographs are usually up to 50 years old, taken in different seasons, which are not always best for the discovery of archaeological features. However, the quality is, despite this small scale, usually extremely good. One of our aims in the research was to investigate the possibilities of application of these images for the detection of archaeological features. Since the majority of the European countries have produced thousands of general purpose or specialised photographs (usually for cartographic production or construction works), manual interpretation of all these archives would be extremely time and labour consuming. Therefore we wanted to see if at least some of the procedures in interpretation and detection of specialised archaeological features could be performed automatically or semiautomatically.

Our aim was to extract archaeological objects automatically from aerial photographs, using advanced digital image processing and image understanding techniques. Maps are increasingly replaced by geo–referenced data bases. Simultaneously, archaeological information is more and more often stored in a computer environment to enable flexible and improved analysis. An important source of archaeological information is aerial photographs that can be effectively scanned (Bosma *et al.* 1989). So, both the final information and data sources can be stored in digital format. This induces the intriguing question, whether automated image interpretation is a realistic option. Our research aim is motivated by the following facts:

- Image interpretation by computer has been successfully realised in a number of other fields of application;
- Archaeological data bases are becoming computerised;
- Scanning of photographs is relatively cheap and easy;

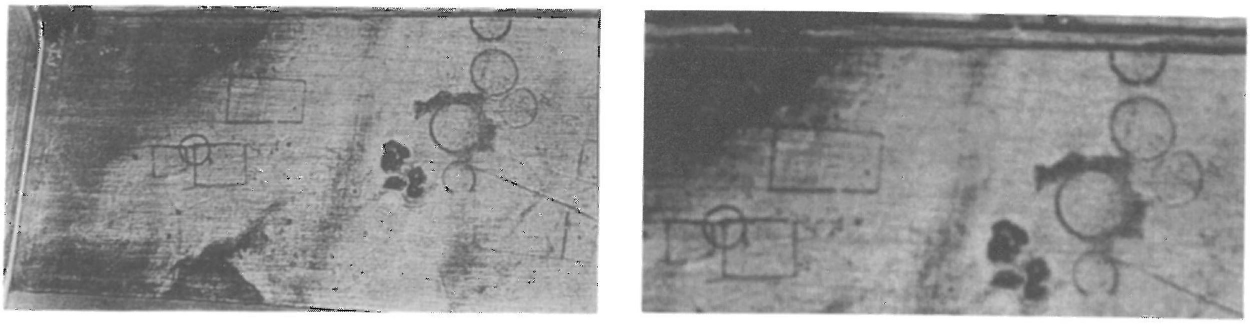

Figure 3.1: Noise reduction by Gaussian smoothing: a) original image; b) smoothed image.

- High capacity computers are relatively cheap with regard to memory and disk storage;
- The majority of European countries have produced thousands of aerial photographs, mainly for topographic purposes. Manual interpretation of these sources is extremely time and labour consuming.

In the next chapter we give some general facts on digital images and image enhancement. After this the circle detection strategy is formulated. Finally the transfer of the method to a feasible computer implementation is discussed and experimental results are presented.

3.2 DIGITAL IMAGE ENHANCEMENT

3.2.1 The image function and noise

A digital image consists of an array of numbers $g(i,j)$, $i=1,\ldots,n$, $j=1,\ldots,m$, where g refers to the grey value usually in the range (0–255), represented by one byte, and where (i,j) are spatial co–ordinates. We model the image to consist of a set of backgrounds on which a set of objects is superimposed, e.g. linear (roads and streams) and circular objects (the objects that we wish to detect in this case study). The difference in grey values between background and objects is not a constant value. Also the background grey values may vary, creating boundaries between background regions. Besides objects, noise and textures are also superimposed on the image. So we need methods to effectively reduce noise and textures without effecting the edge structures of the objects.

3.2.1.1 Noise reduction by smoothing

One obvious way to reduce the effects of noise is to carry out a weighted or un–weighted averaging of the local image function, using convolution kernels. If the weighted function is a discrete version of the 2–D Gaussian normal distribution, we refer to a Gaussian smoothing filter. Although the image noise is effectively reduced by such linear smoothing filters, their disadvantage is that the edge strength is reduced too.

Some of our test images were obtained by scanning of published rasterised photographs. Sampling of a raster induces a special kind of noise. An efficient way to reduce it is by blurring the image with a Gaussian filter. As an illustration of this process see Figure 3.1, where first the original image is presented and then the result of 5×5 Gaussian smoothing.

To reduce the noise without affecting the edge strength significantly, edge preserving non–linear smoothing filters should be used. Two paramount examples are the median and the Kuwahara filter. In the median filter (Scollar *et al.* 1984) the grey value of the centre pixel of a $w \times w$ window, w odd, is replaced by the median of the grey values in that window. Each pixel is examined in this manner. Median smoothing filters effectively reduce noise while preserving edges. However, thin structures, possibly representing objects of interest, are removed. For example, one pixel thick lines in 3×3 windows disappear.

In the Kuwahara filter four windows are placed around the pixel under consideration, so that the pixel is located in one of the four corners. The corner is of course different for each of the four windows; typical window size is 3×3. The variance of the grey values in each window is computed. Next the mean of the window with the lowest variance is assigned to the pixel. Each pixel in the image is examined in this manner. The edge preserving characteristics are due to the fact that if the pixel is located at or nearby a ramp edge, the windows that cross the edge have a high variance, while the windows that occupy only one region have low variance. The un–weighted averaging is performed over the low variance window.

A beneficial property of the Kuwahara filter is that it also reduces textures as well as noise. Texture reduction, however, goes at the cost of the introduction of phantom edges. The edge strength of thin structures is considerably reduced. The performance of the Kuwahara and the median filter are presented in Figure 3.2 on the example of the image from Wilson (1982:77).

3.2.2 Edge detection

An abundance of edge detection techniques was developed in the course of time. Within the framework of edge detection in aerial and satellite images we can categorise them into five broad classes:

1) comparison of the local image function with a prototype edge — template matching;
2) derivatives of the image function — gradient operators;
3) statistical comparison of the both sides of the hypothesised edge of the area;
4) surface fitting techniques;
5) others.

Gradient operators based on first derivatives in column and row direction are for example the Roberts (1965), Prewitt (1970) and Sobel operator. The Laplace operator is based on second derivatives (Haralick 1984). Surface fitting techniques compute two principal curvatures of the local image function around each edge. The strengths of the curvatures are an expression of the type and significance of the edge. In our work we used edge detection by template matching.

A usual method to decide whether the edge filter response indicates an edge is by comparing the response to a pre–defined threshold. This is the so called edge enhancement/thresholding scheme (Pratt 1978). More advanced techniques exist that use contextual information and even *a priori* information, using relaxation, graph search and dynamic programming methods.

3.3 DESCRIPTION OF THE CIRCLE DETECTION STRATEGY

Very important criteria in the mathematical implementation and program strategy are computational effectiveness, enabling interactive sessions. The process consists of three steps: — identification and rough localisation; — parameter estimation; — verification.

We assume that no *a priori* knowledge about location, shape, size and orientation is available. Consequently, we have to formulate the problem as hypothesis testing. Two formulations are possible: — hypothesise that each pixel (*i,j*) lies on the boundary of a circle; — hypothesise that each pixel (*i,j*) lies inside the circle.

We have chosen the last approach since it is easier to apply.

3.3.1 Identification and localisation

We suppose that each pixel (*i,j*) could be positioned inside a circle. To check this hypothesis, that is identification of the circle, we start from (*i,j*) and look in all directions to see whether there is a significant gradient present in that particular direction. In each direction the maximum gradient is taken, which should exceed a threshold pre–defined to be accepted as a circle edge point (x_i, y_i). The search area is limited, i.e. to some a priori knowledge about the size of the circles required in the form of a region of interest (ROI). A multiresolution approach makes the method relatively size–independent.

The next step in the procedure is checking whether the pixels with high gradient values

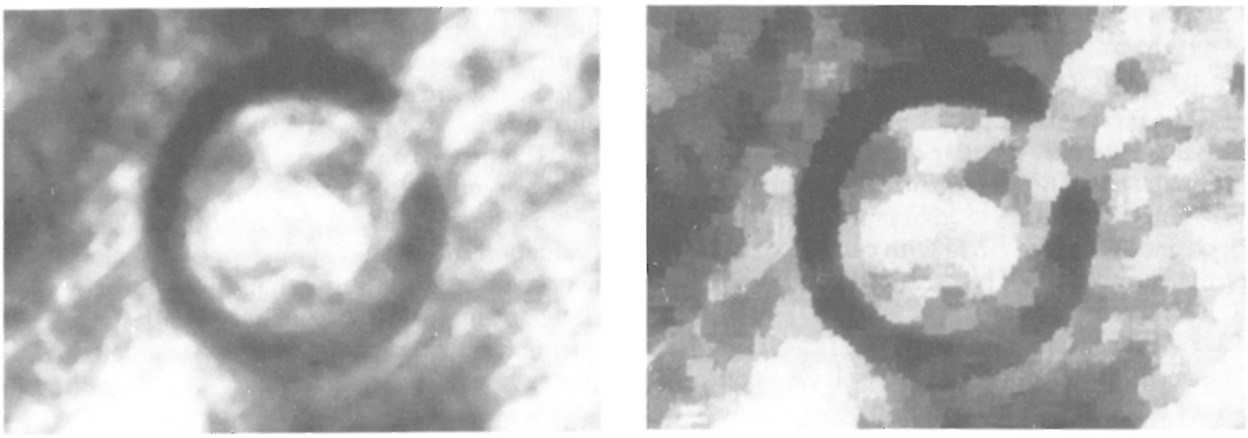

Figure 3.2: a) performance of the median filter; b) performance of the Kuwahara filter.

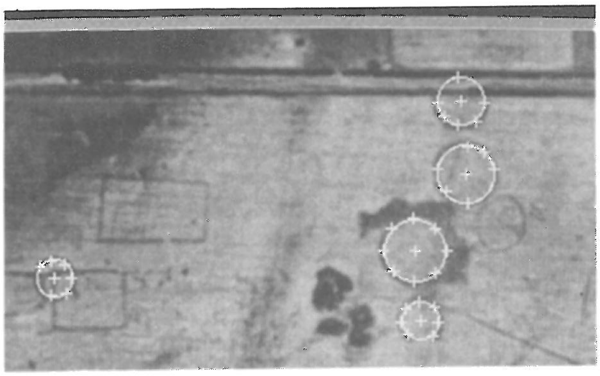

Figure 3.4: Oxfordshire image — experiment 1; size 200 by 400 pixels. The threshold of the edge strength is 40. The crosses indicate the circle edge points (x_i,y_i) that have passed the verification stage.

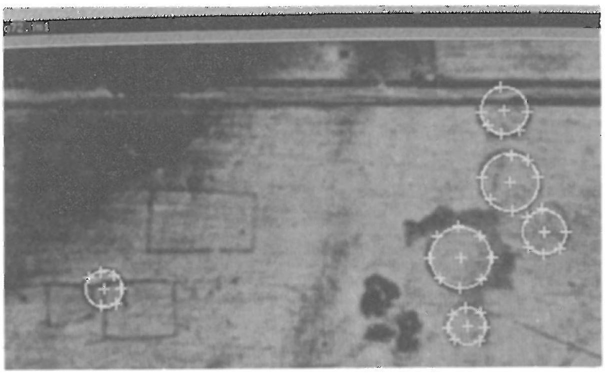

Figure 3.6: Oxfordshire image — experiment 3. The threshold of the edge strength is 39. The number of rejected points in the verification stage should not exceed 1 (in previous experiments it was 2).

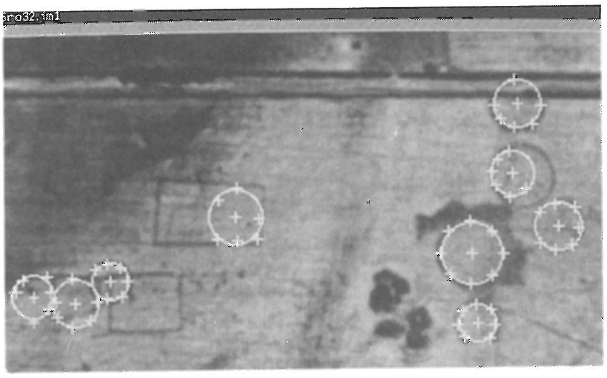

Figure 3.5: Oxfordshire image — experiment 2. The threshold of the edge strength is 30.

circles, but also objects with circle–like properties. For example, squares and rectangles have, in the present circle detection strategy, circle–like properties. As discussed, in some of the examples presented they really were detected as circles. For achieving higher reliability, detected circles have to be tested against alternatives. Therefore alternative objects should be indicated and their appearance in the image domain should be formalised, much in the same way as we did for the circles. Further more, appropriate test statistics, that is the ability to choose between circle and alternatives, should be formulated.

Since the computational burden is modest, the procedure is suited for use in interactive sessions, in which a part of the hypothesis testing is carried out by a human operator. The adjustment of the circle centre and radius is performed extremely well by the procedure alone. Although our final aim is automation, we believe that it is unrealistic to expect that automatic image interpretation systems of aerial images will be realised soon. Nevertheless, we believe that the value of our attempt is that the process can support the human interpreter in measuring and interpretation tasks during interactive sessions (Lemmens 1991).

It is also our strong opinion that computer interpretation of aerial and satellite images should not be considered as an isolated process. It can only become operational in full integration with geographic information systems (GIS). The GIS provides a wealth of *a priori* information that should be effectively exploited in the image interpretation process (Lemmens 1990). One important reason for this is the necessity to export the results of the image processing routines to the GIS. It is probably just a matter of time before all regional and state sites and monuments records will be computerised and for analytical purposes integrated into GIS. Therefore it would be unreasonable if the results of the digital image processing routines should be understood as a separate process.

An important reason for the integration of digital image processing systems into GIS is the fact that for the purposes of effective interpretation of digital images, much information can be found in other spatial databases. GIS should therefore be observed only as an overall cover for the spatial databases, digital image processing systems and statistical modules, enabling exchange and transfer of data in all needed directions. Existing spatial databases would in this case provide the information needed to distinguish existing circular, non– archaeological objects from the newly detected archaeological features. Unfortunately for the fully operational performance of the system much more research is needed especially in the field of knowledge–based digital image processing and GIS–digital image interaction.

Acknowledgement

One of the authors received a scholarship from the Dutch Ministry of Education and Science. Special thanks go to the CAA for the travelling grant enabling presentation of the paper on the CAA92 conference. D.R.Wilson (Cambridge University Collection: copyright reserved) and Ashmolean Museum kindly allowed us to use their photographs in the research. Phil Mason made the text sound more English.

References

Allen, G.W.G.
1984 Discovery from the air. *Aerial Archaeology*, 10.

Bosma, M., J. Drummond & B. Raidt
1989 A preliminary report on low–cost scanners. *ITC Journal* 2:115–120.

Dassie, J.
1978 *Manuel d'archeologie aerienne*. Editions Technic, Paris.

Haigh, J.G.B.
1983 Practical methods for the rectification of oblique aerial photographs. *Proceedings of the 22nd Symposium on Archaeometry* (April 1982): 1–10.

Haralick, R.M.
1984 Digital step edges from zero crossings of second directional derivatives. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol.6:58–68.

Lemmens, M.J.P.M.
1990 Automized interface of digital spatial imagery and geographic information systems. *Int.Arc. of Photogrammetry and Remote Sensing*, Vol.28:374–385.
1991 Integration levels of topo databases and geo imagery. *Proceedings of the ISPRS/OEEPE Joint Workshop on Updating Digital Data by Photogrammetric Methods, 15–17.September 1991, Oxford, UK.*

Limp, W.F.
1987 The identification of archaeological site patterning through integration of remote sensing, geographic information systems and exploratory data analysis. *Proceedings of U.S.Army Corps of Engineers Sixth Remote Sensing Symposium, Galveston, Texas*:232–262.

Pratt, W.K.
1978 *Digital image processing*. John Willey and Sons, New York.

Prewitt, J.M.S.
1970 Object enhacement and extraction. In Lipkin B.S. & Rosenfeld A. (eds.) *Picture Processing and Psychopictorics*. Academic Press, New York.

Roberts, L.G.
1965 Machine perception of three–dimensional solids. In Tippett *et al.* (eds.), *Optical and Electro–optical Information Processing*. MIT Press, Massachussets.

Scollar, I.
1975 Transformation of extreme oblique aerial photographs to maps or plans by conventional means or by computer. *Aerial Reconnaissance for Archaeology*. Council for British Archaeology. Research Report 12, pp. 52–59.

Scollar, I. & B. Weidner
1979 Computer production of orthophotos from single oblique images or from rotating mirror scanners. *Aerial Archaeology*, 4:17–28.

Scollar, I., B. Weidner & T.S. Huang
1984 Image enhacement using the median and the interquartile distance. *Computer Vision, Graphics and Image Processing*, 25:236–251.

Wilson, D.R.
1982 Air photo interpretation for archaeologists. Batsford, London.

Authors' addresses

J.P.M. Mathias Lemmens
Lab. for Photogrammetry and Remote Sensing
Faculty of Geodesy
Delft University of Technology
Thijsseweg 11
NL–2629 JA Delft

Zoran Stančič
Department of Archaeology
University of Ljubljana
Askerceva 12
61000 Ljubljana, Slovenia
email: zoran.stancic@uni–lj.ac.mail.yu

Ruud G.Verwaal
Lab. for Photogrammetry and Remote Sensing
Faculty of Geodesy
Delft University of Technology
Thijsseweg 11
NL–2629 JA Delft