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Image Processing In Archaeological Remote Sensing

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12.1 Introduction

A variety of techniques suitable for the graphical display of geophysical data have been discussed by Aspinall & Haigh 1988. They were using methods largely based on dot-density patterns and on plotted contours, the latter utilising a bilinear interpolant. On the basis of their experience with these methods and results of Scollar *et al.* 1986 on magnetometer surveys, they looked towards grey-scale representation, possibly augmented by suitable colouring, bicubic interpolation to give a smoother visual presentation of the data, and further image processing procedures such as histogram manipulation and Fourier filtering.

Most of these suggestions have now been implemented on an image processing system built round a general purpose computer, an Acorn Cambridge Workstation ACW443 with images displayed via a modified Digisolve VGP-64 graphics processor. This system had been set up originally to drive a high-resolution scanner for digitising photographic negatives, so it was also convenient to use for trials on aerial photographs available as the original negatives. This paper describes the ACW system and its application to archaeological aerial photography using the example of a difficult photograph of Hirsel Law. An example showing how similar techniques may be applied to geophysical data is presented, using the results of a resistance survey at Binchester, County Durham.

With the recent advent of VGA displays it has become possible to implement some of these imaging procedures on PC compatibles, so that they may become more widely available. Because of the restrictions of MS-DOS and the grey-level range of VGA, only a limited number of such procedures can be implemented successfully and the results of the authors' work in this direction are discussed in section 12.6.

12.2 The image processing system

An overview of this system is shown in Fig. 12.1. The ACW has 4 Mb of addressable RAM, allowing memory-hungry processes such as Fourier transform filtering to be carried out in images up to a size of 512 × 512 pixels. This requires 2 Mb of RAM for array storage alone. As the ACW display is completely inadequate for images, it has been interfaced to a frame buffer which allows the display of images with up to 64 grey levels. Hard copy of images may be obtained either by dumping to a laser printer providing 512 × 512 images with up to 17 grey levels, or by photographing the display. Image input is via a high-resolution optical scanner or by floppy disc from PC-based systems.

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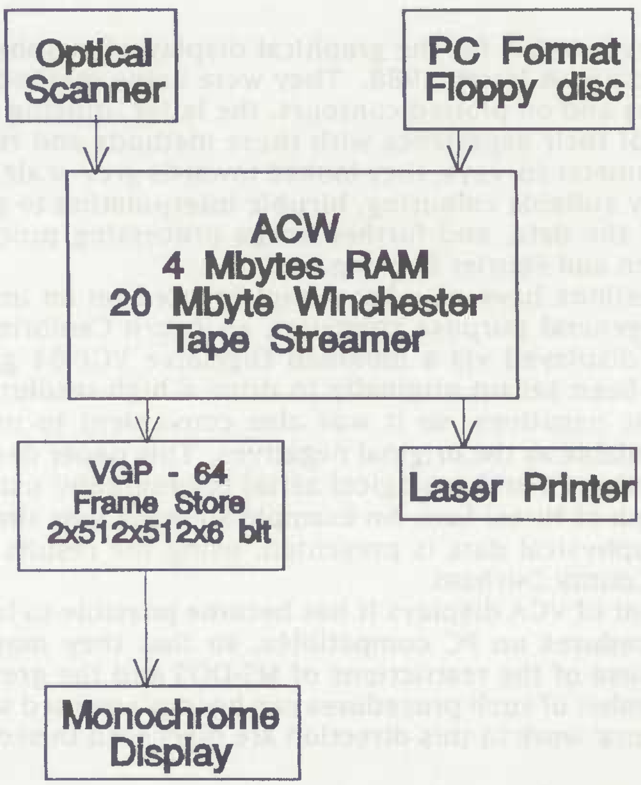

Figure 12.1: Block diagram of the ACW image processing system

In the optical scanner, the negative to be digitised is placed on a stepping motor stage, illuminated from below, and imaged by a lens onto a CCD line sensor containing 1728 individual photodetectors. As the stage is moved in precise steps, adjacent strips of the image are brought onto the line sensor and digitised to a resolution of 256 grey levels to produce a digital image of the entire negative. By changing the position of the lens and the sensor it is possible to accommodate a wide range of object sizes from 70mm negatives to microscopic objects. Although this system is slower than a TV-based image capture system it has much higher resolution, coupled with excellent geometric integrity and wider dynamic range. High-resolution images require large amounts of memory (a 1536 × 1536 image requires 2.25 Mb), so facilities are also provided for scanning a negative at lower resolution by retaining only every second pixel (or every third pixel), with the line spacing adjusted accordingly. Alternatively, a part of an image may be scanned with full resolution.

12.3 System software

Image-processing software has been written specifically for the ACW system. High-resolution images which are too large for direct display may be displayed in full at lower resolution and portions may be displayed at full resolution, or after further magnification. Grey-scale manipulation of images to enhance contrast may be performed in two ways. In the first of these the grey-level transformation required is specified directly by the user. In the second method the user specifies the shape required for the grey-level histogram of the transformed image, and the system computes the corresponding grey-level transformation. In each case, the system displays the shape of the histogram before and after transformation.

More specialised techniques implemented on the system include: convolutions for smoothing, sharpening and edge detection; median filtering; magnification; Fourier transform filtering; and a range of image restoration techniques.

12.4 Application to an aerial photograph

An aerial photograph of Hirsel Law, supplied by the Royal Commission in Edinburgh and showing its hill-top fortress enclosure as grass marks, was of particular interest because a magnetometer survey carried out by Arnold Aspinall had revealed the existence of a semicircular barbican structure at one corner. It was difficult to ascertain whether the photograph provided evidence for the barbican, since the picture was of unusually poor quality: it had been slightly fogged during exposure; the lighting had left one side of the ridge in shadow; and the camera position made the outline of the site very foreshortened in one direction. Fig. 12.2 shows a laser print of the whole region of the enclosure, scanned at low resolution to give a 512 × 512 pixel image, the grey-level range being reduced from 256 to 17 to match the printer. Unfortunately the laser printer introduces subtle horizontal and vertical stripes, which are particularly obtrusive in images containing large regions with single grey levels. The grey-level range of the negative is so great that detail was readily discernable in the screen display only in a narrow band, with the remainder of the image either too light or too dark. It was hoped to process the image in such a way that detail was uniformly visible throughout and, in particular, that the barbican should be clearly apparent.

Several grey scale transformations were applied to this image including a linear contrast stretch, and transformations obtained by specifying the transformed image to have a flat histogram (histogram equalisation) or histograms in the form of upward or downward ramps. A representative example is shown in Fig. 12.3, which is a laser print of the image resulting from histogram equalisation. All of these were

Figure 12.2: Laser print of Hirsel Law aerial photograph before image processing

unsatisfactory in that detail was enhanced in some regions but remained obscure in others. A plot of the grey-level intensities on a vertical line through the middle of the image shows there is a steady increase in intensity from top to bottom of the negative, which makes it impossible to achieve a uniform enhancement of the whole image.

To remove this shading without introducing spurious detail in the regions of interest, a high-pass Fourier transform filter was applied to the 512 × 512 image. A filter suitable for this purpose was found to be a second-order Butterworth filter, falling to 0.707 of maximum at wavenumber 10 (Gonzalez & Wintz 1987). Except at the top and bottom edges of the image, which are of no archaeological interest, the effect was to remove completely the shading from the image, making the image appear much more uniform, although lacking contrast.

In Fig. 12.4 is shown a laser print of the filtered image after applying histogram equalisation. The combination of high-pass Fourier filtering and contrast stretching is very effective in making the detail uniformly visible over most of the area of the image. The light and dark bands at the top and bottom of the image are an artefact of the filtering process. The enclosure markings are now clearly visible over almost all its perimeter and the image is in a suitable form for rectification, in order to make a proper comparison with the magnetometer data. Evidence for existence of the barbican can be seen at the lower left-hand corner of the enclosure. A problem arises in that, although the screen display and its laser print show exactly the same information, they are not perceived as being exactly equivalent. This is because the overall contrast in the print, a passive display in ambient lighting, is much lower than in the active display on screen. To compensate for this effect, it is necessary to produce a screen display with higher contrast than seems to be optimal.

12.5 Application to a resistance survey

The first collection of data to be displayed using the ACW system was from resistance surveys of the Roman fort at Binchester carried out by Steve Dockrill and Mark Gillings. The resistance data of overall size 180m × 160m were supplied preprocessed to cover the numerical range from 1 to 255 corresponding to the grey-level range of image data. The resulting display was very satisfactory, somewhat resembling an aerial photograph in appearance, allowing the geometrical structure of the data to be readily comprehended. Compared with the normal display size of 512 × 512 pixels, the resistance image was rather small and for ease of viewing it was necessary to apply magnification. This was done simply by replicating each pixel to increase its size on the display. This gives a perfectly satisfactory result, unless the magnification is sufficient to make the individual pixel 'blocks' visible at a normal viewing distance, when their presence may obstruct the visual interpretation of the data. Unfortunately, most collections of resistance data are rather small in size compared with normal images and large magnification is often desirable. A more satisfactory way of enlarging a resistance image is to add extra pixels with grey levels found by interpolation between the original neighbouring values. Bilinear interpolation is the quickest and simplest method to apply, but bicubic interpolation yields a smoother result and this was the method adopted. This results in images, smooth in appearance, regardless of degree of magnification, and viewers tend to find it more acceptable than the 'blockiness' associated with pixel replication.

The appearance of the Binchester resistance images were very acceptable, but it was decided to see if any significant improvement could be achieved by applying a high-pass Butterworth filter to remove shading before applying contrast enhancement. Although the resulting resistance image was more uniform in grey level, the improvement did not reveal a significant amount of new information.

Figure 12.3: Laser print of Hirsel Law aerial photograph after grey-scale manipulation

Figure 12.4: Laser print of Hirsel Law after Fourier filtering

In Fig. 12.5 is shown a laser print of the Binchester resistance survey magnified by a factor of three using bicubic interpolation, but with no other processing apart from the reduction in the number of grey levels to match the printer.

12.6 Implementation on a PC

Before the imaging techniques described in sections 12.4 and 12.5 could be transferred to PC compatibles, consideration had to be given to the properties of the VGA display and the MS-DOS operating system. The standard VGA display permits an array of 640 × 480 pixels to be shown in 16 different shades. For the purposes of image display, it is natural to alter the look-up tables in the output, so that the somewhat arbitrary selection of default shades may be replaced by a range of grey-level intensities. The MS-DOS permits direct control of only 640 kbytes of RAM. Since Fourier operations on a 512 × 512 × 1 byte image require the manipulation of a 2 Mb array, the memory restriction precludes the application of many imaging processes to large images. Although various steps could be taken to circumvent both these restrictions, they are likely to make the resulting software inaccessible to most PC users.

Bearing in mind the restrictions to 16 grey levels and to smaller images, it was felt that first priority should be given to the enhanced display of geophysical data, rather than to techniques of image restoration. In effect this means the use of bicubic interpolation to give a display in 16 grey levels over the greater portion of the VGA screen. New options have been added to existing PC software for the analysis of geophysical data, so that the data may be displayed either as rectangular blocks of the different shades of grey or smoothed out by bicubic interpolation. A hard copy of the display can be obtained from a laser printer, in the manner discussed in earlier sections. The new options are arranged in such a way that the hard copy is printed at a scale which may be preset by the user. For the display to be produced reasonably quickly, the PC computer needs to have a mathematics coprocessor and a RAM BIOS.

Full histogram manipulation has not yet been provided within the PC software, but the user is able to adjust the contrast by setting the minimum and maximum levels for the displayed grey scale. The data values for the intervening grey levels are then determined by linear interpolation. For some data sets, it is clearly inappropriate to use a linear scale of intensities, and the authors are looking for a non-linear scale which is simple to apply and yet which gives satisfactory results in the majority of cases. An inverse-tangent relationship seems at present to be the most likely candidate (Scollar *et al.* 1986).

By manipulating the look-up tables, the shades of grey can readily be replaced by a suitable range of colours. Experiments have been made with various selections, including the rainbow hues, and a variation from intense blue to intense red through unsaturated shades around white. A variety of opinions have been expressed about the results, but the general consensus is that while colour displays, particularly the blue-red form, may be helpful in making a detailed analysis of the data, the final presentation is best in monochrome. Nevertheless, consideration is being given to the possibility of using a colour printer to reproduce some of the colour displays. It is interesting to note that the coloured displays of the 16 available intensities are in effect solidly coloured contour plots. Thus the advantages of contours and density representations are combined in one method of display.

The extended suite of software has proved to be enormously successful in analysing both resistance and magnetometer data. Facilities already existed to allow data from the field to be swiftly assembled for display. The new options have been found to provide a helpful but unprejudiced view of the data, from which the user can readily spot the features likely to be of archaeological interest. Some of the greatest

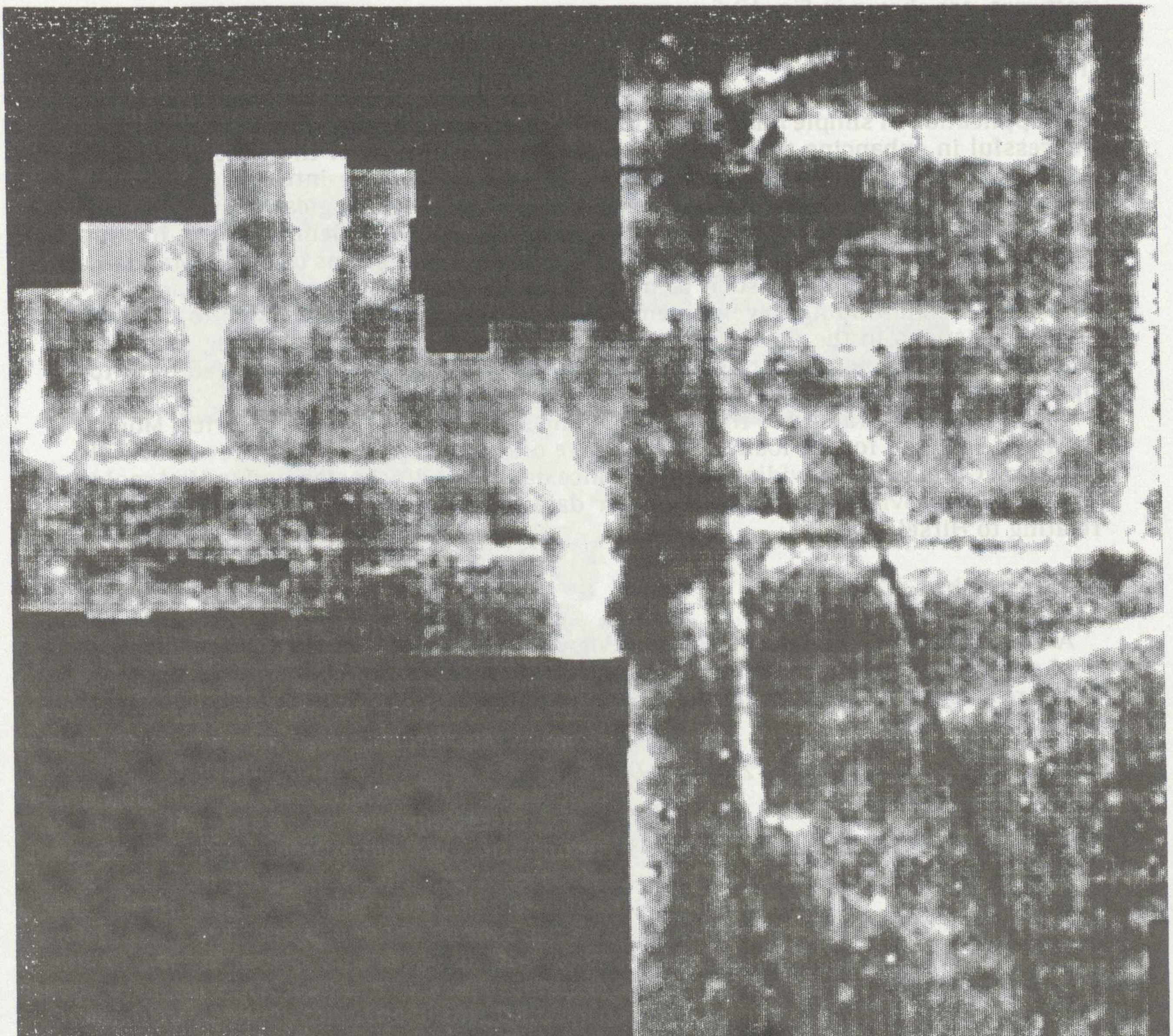

Figure 12.5: Laser print of the Binchester resistance survey

successes have occurred during the re-examination of older data, when the new options have frequently provided a completely new insight into the structure of the results. Since the PC software is modelled closely on that produced for the ACW workstation, the laser output from the two systems is very similar. Thus the PC output for the Binchester resistance survey closely resembles Fig. 12.5, except that the PC software is capable of arranging that the results should be printed at a preset scale. For comparison, the results of a magnetometer survey, produced by the PC software, are shown in Fig. 12.6.

12.7 Conclusions

The application of simple imaging techniques to geophysical data has been extremely successful in enhancing the quality of the output, and most of the expectations of Aspinall & Haigh 1988 have already been fulfilled. The more intricate techniques of image restoration are already being applied for archaeological purposes, and the significance of their use in aerial photography is well demonstrated by the example discussed in section 12.4. Unfortunately, the limitations of the PC standard preclude the availability of such techniques on the majority of current computers. However, the continuing development in computing standards is likely to remove such restrictions in the next few years, to make a wide range of imaging methods available to the general user. In archaeology, they are likely to be applied both to optical images and to geophysical data.

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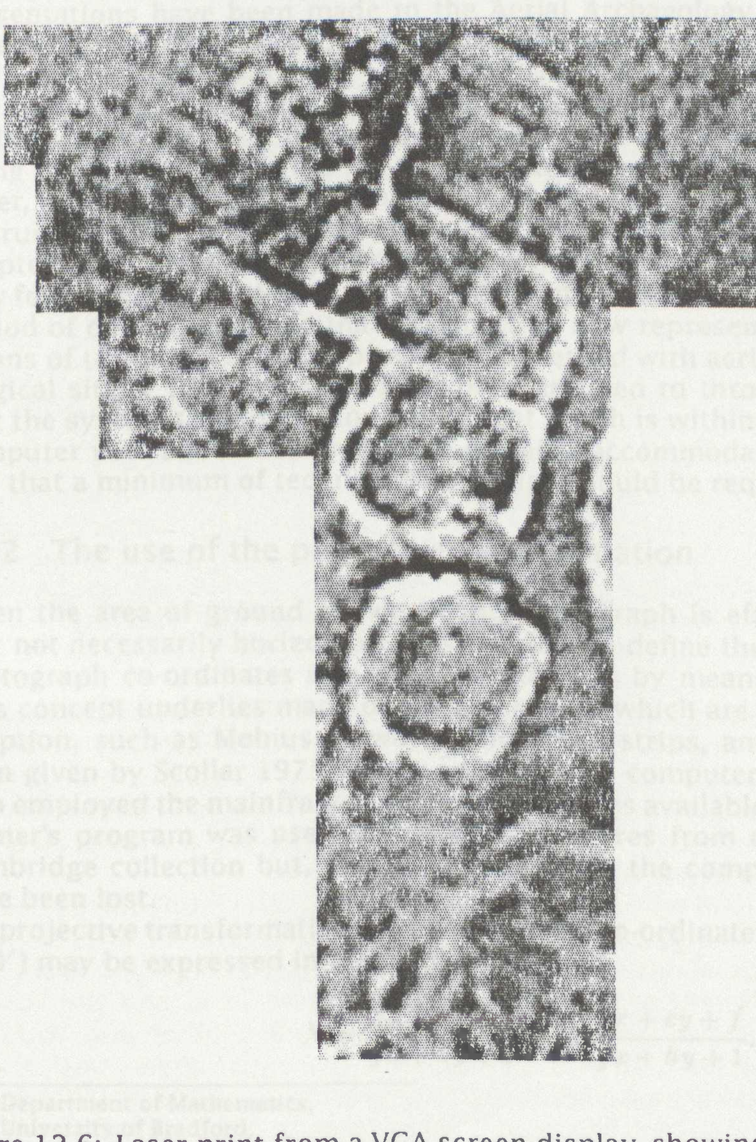

Figure 12.6: Laser print from a VGA screen display, showing a magnetometer survey at Bampton, Oxfordshire