27. An inexpensive PC-based imaging system for applications in archaeology

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27.1 Introduction

There are widespread applications of imaging technology in many areas of archaeology such as analysis of wear and growth patterns (Custer & Doms 1990), studies of ancient metals and pottery (Underwood 1985; Carr 1990; Carr & Riddick 1990; Starley 1990), palaeopathology (Bell 1990; Lieberman *et al.* 1990) and geophysics (Tabbagh *et al.* 1988). In addition imaging with aerial and satellite remote sensing is regularly discussed at meetings of the Aerial Archaeology Research Group. Many archaeologists now have access to personal computers which are powerful enough to handle the image processing tasks required, but they also require hardware to capture digital images and software to manipulate the image data; a recent survey of commercially available systems has been carried out by Parslow (1990). In the present paper we describe a PC-based system for the capture and analysis in digital form of images from a variety of sources including photographic negatives, prints and live scenes. We concentrate on the application to aerial archaeology because this subject is of long standing interest to us (Haigh 1989), involves large memory operation, requires accurate image capture from photographic negatives and uses facilities which are not available in inexpensive commercial systems. However, the facilities developed are suitable for a wide variety of archaeological applications.

Our current system has evolved from earlier work described by Haigh and Ipson (1989) when we had two separate image processing systems. One, described in that paper, was based on an Acorn Cambridge Workstation, a 1728 pixel CCD line scanner and in-house software. The other was a commercial system supplied by Synoptics Ltd which comprised a Matrox PIP1024 frame grabber installed in an Olivetti M24 computer, a CCD TV camera and Semper IV software. Neither system was ideal for the archaeological applications we investigated. The workstation system was flexible and powerful but slow in use and essentially restricted to capturing images of photographic negatives or flat objects of a similar size. The commercial system provided fast and flexible image capture facilities but the software proved difficult to tailor to the requirements of aerial archaeology and the reliance on MS-DOS limited the available memory to less than 640 Kbytes, which greatly restricts the range of image processing operations.

Our objectives were to combine the best features of both systems into a new system with hardware built entirely from off-the-shelf components controlled by our own software, and to make it readily available to practising archaeologists. The recent advent of 386-PCs with several Mbytes of cheap memory, together with DOS extenders such as the Salford Fortran 77 compiler making this memory accessible, has now made it possible to achieve these. Below we describe our current system and give a few examples of its use. Some of these would not be possible for images of 512 by 512 pixels if memory access were restricted to the MS-DOS limit.

27.2 Description of the PC-based system

The hardware of our current system comprises a PC compatible with 386SX 16MHz processor, a 387 co-processor, a colour VGA card, 8 Mbytes of memory, a 125 Mbyte hard disk and a mouse. Also installed in an expansion slot of the PC is a Matrox PIP1024B frame grabber card. We use a Philips CCD TV camera for image capture, and a medium resolution RGB colour monitor for image display. A camera based on a CCD sensor rather than on a vidicon tube is essential for applications such as the rectification of aerial photographs, because a CCD sensor does not introduce geometric distortion into the image. A large amount of memory is essential both to permit Fourier processing operations, which require 2 Mbytes for 512 by 512 images, and to permit software expansion by, for example, the inclusion of specialist routines such as the software for the rectification of aerial photographs (Haigh 1989).

Fig. 27.1 shows the system being used to examine a photographic negative mounted, for easy positioning, on an xy-stage originally designed for a microscope. The illumination is provided by a simple light box hidden behind the image display monitor in this figure. We use a 50mm fixed focal length TV camera lens because it provides, at a convenient working distance, a suitable reduction for imaging 70mm negatives onto the 12.7mm diagonal CCD sensor.

The software for our current system is a modified version of the software originally written in Fortran 77 for the Acorn Cambridge Workstation. The software contains embedded assembler routines for operations where speed is critical and uses the Salford FTN77/386 compiler to allow access to the whole of the extended memory of the PC.

27.3 Hardware facilities

We have chosen to base our system on the PIP1024 card because this provides, at moderate cost, a useful range of facilities for our applications without being unduly complicated. The PIP card is able to store a single image of 1024×1024 pixels with 256 grey levels, or four images of 512×512 pixels; the latter feature makes it easy to compare different images and the results of different operations, since switching the display from one image to another is virtually instantaneous. A hardware facility is provided to change the offset and gain applied to the TV signal before it is digitised, thereby allowing user software to optimise the capture of the image. In some applications it is helpful to be able to align the object with the TV camera xy-axes and the PIP card has a video-keying facility, which is used by our software to superimpose adjustable cross wires on the live TV image for this purpose. Contrast manipulation of images is a fundamental and highly useful operation in image processing, and the PIP card has hardware look-up tables which speed this up and allow it to be applied to live images. The Matrox card provides the host PC with quick access to the stored image data, allowing suitable software to complete most image processing operations in an acceptable time scale.

27.4 Software facilities

The software is menu driven, using keyboard and mouse, and provides a wide range of standard operations for image processing and analysis (Jain 1989), equivalent to those found on many commercial packages. The facilities include: transfer of images between the PIP card, memory, winchester and floppy disk with storage in a variety of formats; contrast manipulation by several techniques; a wide range of convolutions; Fourier filtering on the full image; image restoration techniques; resizing of images using bilinear or bicubic interpolation; hardcopy; superposition of text on the image; false colour display; feature measurement; and many other miscellaneous facilities. Calls to the operating system, for example to check a directory listing or to format a floppy disk, may be made without leaving the image processing software.

A significant feature of the software is the speed of response which is very good for the majority of operations. The following examples are based on a 512×512 image: image transfer between PC system memory and the PIP, 1 second; calculation of an image histogram of an image in frame store, 1.1 seconds; operations based on 3×3 convolutions such as smoothing, sharpening, edge detection etc., 3 or 4 seconds; erosion and dilation operations, 3 seconds. In critical operations the performance has been optimised by incorporating assembler code, and is slightly faster than the corresponding software provided by Matrox and written in C. The most time consuming calculations are Fourier filtering operations which take about 8 minutes to complete a cycle of transform, filter and inverse transform on a 16MHz 386 PC. The use of faster PCs would obviously reduce this time and as yet we have made no attempt to optimise these routines by using assembler code.

27.5 Application of the system to aerial archaeology

To illustrate some of the operations available we have chosen to concentrate on two 70mm negatives supplied by the Royal Commission in Edinburgh. These are aerial photographs of Hirsel Law from two different viewpoints, showing its hill-top fortress as grass marks. The quality of the negatives is unusually poor by the standards of the Royal Commission, because of adverse lighting conditions and fogging which has occurred at some stage of the photographic process. In addition the grass marks of interest are not ideally positioned in the negatives because they extend rather close to the edges of the photographs.

All the images presented in this paper were captured and processed as 512×512 images. Two operations were performed on all the images prior to capture. Firstly, the offset and gain applied to the TV signal were adjusted to optimise the signal received by the analogue-to-digital converter on the PIP card; this was done interactively to give the optimum histogram of the displayed digitised image. Two examples of image histograms, in the form displayed during the interactive process, are visible on the PC monitor in Fig. 27.1.

Secondly, the Philips CCD camera we used produced significantly more noise than we would expect from a more modern camera and this noise was made evident because different images of the same negative, captured under the same conditions, were visibly different. All TV cameras will generate some electronic noise, the amount depending on the sensor technology employed and how modern the camera is. The software contains a facility for the temporal averaging of successively captured image frames and this was used over 25 frames. This process took about 32 seconds and should improve the signal to noise ratio by a factor of 5 for random noise. The actual improvement from such averaging can be seen in Fig. 27.2, which shows two plots of the variation of grey-level with position along a horizontal line, half way down the image. The upper plot is from a single captured image and the lower is a plot from an image of the same scene after averaging over 25 frames. The comparison of the two plots shows that the electronic noise has been significantly reduced by the averaging. This facility would still be useful, because there would be a real improvement in quality, even if the camera had an excellent signal to noise ratio. Also, other sources of images used by scientific archaeologists such as electron microscopes are intrinsically noisy.

Fig. 27.3 is a photograph of the display screen on which four images, obtained from the first negative of Hirsel Law, have been combined using our system software. In order to display all four images on the screen simultaneously, for ease of comparison and compactness of presentation, each image has been reduced to 256×256 pixels. Images 3A and 3B show respectively the original negative and a grey-scale reversed version which gives the appearance of a print. The software enables the user to accomplish this reversal virtually instantaneously, by a single keystroke and we envisage that a significant use of the system would be the rapid inspection of photographic negatives without the necessity to generate prints. All the images presented except Fig. 27.3A are grey-scale reversed to resemble prints.

The important grass marks in the scene are just about visible all the way round the fortress but, unfortunately, the lighting was such that one side of the hill was in sunlight and the other in shadow, so the marks are superimposed on a strongly varying background. The

Figure 27.1: A view of the image processing system being used to examine a photographic negative of Hirsel Law. Shown to the left on the PC monitor is the grey level histogram of the captured image with the histogram of the displayed image resulting from contrast manipulation on the right.

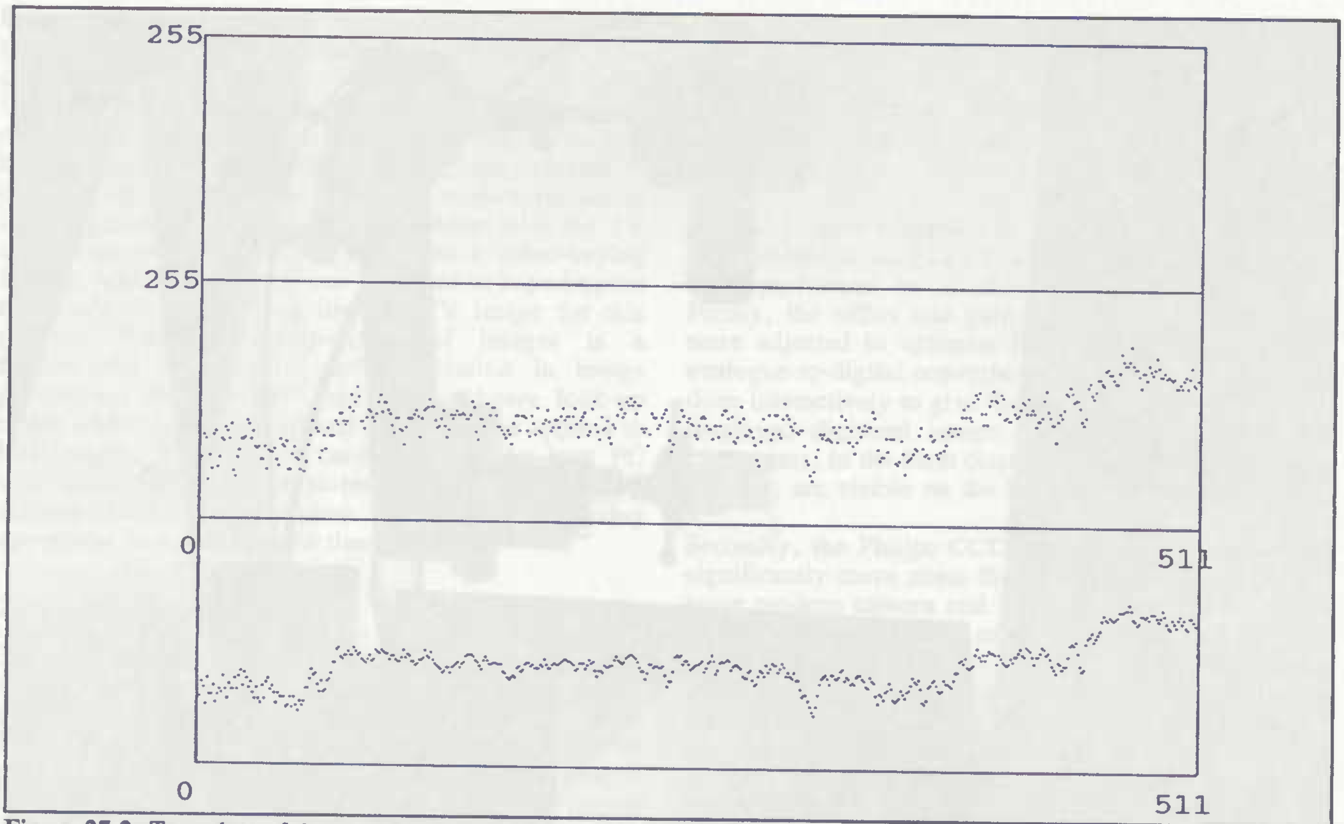

Figure 27.2: Two plots of the grey level intensity along a horizontal line half way down a captured image. The upper plot is from a single captured frame and the lower plot shows the reduction in noise resulting from averaging over 25 captured frames.

contrast of these images has already been optimised through offset and gain adjustment and the application of a simple contrast stretching cannot improve the visibility of the marks throughout the image; although some improvement would be gained in some regions, there would be a corresponding deterioration in others.

One standard procedure for tackling this type of problem is by applying Fourier high-pass filtering to the image followed by contrast stretching and the result of this procedure is shown in Fig. 27.3C. The value of the cut-off frequency is not critical but it is important to choose a filter which rolls off slowly, otherwise obvious artefacts appear near any pronounced edges in the image. In this case a second-order Butterworth filter with a cut-off at wave number 5 was chosen. Even so the filtering process has distorted the image close to the top and bottom edges, between which there is a large difference in intensity. The image resulting from Fourier filtering has the same low contrast for fine details as the original image but, since the overall contrast has been reduced, the details can now be revealed by strong contrast stretching. Fig. 27.3C demonstrates the remarkable improvement that can be obtained using this method, since the grass marks of interest are easily visible all the way round the fortress. The degree of contrast stretching applied to produce the most satisfying result is subjective and is largely a matter of the particular user's taste. The software has therefore been written to allow the contrast stretching to be carried out interactively with the aid of either the keyboard or the mouse. The more complicated grey-scale transformations described in our previous paper (Haigh & Ipson 1989) can also be carried out interactively and almost instantaneously, enabling the user to achieve the best displayed result easily and rapidly.

An alternative method of removing background shading is morphological filtering (Giardina & Daugherty 1988), which is currently of particular interest in image processing, and the result of applying this type of operation to the image 3B is shown in Fig. 27.3D. This image was produced by first applying an erosion operation followed by a dilation operation, to estimate the background shading, and then subtracting the result from the original image, before final contrast stretching. Although the grass marks of the fortress are visible all the way round in image 3D, there are local regions where the grey levels of the details of interest have been reversed compared with the original and on the whole we prefer the results from the Fourier approach. The advantages of the morphological approach are that it is faster and will run within the 640 kbyte MS-DOS memory limit.

Fig. 27.4 is a photograph of the display screen showing four images obtained from the second negative of Hirsel Law. This negative had been more seriously fogged than the previous one, as is evident from inspection of Fig. 27.4A, which shows most of the original photograph. The fortress grass marks, seen from a different viewpoint, are visible in the upper half of this image and fortunately are not disastrously affected by the fogging in the lower third. In Fig. 27.4B is shown the result of applying high-pass Fourier filtering using a second-order Butterworth filter, with cut-off at wave number 10, followed by contrast stretching. This has had the effect of largely eliminating the fogging and detail is now visible in previously fogged regions.

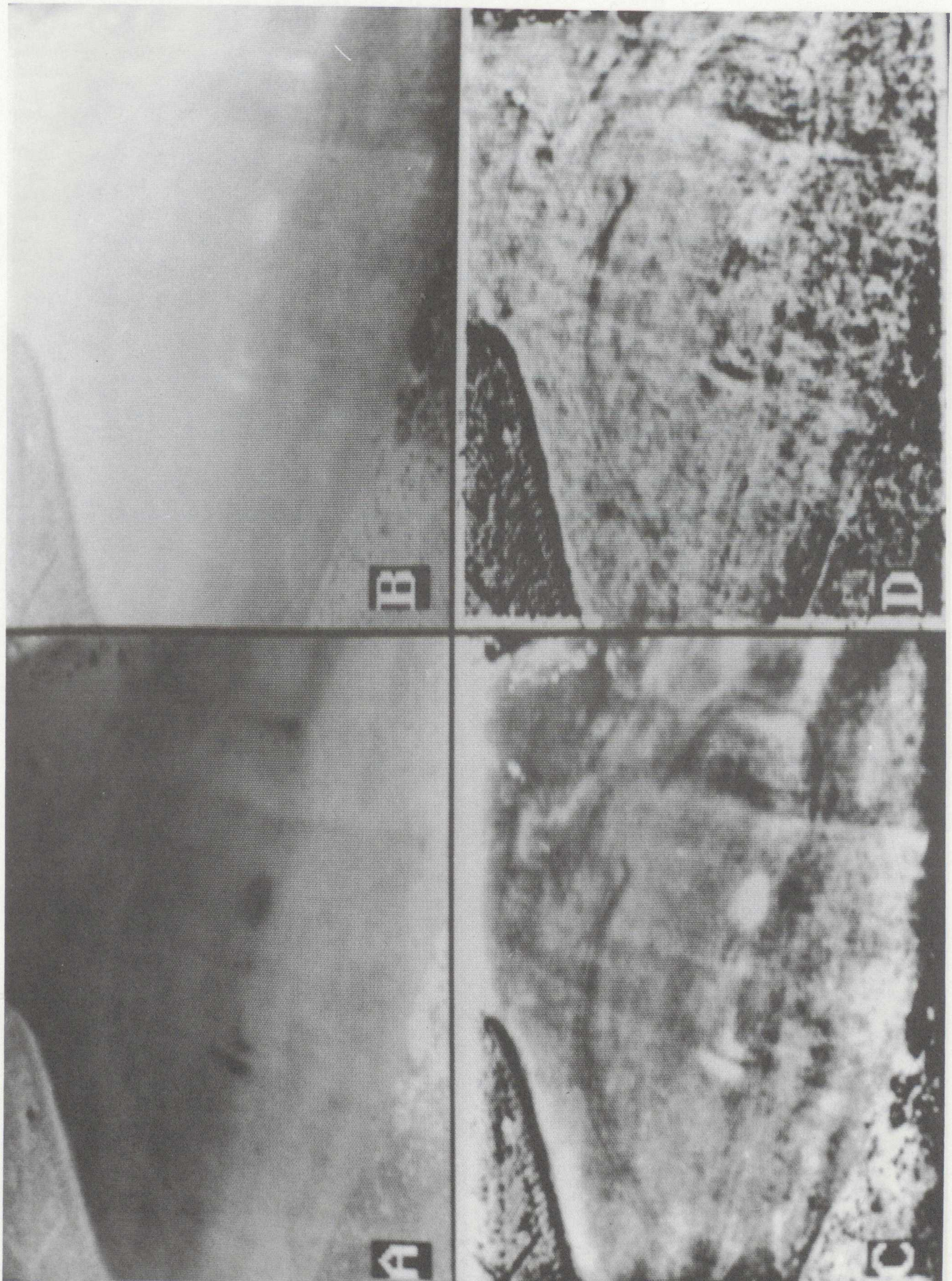

Figure 27.3: Photograph of the image display screen showing four operations on the first negative of Hirsel Law:
A. original image held in memory resembling the photographic negative;
B. grey scale reversed version of A to resemble a photographic print;
C. result of applying high-pass Fourier filtering and contrast stretching to B;
D. result of applying morphological filtering and contrast stretching to B fogged regions.

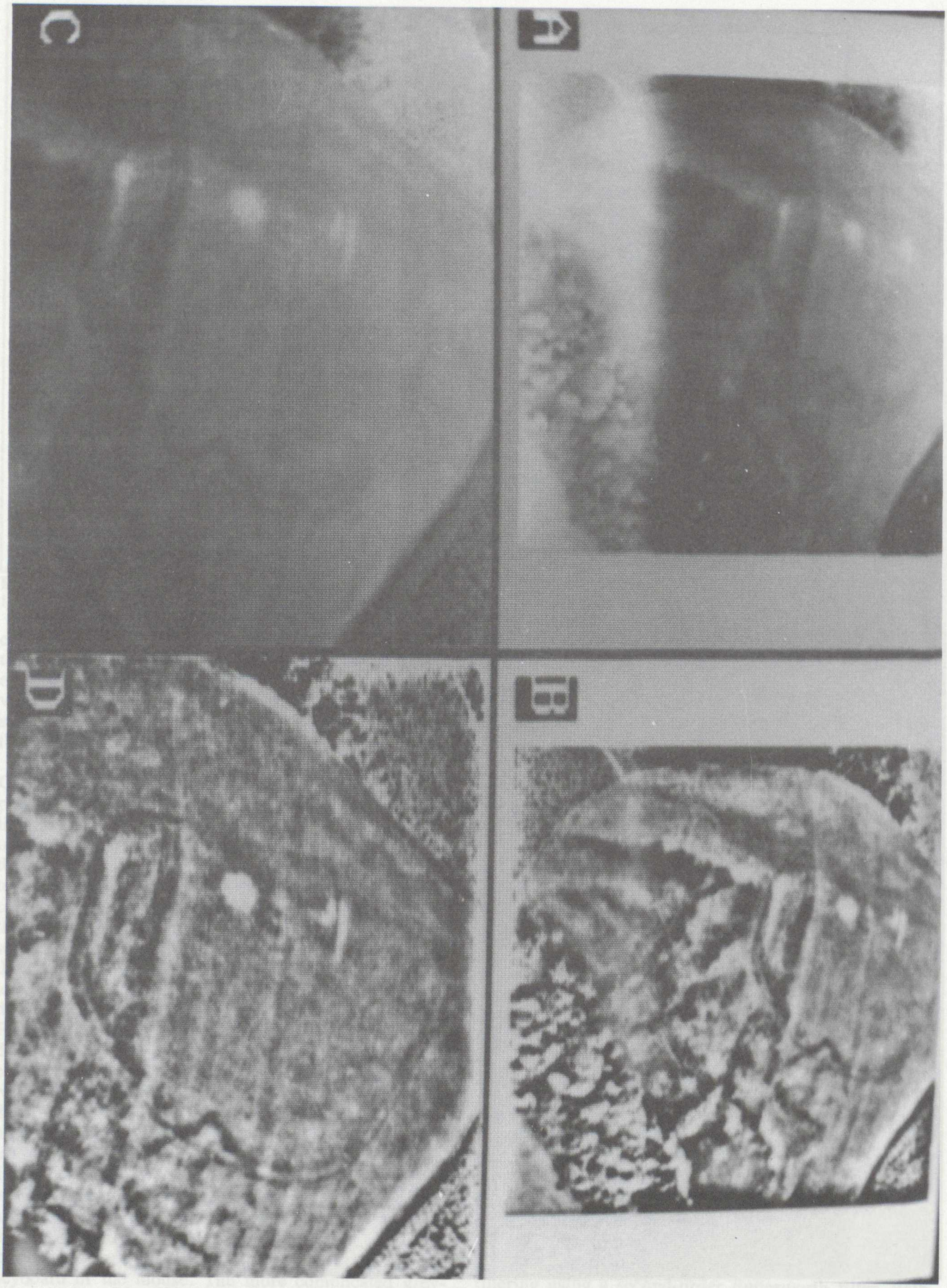

Figure 27.4: Photograph of the image display screen showing four operations on the second negative of Hirsel Law:
- A. grey scale reversed image showing the extent of the fogging on the original negative;
- B. result of applying high-pass Fourier filtering and contrast stretching to A thereby removing most of the fogging;
- C. magnified image showing the region of the grass marks on the original negative;
- D. result of applying high-pass Fourier filtering and contrast stretching to C.

An attempt had been made by one of our colleagues to achieve a similar improvement in the darkroom by selectively masking parts of the print during exposure. Although this was partially successful, it was much more difficult to carry out than the image processing method.

The image shown in Fig. 27.4C is a magnified view of the same negative showing only the region of fortress grass marks. This was captured by refocusing after shortening the separation between camera and negative, rather than by software based magnification. The problem of background shading in this image has been solved by applying high-pass Fourier filtering in the same way as for the first negative and the result of this operation is shown in Fig. 27.4D. Again there is a dramatic improvement in the uniformity of visibility and the grass marks can be seen all the way around the enclosure. It should be emphasised that the images reproduced here are considerably less clear than the corresponding images on the monitor, partly because the area resolution has been reduced by a factor of four and partly because some detail has been lost in the production of the prints. The quality of the filtered images is advantageous for photogrammetric analysis since the features of interest are clearly defined and control points can be pin-pointed with great accuracy. Where there is considerable intensity variation over the scene, control details on a photographic print may be hidden in deep shadows or strong highlights. Consequently it may be difficult to obtain accurate photographic coordinates by means of a digitising tablet. Although the screen display has an inherently lower resolution than the digitiser, the ability to enhance visibility may lead to greater accuracy in the final result. Since aerial photographs for archaeology are often taken with the sun at a low angle, it is quite common to find large variations of illumination in the scene and enhancement of this kind is very desirable.

27.6 Conclusions and further work

The examples of image capture and manipulation presented here give some indication of the facilities available within the system from both hardware and software. The system has been used by several undergraduate and postgraduate students who have operated it successfully with little instruction. It has proved to be very flexible in allowing the user to perform easily any combination of the available operations. The current PC-based system has overcome the limitations of earlier PC systems — highlighted in the conclusions of Haigh and Ipson (1989) — and achieved our aim of making available to the general user a wide range of imaging techniques. As a rough indication, the combined cost of framestore, display and camera is about £3500. We hope that the image processing software will eventually become available at a price which will cover the cost of development and installation.

Our next objective is to combine into one package the rectification software described in Haigh (1989). This should be straightforward since they are written in the same language and are both highly modular. A desirable new facility will be the rectification of raster images. Furthermore the screen image provides an attractive alternative to the digitising tablet as a source of vectorised information for the construction of maps and plans. This avoids the necessity to work from photographic prints, allows close control over the contrast of the image and improves the management of the data. A difficulty with using a screen image is that the resolution is lower than a print but we intend to overcome this by creating controlled zoom facilities. We hope the combination of these facilities will enable a non-technical user to carry out sophisticated analysis in aerial archaeology.

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