

16

Interpreting earth measurements by image enhancement techniques

J. L. H. Hartmann*

16.1 Introduction

In this paper, I will discuss some methods for evaluating a wide range of topographical measurements common in archaeology, by means of micro-computers without special hardware. Examples will be taken from height-, phosphate- and resistivity- measurements, but the methods discussed are applicable to all kinds of spatially distributed measurements, including grid cell and point location counts of artifacts. These methods originate from the very wide field of image enhancement by computer; they have to be adapted, however, to the special requirements demanded by non-visual data and by the non-specialised hardware that is only available to most archaeologists.

Traditionally, topographical measurements have been subjected to a wide range of statistical techniques from the field of spatial analysis (Carr 1984). Some common aims are the establishment of global properties of distributions (e.g. random / clustered) and the detection of meaningful subdivisions. It has always been very difficult, however, to connect the mathematical results with the archaeological reality: what is the relationship between the 'clusters' of cluster analysis and the 'activity areas' archaeologists are really looking for? Besides, almost all techniques are heavily model-bound and can only be applied in special circumstances. The last twenty years have seen a proliferation of methods for spatial analysis, but a common base still seems to be lacking. As a result, spatial analysis has remained largely the sphere of experts and has always been difficult to 'sell' to practising archaeologists.

Image enhancement techniques meet some of the problems discussed above. In the first place they are very good in detecting intuitively appealing patterns. Secondly they form part of a very well researched subject, with major contributions from such divergent areas as medicine, weather forecasting and space travel. There is a common set of techniques which are well understood, easy to implement and have proved their merits. Thirdly, even the cheapest personal computer has nowadays graphical and computational capabilities which bring simple image enhancement techniques within range.

* Instituut voor pre- en protohistorie
Singel 453
1012 WP AMSTERDAM
Netherlands

This does not mean, however, that image enhancement techniques will solve all problems. One has to be very careful in choosing the right data to submit and the right methods to subject them to. Visual data tend to come in amounts that are unworkable but for the largest computers, while the time taken by image enhancement algorithms tends to grow exponentially with the increase of data. Moreover, the patterns discovered by image enhancement techniques, are in no sense more 'real' than those detected by the more traditional approaches of spatial analysis. Most filters we will discuss for example are mathematically extremely simple, but their effects on the patterns we see can be very complex. Ultimately, it remains the job of the archaeologist to give a meaningful and archaeologically convincing interpretation of the images.

16.2 Hardware requirements

As has been said, the data we will consider are not visual data at all. Photographic image processing has been applied in archaeological contexts for years by Scollar in Bonn (Scollar *et al.* 1984) and Becker in Munich (Becker 1985). By now low-budget hard- and soft-ware is available to scan photographs and subject them to some basic image-processing. We will consider the extension of these techniques to all sorts of topographic measurements. Clearly, there are some differences between a digitised photograph and a set of (e.g.) height measurements. As a rule, there will be far less measurements than photographic pixels. At the minimum, a digitised photograph contains about 60000 pixels, while in more advanced systems this number lies around a million. A series of measurements taken in an archaeological context will seldom exceed some few thousands numbers. The dynamic range of these measurements, however, will almost always be much greater than that of a digitised picture. Practically all scanning and image-processing hard- and software is based on a maximum of 256 discrete levels. For virtual images this is generally amply sufficient, as images with as few as 100 intensity levels will appear reasonably smooth to the eye (Niblack 1986). Constraining field measurements into a range from 0 to 255, however, can cause a significant loss of accuracy, especially when, as in most cases, the measurements are not uniformly distributed.

As a result, field measurements cannot be displayed or processed by standard image processing hardware without some preprocessing. Scollar has described the steps needed to adapt magnetic measurements to a high resolution image processing system (Scollar *et al.* 1984): first of all the number of measurements has expanded by interpolation, in order to fill the 1024 by 1024 pixels of the whole screen; secondly the range of the measurements has to be compressed to a number between 0 and 255, by means of transformation. Scollar uses an arctangent function, but a whole range of transformations, especially logarithmic ones, is possible. Only after these quite drastic modifications the measurements can be subjected to image enhancement (Scollar *et al.* 1986). Interpolation and transformations are very important in processing data and we shall have much to say about them.

Far-reaching modifications are needed to adapt topographical data to a dedicated image processing system. In most environments, much less computing power is available. The number of colors or grey-levels on personal computers, and even on medium sized ones, is generally 16 and does as a rule not exceed 64. The number of pixels varies inversely with the number of available colors, but fluctuates in most cases

around 600 horizontally and 400 vertically. Even more prohibitive is the impossibility of getting hardcopy results. Both problems can be circumvented by a technique, traditionally known as 'dot density plotting', or as 'half-toning' (Ulichney 1987). In this technique, gray levels are not rendered by individual pixels, but by small rectangles of pixels, randomly filled up in proportion to the desired brightness. The method, which has been widely applied in archaeological prospecting, solves some of the above mentioned problems. First of all gives very good results on the current generation of micro-computers. Secondly, surprisingly good hardcopy output is possible even on the cheapest dot-matrix printer with graphical capabilities. Output on a laser-printer could well be up to publishing standards. Moreover, as printouts can be delivered on scale, they are directly comparable to other cartographic material. Most important, images rendered by halftoning can be subjected to image processing. Although the method is not very important for photographic material and does not take place in real time, it solves most of the problems mentioned for non-visual data.

As has been said, most datasets of topographic measurements are relatively small. Grids of up to 256 by 256 measurements can be processed by micro-computer, although for a series of more than 10000 measurements a fast processor and a good graphics card will be necessary. As output takes place by means of dot density plots with adaptable cell-sizes, it does not make sense to scale raw data into a predefined range. Therefore, data can be held in raw form, or for computational ease, normalised to 0-1 or 0-32768. In this way, transformations and interpolations can be integrated in a flexible way within the processing system. Moreover, processing a single image requires as a rule a whole series of consecutive manipulations. Keeping the data in their original form will prevent round-off errors. As last advantage the data do not have to be expanded to fit into the image: instead the grid-size of the dot-density plot can be adapted to allow for the required dimensions.

16.3 A simple example

The Institute for pre- and protohistory of the University of Amsterdam is in an excellent position to study the possibilities of processing topographical datasets. There is much demand from governmental agencies for large scale archaeological evaluations of threatened areas, so much prospecting has been done the last few years. As only very small parts can actually be excavated, interest has been centred in methods of indirect and non-destructive archaeology. For some time now field measurements, especially height, phosphate, and resistivity measurements, have been routinely subjected to a set of image processing techniques, implemented on IBM PC's. As an example I will show some manipulations on a small dataset of 483 height measurements taken at a medieval raised house platform in Uitgeesterbroek in Holland. Measurements were taken on a rectangular grid of 20 by 22 metre with an interval of one metre.

Fig. 16.1 shows the height measurements by contour-lines. (Note by the way how quite workable output can be obtained from cheap printers). The global properties of the site can be seen quite clearly: the raised mound in the middle and two ditches to the north and south. For the rest the picture is far from ideal: the contour lines look too jagged and there seems to be a lot of noisy detail.

This can be seen even more clearly on Fig. 16.2, which shows the same measurements as a three-dimensional plot. This is the most honest rendering of the original data and

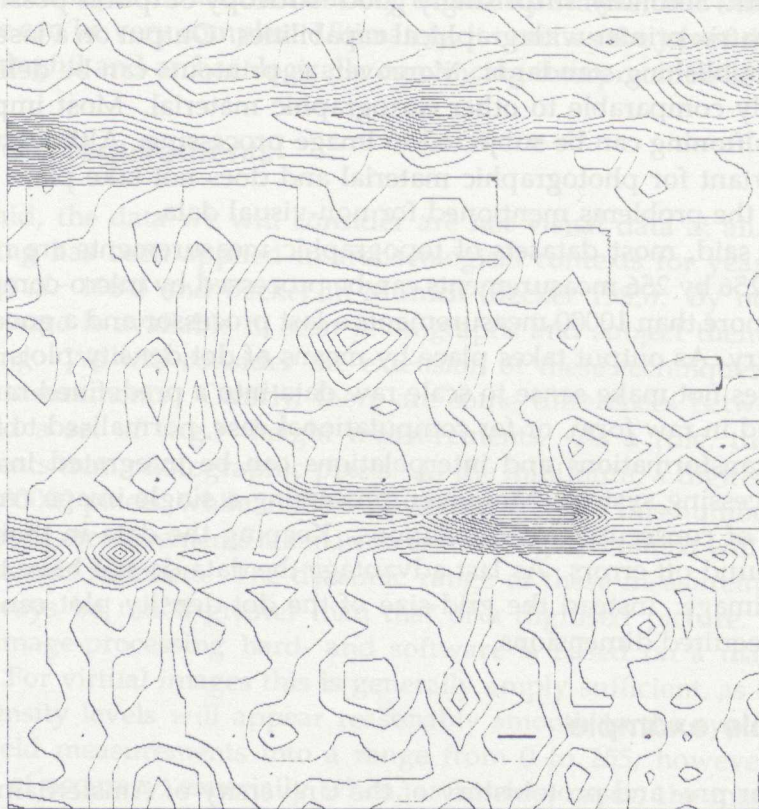


Figure 16.1

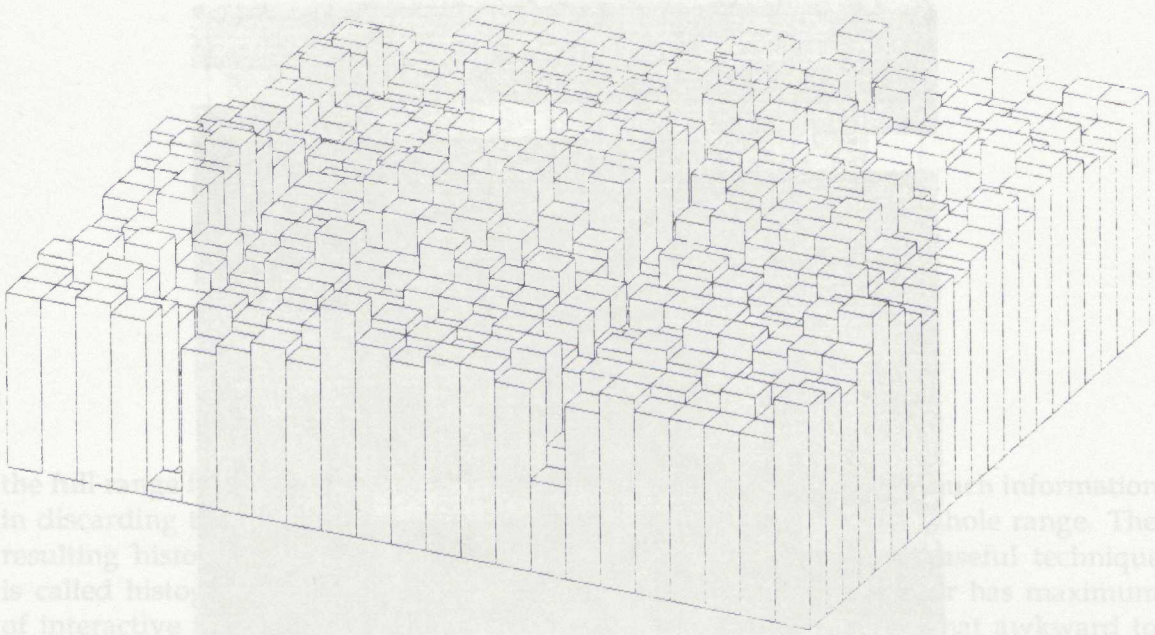


Figure 16.2

seems even less promising than the first one. Although the raised platform and the two ditches are still visible, there is clearly a lot of statistical noise in the measurements. This is not very astonishing, as the measurements range only between 1.48 and 1.15 meter below sea level. With a maximum difference of 33 cm between highest and lowest point any small deviation will be dramatically enlarged.

Fig. 16.3 is a halftone rendering of the measurements: high is black, white low. Compared to the dot-density plots of some years ago, this picture from a cheap matrix printer already shows a marked advantage in resolution: it contains about 200K of graphical information. Yet even so, the results are not encouraging. Take for example the ditches. We know they are there, because we saw them while measuring. However, by just looking at this plot you would not have seen two ditches, but five or six holes. This is, of course, a result of the size of the grid system. The ditches were too narrow for the 1 meter grid, so sometimes they got measured and sometimes they fell between measurements, a fundamental problem with all measurements. We will see that the image processing techniques can under some conditions detect entities at one half to one third of the measurement size.

A second reason for the unsatisfactory look of this plot is its overall grayness. Except for some white spots, the picture is uniformly dark-gray. All those many small details on the contour and three-dimensional plots seem to be missing on this one. The reason for this can be seen on one of the most important tools in image processing: the image histogram (Fig. 16.4).

The image histogram shows how many grid-cells are contained in each gray-level. It is not only important for describing and analysing the image, but also forms the basis for a whole family of image transformation techniques. In this case it can be seen the most of the gray levels lie within a small interval, containing only about 25 percent of

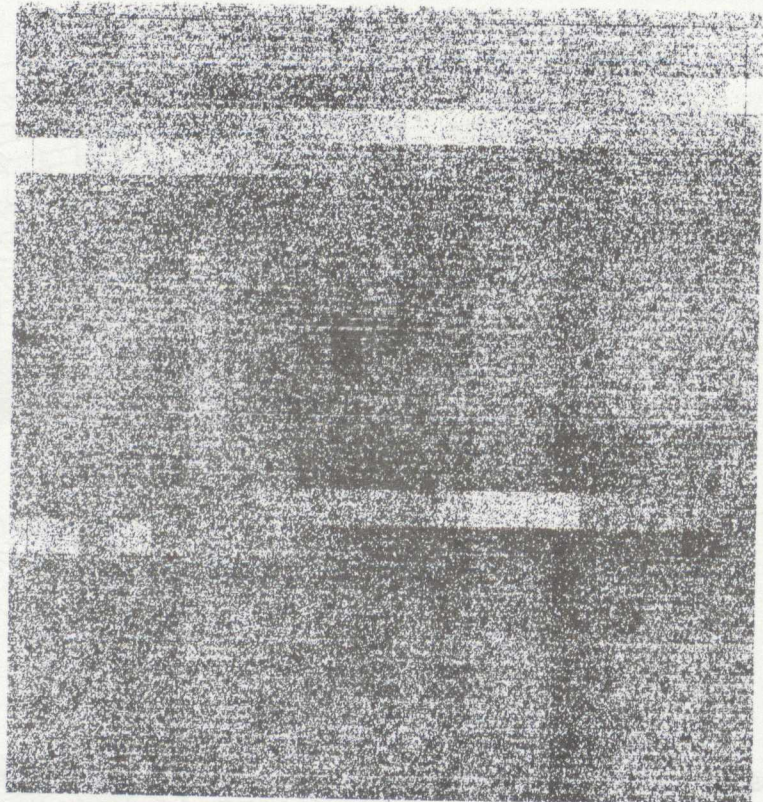


Figure 16.3

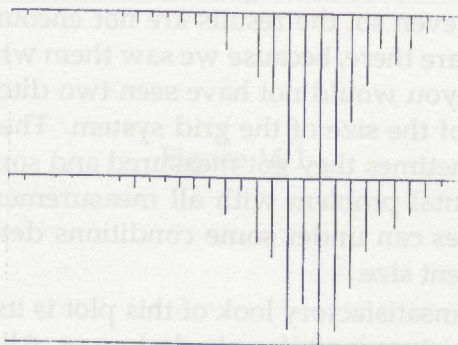


Figure 16.4

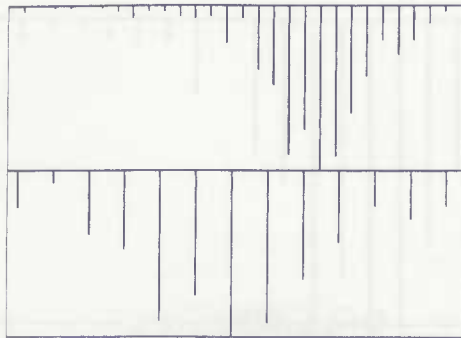


Figure 16.5

the full range from white to black. It is evident that you will not lose much information in discarding the outliers and spreading the central values over the whole range. The resulting histogram is shown in Fig. 16.5. This very simple, yet useful technique is called histogram stretching; it is only practical however, if the user has maximum of interactive influence over the operation, and this makes it somewhat awkward to implement. The resulting plot is shown in Fig. 16.6; as you can see there has been a marked improvement in contrast, at the loss of data at the highest and lowest points. Of course you can fill up these holes with black and white values, but as a rule it is better to leave them as they are. If missing values are added, the resulting image histogram will contain pikes at the extremes, and this tends to give very unsatisfactory results which further processing.

Image stretching techniques are especially useful for looking at parts of the data. It is also possible to stretch differently different parts of the histogram, to enhance regions of interest. However, it has some drawbacks. There is a certain loss of information, and the overall smoothness of the image tends to decrease. In our experience, smoothing is almost invariably needed to get visually appealing output. The first method that comes to mind is average smoothing: replace every grid-cell by the mean of itself and its neighbours. The number of neighbours should be user definable. Fig. 16.7 shows the effects on the histogram of smoothing: extreme values disappear, and values in the middle range get smeared out. Because outliers have been smoothed away, you can stretch the image without further loss of information.

Average smoothing can remove some local noise, but it can blur meaning high gradients. Very often it is more profitable to smooth by median filtering: every grid cell is replaced by the median of its neighbours. As can be seen in Fig. 16.8, no intermediate values are generated. Individual outliers are removed but more global transitions are preserved. By choosing an adequate number of neighbours, you can to a certain extent influence the smoothing and sharpening characteristics of median filtering.

Results of average filtering are shown in Fig. 16.9. Both house platform and ditches have been blurred a bit. The median filtered plot (Fig. 16.10) has kept clearer outlines, but as can be seen, the southern ditch has disappeared almost completely.

Extensions of filtering techniques are filtering with thresholds (only use values which do not deviate more than some chosen limit from the central value), and normalizing data by replacing them with their standardized values from the mean of chosen region.

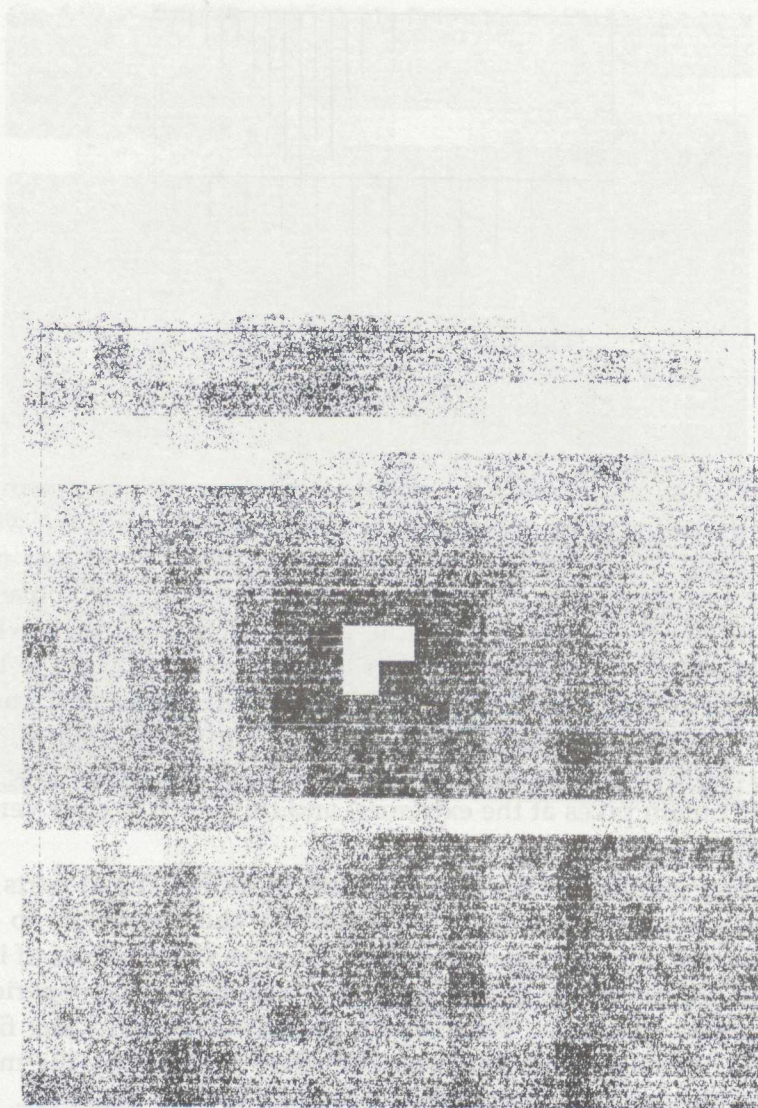


Figure 16.6

Average smoothing can remove salt-and-pepper noise, but it can blur meaning high gradients. Very often it is more profitable to smooth by median filtering: every grid cell is replaced by the median of its neighbors. As can be seen in Fig. 16.8, no intermediate values are generated. Individual entities are removed but more global transitions are preserved. By choosing an adequate number of neighbors you can to a certain extent influence the smoothing and sharpening characteristics of median filtering.

Results of average filtering are shown in Fig. 16.9. Both house platform and ditches have been blurred a bit. The median filtered plot (Fig. 16.10) has kept clearer outlines but as can be seen, the southern ditch had disappeared almost completely.

Extensions of filtering techniques are filtering with thresholds (only use values which do not deviate more than some chosen limit from the central value), and normalizing data by replacing them with their standardized values from the mean of chosen region.

16. INTERPRETING EARTH MEASUREMENTS BY IMAGE ENHANCEMENT TECHNIQUES

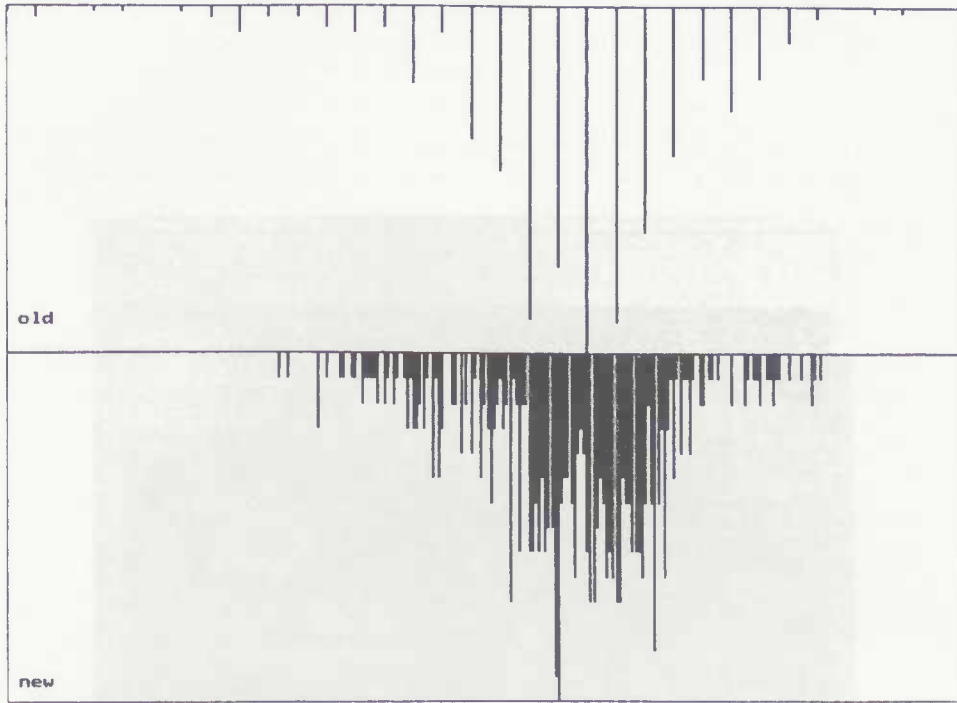


Figure 16.7

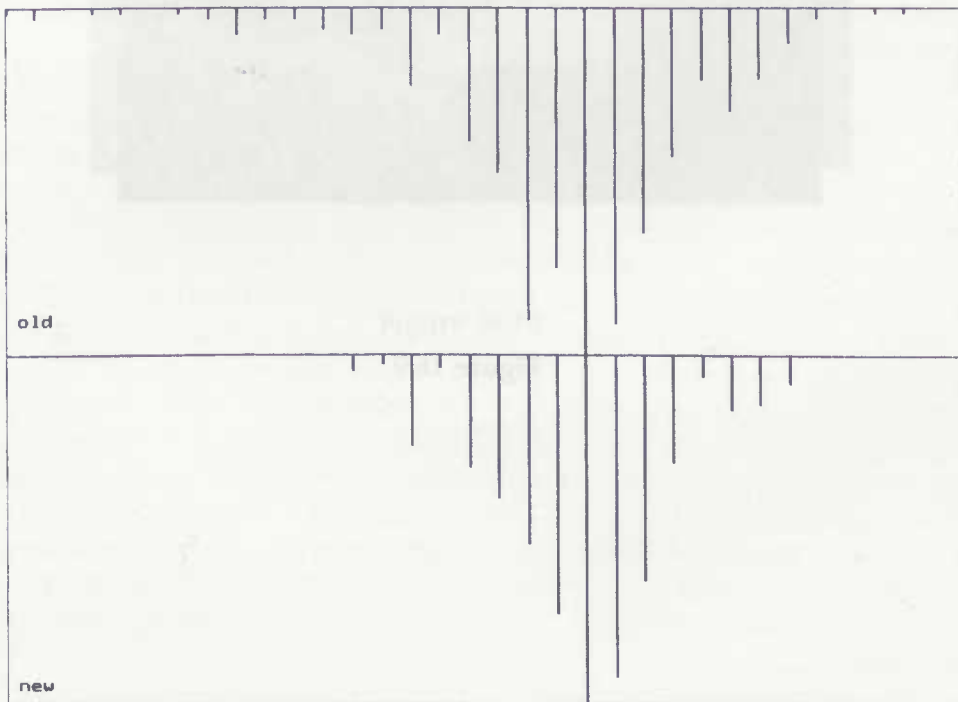


Figure 16.8



Figure 16.9



Figure 16.10

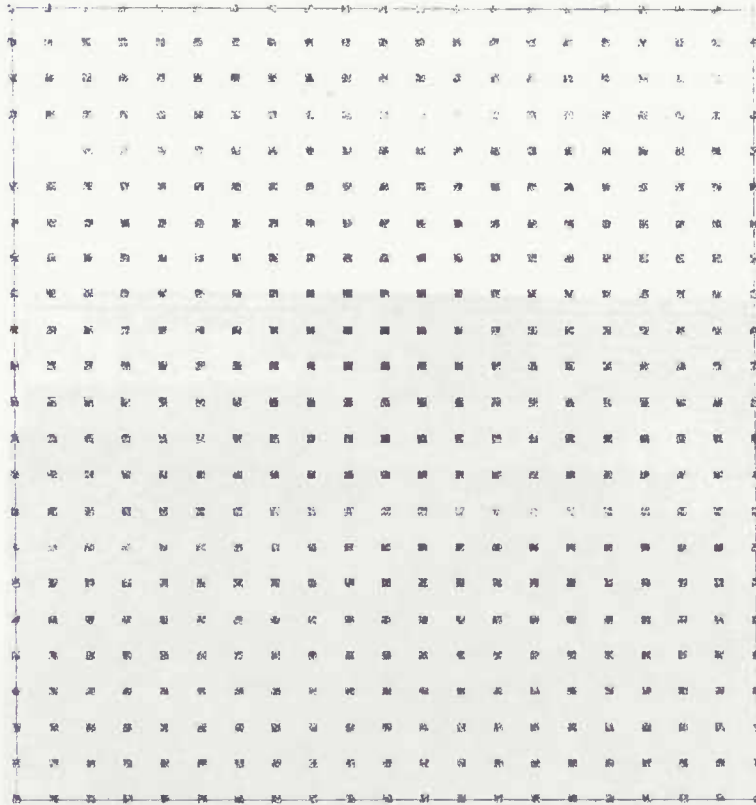


Figure 16.11

As Scollar has shown (Scollar *et al.* 1984), more robust results are obtained by replacing mean and standard deviation by median and interquartile difference.

A fundamental problem in applying global filters is the interdependence of filter size and object size. As different objects in one plot will not have the same size and form, applying one general filter can enhance some features at the expense of others. We have found it quite difficult to predict the effects of applying filters on measurements. Some experimenting is required to get good results. Local filters could give a partial solution, but more practical information is needed, I think, on the interrelationship between measurements done and the actual archaeological remains we are looking for.

The major problem of the height measurements is the grid size, which is too large for the objects we are looking for. Setting the grid size to one fourth of the original yields Fig. 16.11, and applying a simple interpolation Fig. 16.12. This does not look as a big improvement. The jerkiness of the original image has disappeared, at the expense, however, of smoothing a picture that contained not much contrast to begin with. The contour-diagram (Fig. 16.13) has improved a lot; in fact, contour diagram almost invariably improve if based on a finer grid than the original measurements. The three-dimensional diagram looks even more improved (Fig. 16.14). It also suggests, by the way, much more precision than we are entitled to on the basis of just 481 measurements.

Of course we could stretch this picture in the same way as the original one to get more contrast. However, there are better ways of doing so. The best known of these, and one



Figure 16.12



Figure 16.13

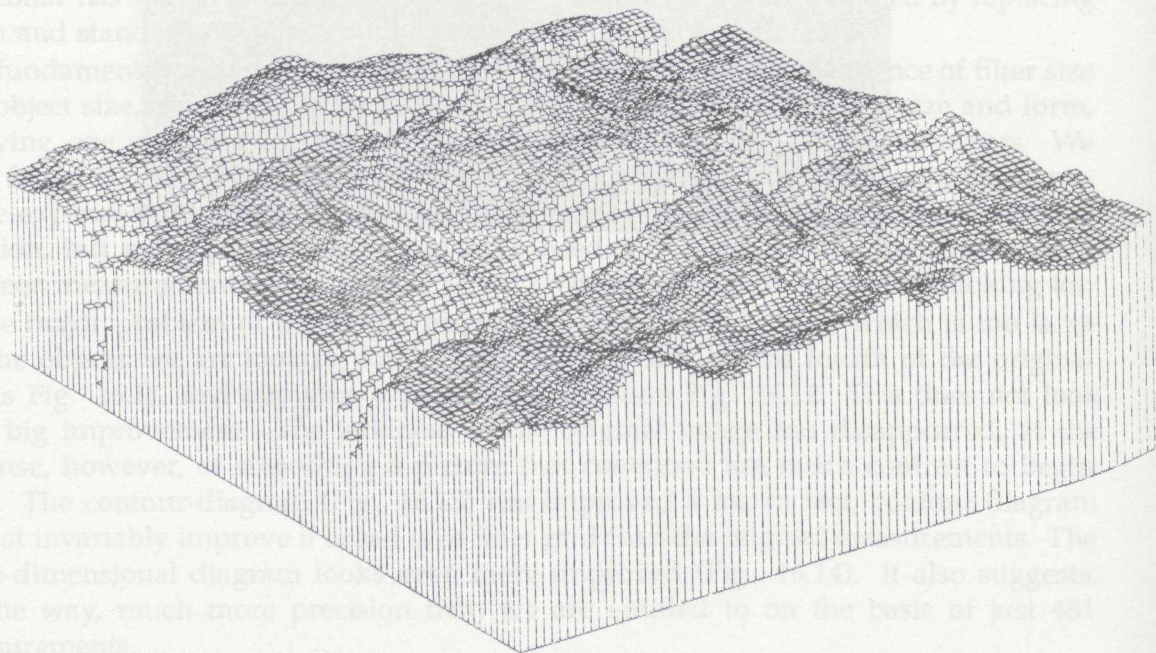


Figure 16.14

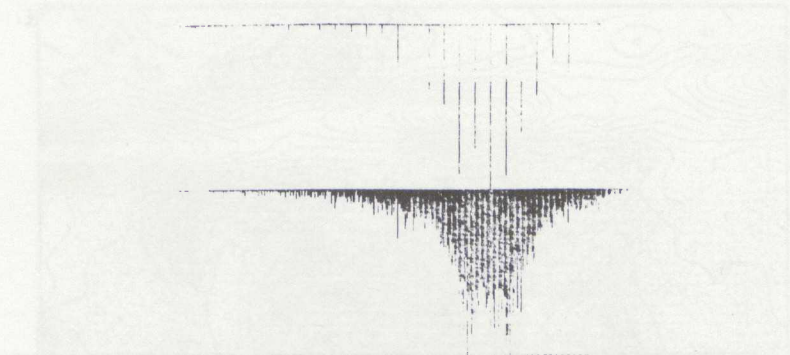


Figure 16.15

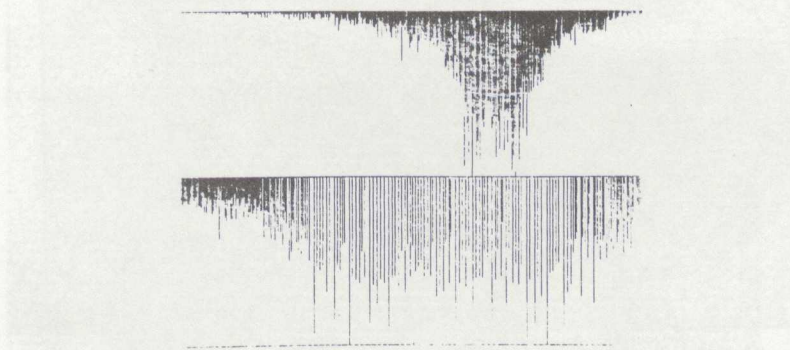


Figure 16.16

that has become practically standard with all measurements we do, is called 'histogram linearisation' or 'histogram equalisation'. We would like to have the gray levels spread more equally over the histogram (Fig. 16.15). Intuitively it can be seen that an 'ideal' histogram would have no peaks, therefore has to be rectangular. All we need to find is a transformation function for each pixel-value, such that the histogram of the resulting picture will be rectangular. For a continuous function, this transformation requires some calculus, but in the case of discrete values only manipulations of cumulative histograms suffice. You can see the result of this mapping in Fig. 16.16. The 'linearized' histogram does not look very rectangular at first sight. In fact, it is quite a good approximation, as the sums of gray-values within equal areas are about equal.

The image resulting from histogram equalisation (Fig. 16.17) shows dramatic improvements over the previous ones. House platform and ditches can be seen more clearly, and two more ditches can be seen at the eastern and western sides of the platform. The house platform itself does not look circular any more, but seems to be elongated and stretches from north-west to south-east. Most important of all, the two original ditches north and south of the platform look very much as if they cut through the original platform. Without doubt they are recent.

Some improvements can be made on equalised pictures. First of all, the original contour lines can be superimposed, which results in showing finer details (Fig. 16.18). Secondly, the overall grayness can be adapted by logarithmic or exponential transformations. The same effect can be reached more naturally by specifying interactively the

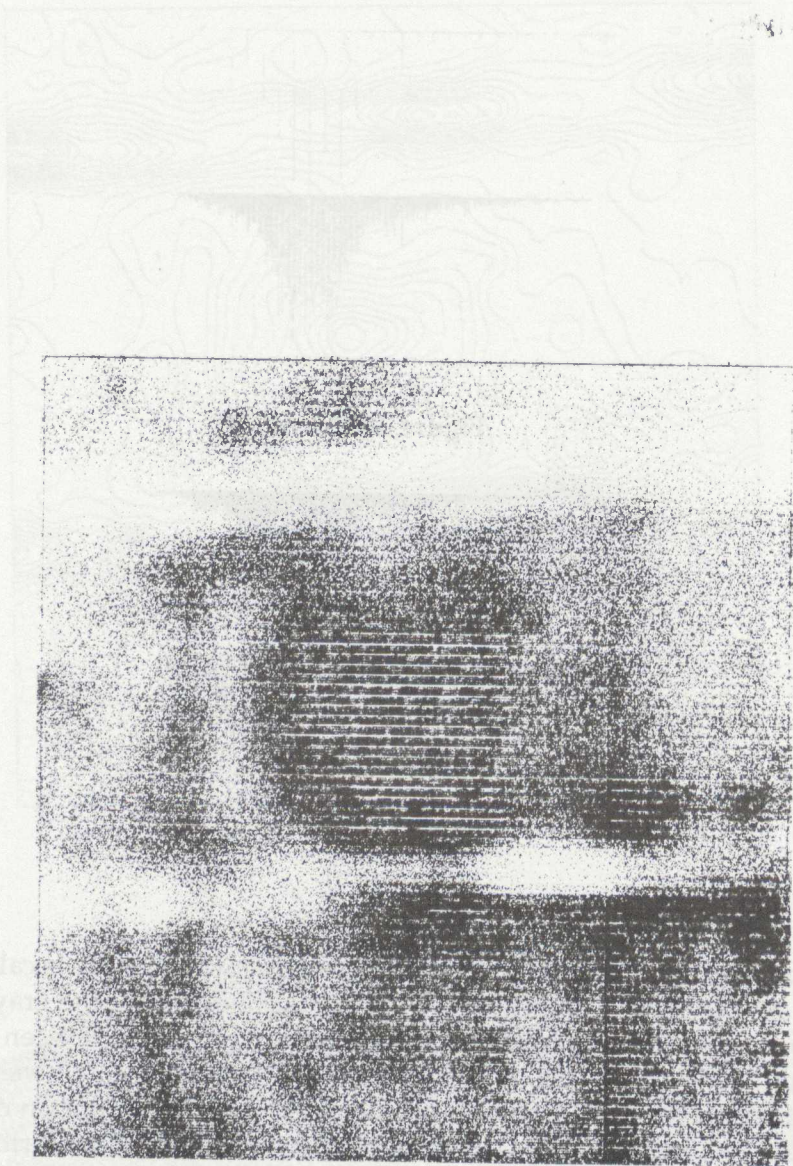


Figure 16.17

...ed histogram
... levels spread
... that an 'ideal'
... and is
... resulting
... reduces
... of cumulative
... is to. The finished
... in fact, it is quite a good
... are about equal.
... shows dramatic im-
... (Fig. 16.17) shows dramatic im-
... can be seen on the eastern and western sides of the
... more, but seems to be
... Most important of all, the two
... as if they cut through
... they are recent.
... Just of all, the original
... (Fig. 16.18).
... or exponential transfor-
... the

... that has been
... investigation
... more equal
... picture
... histogram
... some cases
... histograms will
... histogram does not look
... approximation as the sum of
... The image resulting from
... movements over the
... clearly, and two more
... platform. The house
... elongated and stretches
... original ditches north
... the original platform. Without
... Some improvements can
... contour lines can be
... Secondly, the overall
... nations. The same effect

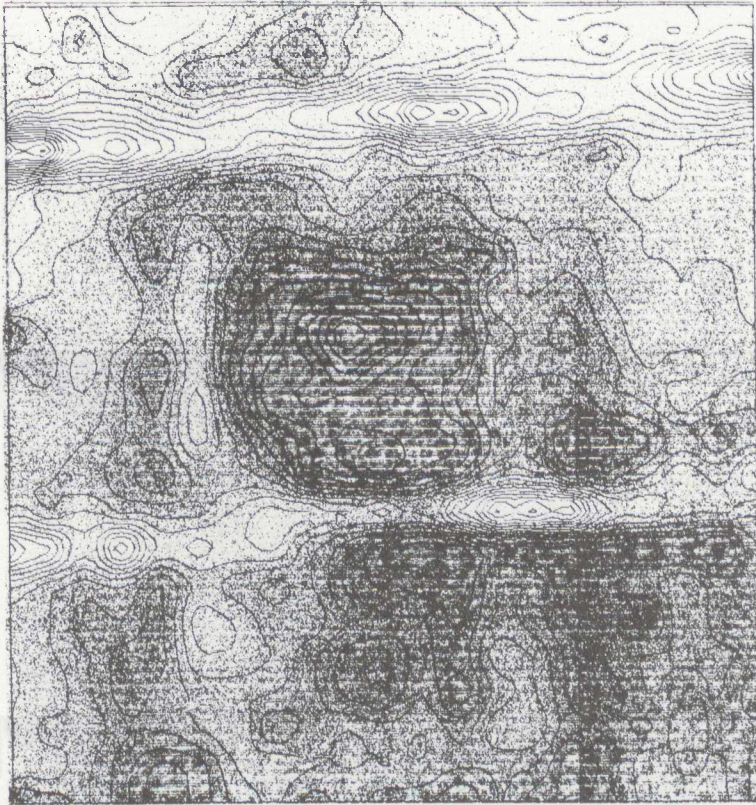


Figure 16.18

desired form of the histogram. As a rule, pictures with rectangular histograms tend to look too black and to lose something on internal range. By specifying a histogram centred on the light size (Fig. 16.19, resulting histogram Fig. 16.20), you get a plot which shows more detail within different parts, for example in the middle of the platform (Fig. 16.21). User defined histograms also come in very handy in separating or joining different bands if bimodal or multi-modal data.

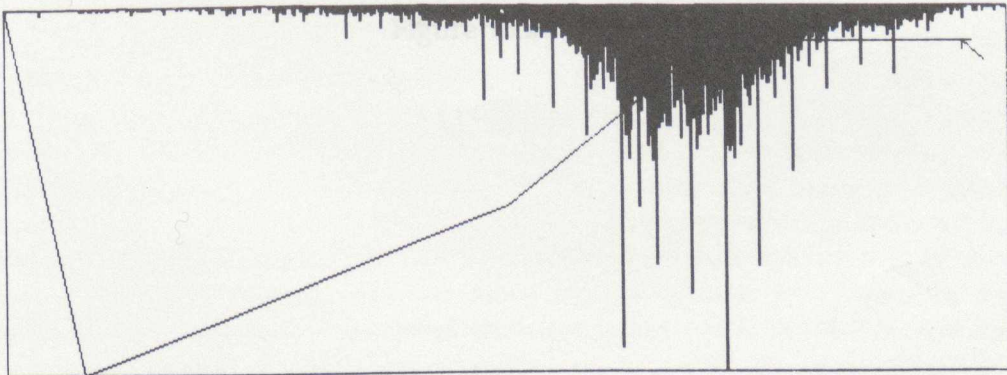


Figure 16.19

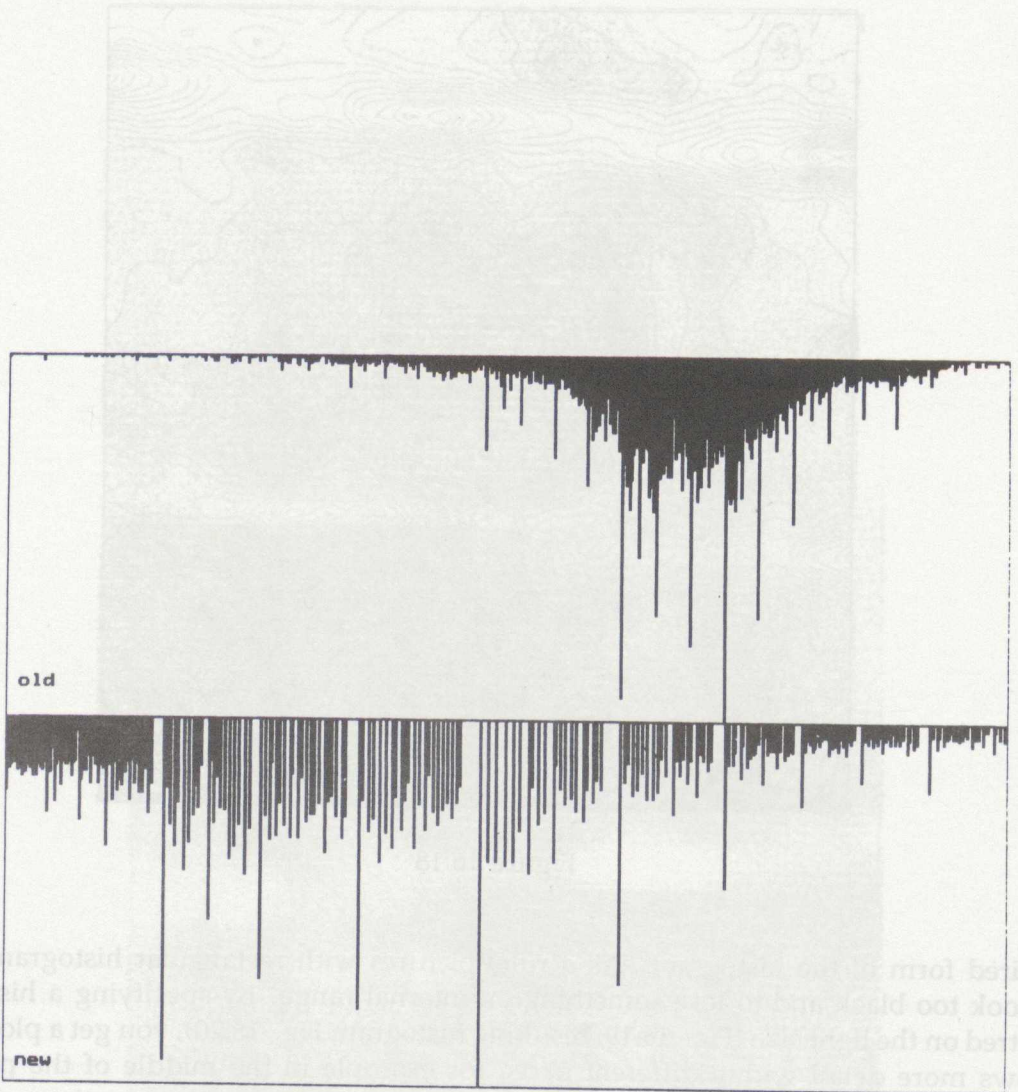
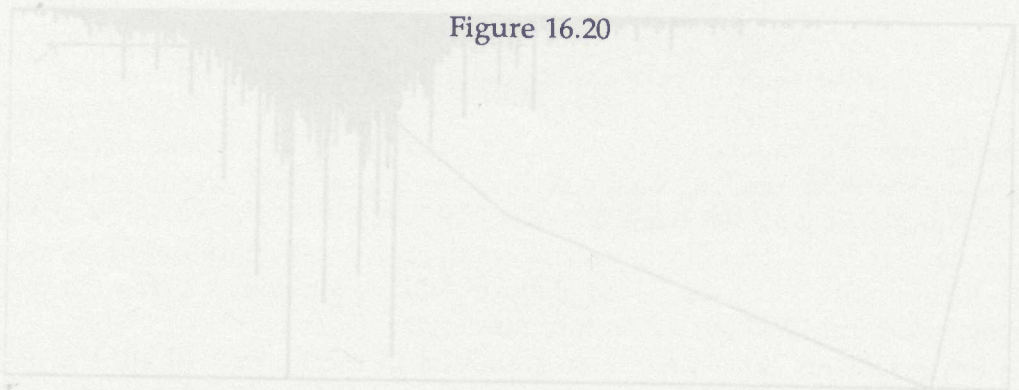


Figure 16.20



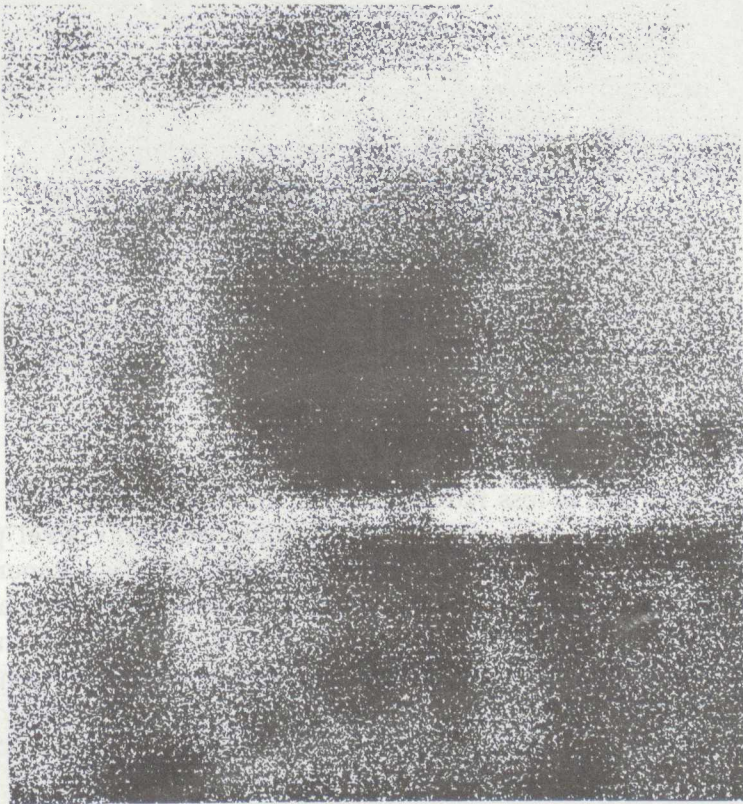


Figure 16.21

can be best seen
 (Fig. 16.22).
 al unpredictable
 background of
 human perception
 measurements
 have been tuned
 would like to

Histogram
 on the three-
 The contrast
 pushing out
 histogram in
 are less ad
 and enhanc
 out to be
 know a lot

Some further
 West, where
 five years
 many other
 mounds themselves
 maintenance-based
 gray-level plot
 image processing
 which helped a lot
 The second example
 house in Babel
 the same surface
 but they too

16.4 Applications
 Some further
 West, where
 five years
 many other
 mounds themselves
 maintenance-based
 gray-level plot
 image processing
 which helped a lot
 The second example
 house in Babel
 the same surface
 but they too

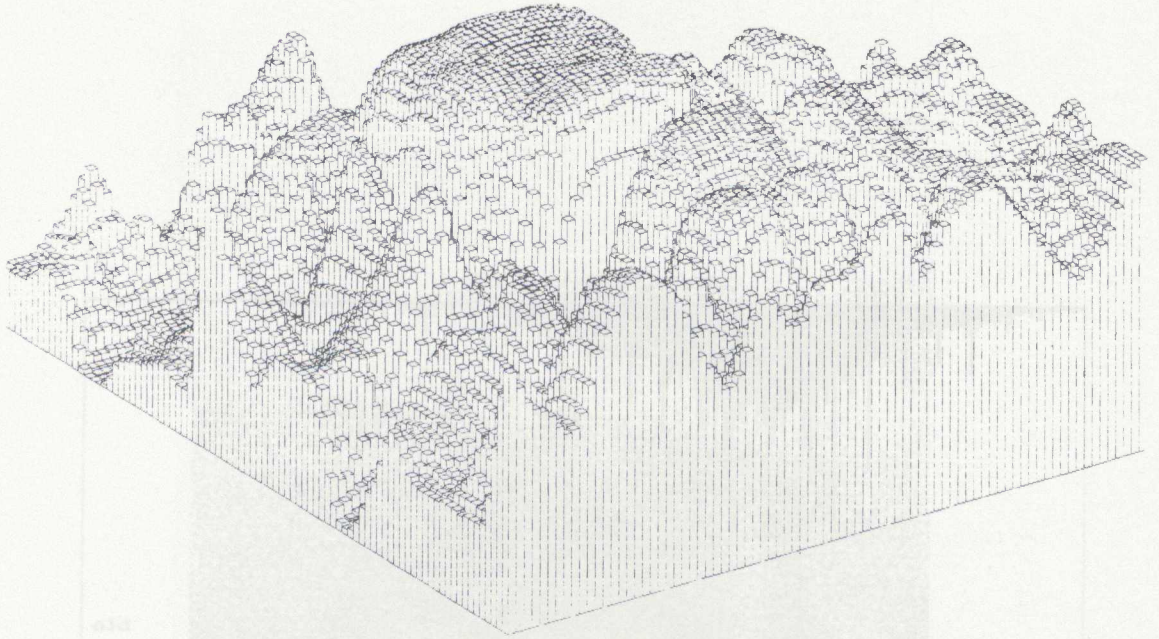


Figure 16.22

Histogram equalization is less natural than it looks, however. This can be best seen on the three-dimensional representation of the equalised gray-level plot (Fig. 16.22). The contrast enhancing effect seems to have been reached by a general unpredictable pushing, pulling and stretching of data. Although the mathematical background of histogram matching techniques is straightforward, their effects on human perception are less so. As far as I can see, they de-trend in a global way the original measurements and enhance the contrast on a smaller scale. Empirically, these techniques have turned out to be so effective, that we subject all measurements to them. We would like to know a lot more, however, on their exact archaeological significance.

16.4 Applications and prospects

Some further applications to conclude. The first comes from a Bronze Age urn field in Weert, which has been measured very extensively in student courses during the last five years. Some 25,000 height measurements were taken in all, but they contained many errors and were, by their sheer bulk, totally unmanageable. Furthermore, the mounds themselves were difficult to recognize on account of sand drifts. Traditional, mainframe-based contouring programmes did not do much good, and even the first gray-level plot did not look very promising (Fig. 16.23). However, after applying some image processing techniques we got some workable output (Fig. 16.24 and 16.25), which helped a lot in determining the exact locations and size of the mounds.

The second example is based on an excavated series of post-holes of a medieval house in Bladel, Brabant. Simultaneously, phosphate measurements were taken from the same surface. At first sight the results looked very disappointing (Fig. 16.26), but they too turned out to be improvable. The connection between excavation and

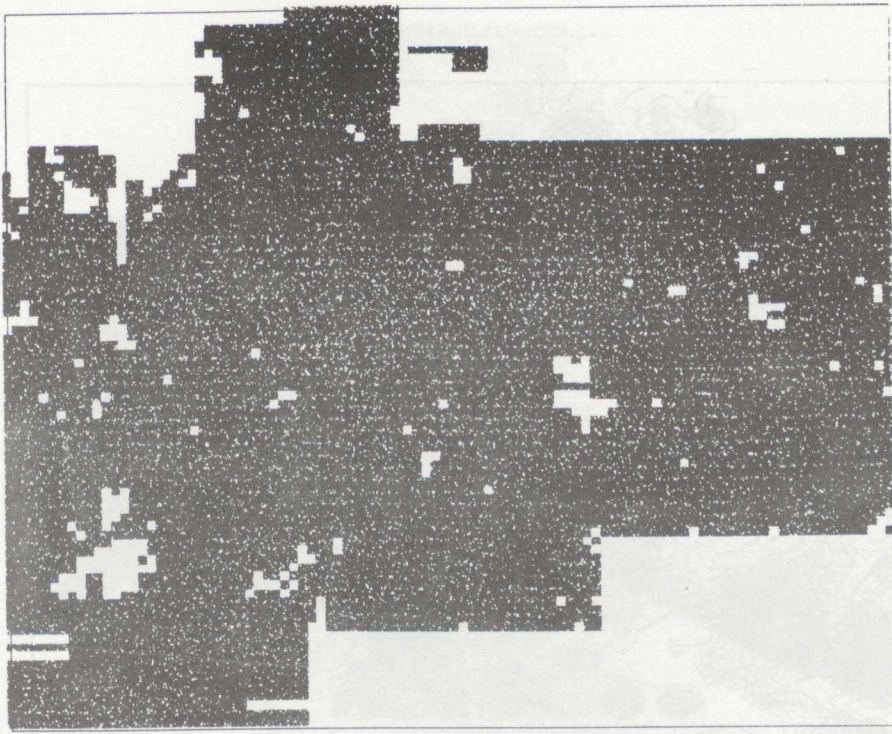


Figure 16.23

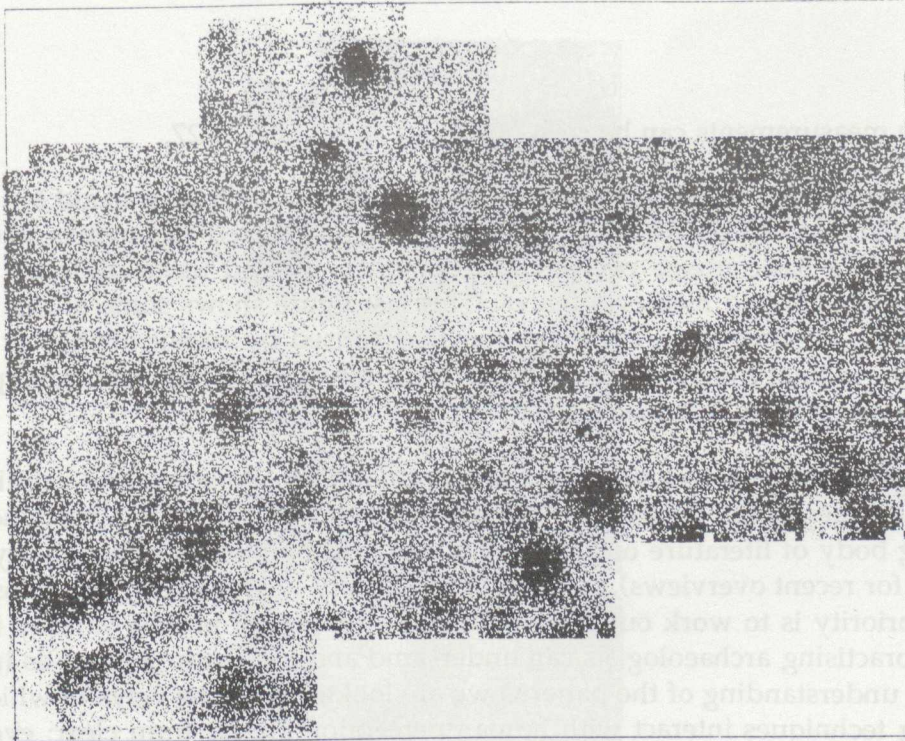


Figure 16.24

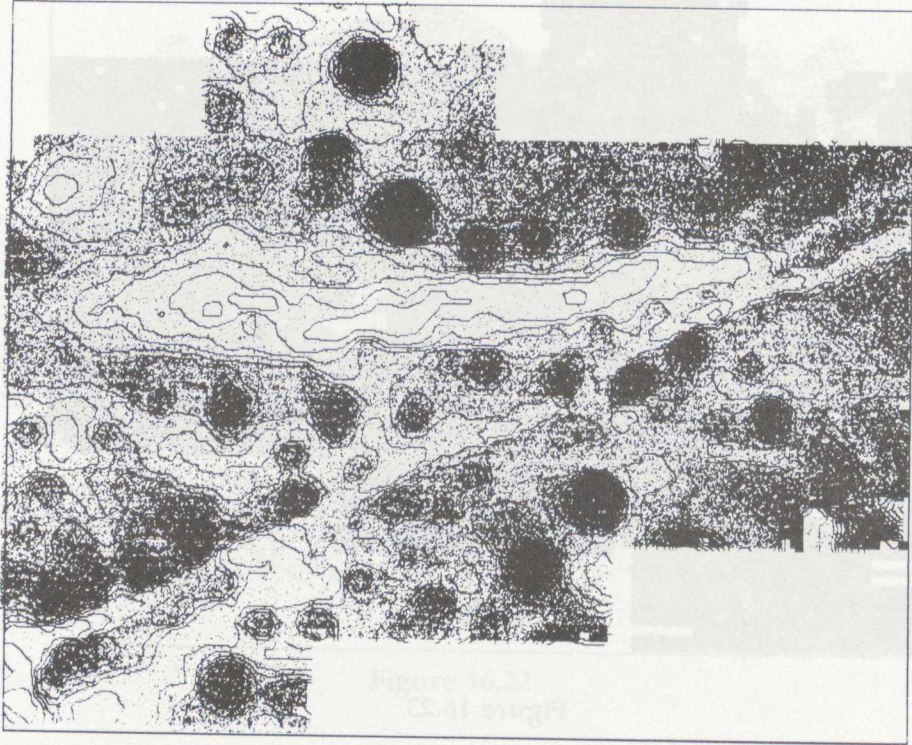


Figure 16.25

phosphate measurements can be seen quite clearly on Fig. 16.27.

Much attention has also been paid to resistivity measurements as an aid for detecting sites. Scollar has discussed the application of sophisticated techniques like Fourier analysis. More basic image processing techniques enabled us to discover Iron Age houses (Fig. 16.28) and medieval fences. This last figure shows some of the problems we are trying to solve now, such as anomalies caused by recent ditches or furrows. Directional gradient filters, like sobel or prewitt filters could be used in emphasizing or filtering away such systematic noise.

As image processing techniques grow more complex, however, the validity of the results in archaeological terms grows more problematical. There is a vast and rapidly expanding body of literature on image processing techniques (see Dougherty & Giardina 1987 for recent overviews), but their applicability to archaeology remains unclear. The first priority is to work out a set of basic techniques of proven validity in such a way that practising archaeologists can understand and use them. Almost as important is a better understanding of the patterns we are looking for. The ways in which image processing techniques interact with human perception are far from clear; even less is known about patterns archaeologists find meaningful. However, even without going into such deep waters, the practical results yielded already by image techniques make this a very exciting research subject for the near future.

References

BECKER, H. 1965, 'Archaeologie und atmosphärische Prospektion', *Archiv für Luft- und Raumfahrt*, 13, 1-10.

CARR, C. 1984, 'The Median Filter: A Spatial Analytic Approach', *Journal of Spatial Analysis and Theory*, 7, 103-222.

DOUGHERTY, E. R. & C. W. RYAN (eds) 1981, *Image Processing in Archaeology*, Prentice Hall, Englewood Cliffs, New Jersey.

NIBLACK, W. 1966, *Archaeological Excavations*, Prentice Hall, Englewood Cliffs, New Jersey.

SCOLLAR, J., BERND W. 1981, 'Using the Median Filter for Image Processing', *Journal of Spatial Analysis and Theory*, 4, 1-10.

SCOLLAR, J., BERND W. 1982, 'Magnetic data', *Geophysical Research Letters*, 9, 1-10.

ULTMANN, R. 1987, *Archaeological Excavations*, Prentice Hall, Englewood Cliffs, New Jersey.

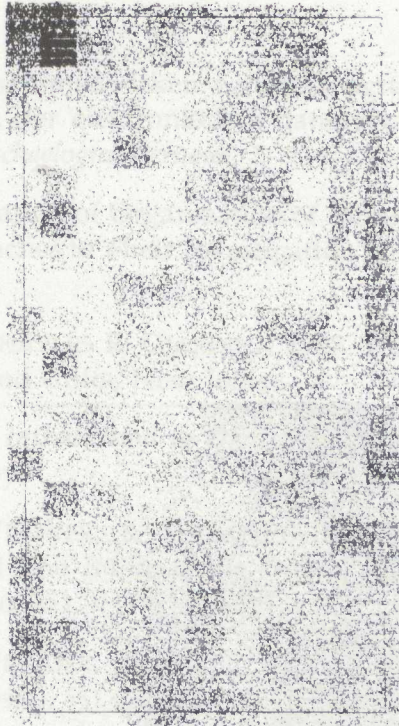


Figure 16.26

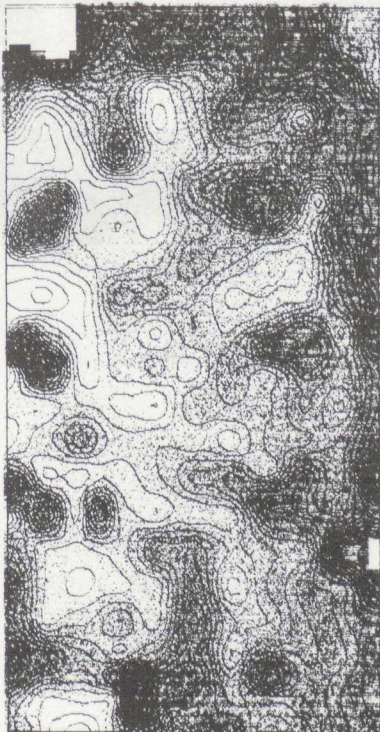


Figure 16.27



Figure 16.28

References

BECKER, H. 1985. "Zusammenwirken von geomagnetischen Messungen, Luftbildarchaeologie und einsatz der elektronischen datenverarbeitung bei der archaeologischen Prospektion", *Archaeologica Peruana*, 1: 119–131.

CARR, C. 1984. "The Nature of Organization of Intrasite Archaeological Records and Spatial Analytic Approaches to Their Investigation", *Advances in Archaeological method and Theory*, 7: 103–222.

DOUGHERTY, E. R. & CHARLES R. GIARDINA 1987. *Matrix Structured Image Processing*. Prentice Hall, Englewood Cliffs, New Jersey.

NIBLACK, W. 1986. *An Introduction to Digital Image Processing*. Prentice Hall, Englewood Cliffs, New Jersey.

SCOLLAR, I., BERND WIEDNER, & THOMAS S. HUANG 1984. "Image Enhancement Using the Median and The Interquartile Distance", *Computer Vision, Graphics and Image Processing*, 25: 236–251.

SCOLLAR, I., BERND WIENDER, & KAREL SEGETH 1986. "Display of archaeological magnetic data", *Geophysics*, 51: 623–633.

ULICHNEY, R. 1987. *Digital Halftoning*. The MIT Press, Cambridge, Massachusetts.