ABC of Computing

D C BARBER

THE COMPUTER AND MEDICAL IMAGES

Much of the information we obtain on patients is in the form of pictures. At present computer image processing systems cannot compete with the ability of the human visual system to analyse the large volume of information in a picture. On the other hand, our eyes, though normally excellent image analysers, can be misled and certainly may be unable to extract all the information from an image, and this is where computers may help. Typical examples of medical images are radiographs, microscope images, and images resulting from radioisotope, ultrasound, and nuclear magnetic resonance investigations. Radiographs and microscope images are examples of images where all the information is present but the eye cannot see the small changes in image density representing the changes in soft tissue density. In other forms of images, such as computed tomograms, the computer is used actually to create and enhance the image.

How the image is represented

An image normally contains a continuous distribution of brightness and colour, and the problem is how to convert this into a form which a computer can store and manipulate. Consider an image such as a planar radiograph; suppose some form of detector can be made to systematically view each part of the radiograph and send to the computer a unique number corresponding to the brightness of that part of the radiograph. The numbers can be stored in the computer in such a way that an image of the radiograph can be reconstructed on a screen, each number being used to adjust the intensity of the screen illumination at the corresponding point. This process of converting the image into an ordered arrangement of numbers is called image digitisation.

When digitising an image there are two important decisions to be made. Firstly, what is the pattern of digitisation? In practice an image can be subdivided into thousands of rectangles, hexagons, or squares, and each one of these picture elements, or pixels, is represented individually in the computer. Squares are commonly used.

Secondly, and more critically, what is an appropriate pixel size for a given image? The more pixels that are used the greater the demand on the computer memory and the longer any computer manipulation will take. For example, an A4 sized image digitised into 1 mm² pixels, each being stored in the computer as one byte, would require at least 60 kilobytes of memory without allowing for the program to process the image.

Displaying the image

Before (left) and after interpolation.

Special image processing techniques

Window (40-90%) of original image shown at top of page.

Smoothed image.

For this reason computer image processing systems are usually implemented on reasonably sized computers with fixed disc facilities. On the other hand, the more pixels there are the finer the image definition. If the number of pixels is reduced, and therefore the area represented by one pixel is increased, there may be appreciable changes in image density within the space represented by one pixel, and this information will then be lost. In fact not only will the information be lost, but false patterns can be created by an effect known as aliasing.

In practice an appropriate pixel size can be judged by attempting to image a set of bar patterns (like a television test card) where the bars are closely spaced together. As a pair of bars in the image are moved closer together they eventually merge. The appropriate pixel size is then half the distance between the bars when they just cannot be distinguished. Because of the large numbers of pixels in an image it is important to consider the range of pixel values which need to be stored. If this can be made small then storage can be much more efficient. A convenient range is 0 to 255 since this can be stored in one eight bit byte of memory, but sometimes a greater range is used.

Displaying the image on the screen of a television monitor is straightforward as each pixel value can be displayed as a brightness level. Sometimes, however, if the pixels are large, they can be seen as small squares on the screen, which may be distracting. This effect can be reduced by replacing the original pixel by a pattern of smaller pixels computed from the value of the original pixel and its neighbours, a process known as interpolation.

The eye's ability to perceive detail depends considerably on the type of detail. For example, the eye likes sharp edges and much information can be extracted from them. Unfortunately many medical images, especially those of soft tissue, are of low contrast and do not have the sharp lines which the eye can use. A wide range of image processing techniques has been developed to clarify the fine details.

Windowing—If an image has been digitised and is represented in numerical form in the computer memory the pixel values would normally run from 0 to 255, representing the range of point brightness from black to white. If the pixels in an image have brightness values from 100 to 150 then the image will be of poor contrast and show little detail as this range just represents shades of grey. The contrast can be improved by arranging that the whole brightness range from black to white lies between 100 and 150.

Histogram equalisation—In a typical computed tomography image the different levels of grey may be inefficiently used, the bones being very white and the soft tissue grey, with little in between. The image can sometimes be improved by allocating each level of brightness to an equal number of pixels. This usually has the effect of allocating more grey levels to low contrast areas and fewer to the high contrast areas, which can anyway be seen clearly.

Image filtering represents a whole class of computer image processing techniques where each pixel is considered in relationship to its neighbours. For example, in a simple filter each pixel value could be replaced by a new value computed from its previous value and the values of the neighbouring pixels—a sort of weighted local average. This technique can be very useful as it helps to reduce the effect of random signals, but, on the other hand, it may reduce the usefulness of the image by blurring sharp lines and edges. This technique is also called image smoothing. Different degrees of smoothing can be achieved by varying the area from which the local average is computed.

Image subtraction is a technique for improving the contrast of the fine details. The image is first digitised and then smoothed. The smoothed

Subtracted image.

image is then subtracted from the unsmoothed image to give a third image. The fine detail in the unsmoothed image will be absent in the smoothed image, but the coarse detail will largely be the same in both. The subtracted image will then contain most of the fine details but at a better contrast level. Sometimes the coarse details can be removed using another image.

Normally in angiography it is difficult to see the blood vessels as they have to compete for the limited contrast range with structures such as bone, and large x ray doses may be needed to obtain adequate contrast. The image can be improved by a digital subtraction technique, whereby the image before injection of the contrast medium—that is, the information which we do not want—is subtracted from the image with contrast medium. The resultant subtracted image shows only the distribution of the contrast medium and at a higher contrast than would normally be managed. X ray exposure can then be reduced. One problem with this technique is that it may not be possible to subtract the background image exactly—for example, because of patient movement—but, nevertheless, results will still be better than those of plain contrast radiology. These subtraction techniques rely on information about the background, in one case by a smoothed picture and in another by a precontrast image. There are also techniques, which have been used in radioisotope imaging, whereby a mathematical estimate of the unimportant details can be obtained by feature extraction methods.

Image restoration techniques attempt to remove the blurring on an image, a problem which limits resolution of many medical images, such as structures in the heart. In practice, because of random signals, only a limited restoration can be achieved, though some success has been achieved with the high quality optical images from aircraft and satellites.

Image analysis and understanding

Techniques of analysing and recognising images are in their infancy and are of particular interest to workers in artificial intelligence. The difficulties are many. Consider the problem of recognising even a simple letter, such as "A." The computer will probably manage well if the A is always exactly the same size, and in the same orientation; unfortunately this is rarely ever the case. Consider even good handwriting, and the possibilities become enormous. Most of the techniques rely on reducing the image to a set of primitive elements—for example, lines, areas of light and dark, regions of uniform texture—which can then be identified and labelled.

A simple example of image analysis is the automatic extraction of the boundary of the left ventricle from the cine angiogram. An example which illustrates the problem of analysing medical images is the computer recognition of the human chromosomes. Chromosomes are very simple medical images, compared with, for example, a radiograph. The microscope image is first digitised, and analysis begins by the computer "working" along an edge. When it finds a pixel of different density it moves round it by a "constant left turn" rule. The chromosome will be fully defined when the computer returns to the point where it found the chromosome in the beginning. The computer now looks for the other chromosomes, checking that it has not found the same ones again. When all the chromosomes have been identified the main axis of each chromosome can be defined and the length calculated. The centromere is located as the point of maximum density on each main axis. The whole problem is vastly more complicated than this account suggests because chromosomes may overlap or shrink on the microslide. The computer may even identify artefacts as chromosomes. While elegant from the computational point of view this technique of computer karyotyping is not reliable and has not yet become fully accepted.

Similar techniques are used to identify malignant cells in cervical cytology specimens.

The central problem in all these image analysis applications is the identification and extraction of the useful primitive elements.

Dr D C Barber, MSC, PHD, is principal physicist, department of medical physics and clinical engineering, Royal Hallamshire Hospital, Sheffield.