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An Interactive Education Program in Digital Image Processing Developed as a COMETT-supported Project*

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Digital image processing (DIP) is increasingly being used as a tool in a variety of fields. Nevertheless many potential DIP users have little experience of this type of technology, and thus the need for training in this area emerged. Within the COMETT II programme, the UETP TATIANA has succeeded in the development of an interactive program for training in DIP. The program differs from other DIP programs in that it is distributed free and has few hardware requirements. The program has two parts: the first explains a number of theoretical aspects about the main functions of DIP, and the second allows the use of these functions and observation of the results with a series of example images.

INTRODUCTION

COMPUTER image processing started in the mid-1960s in NASA's laboratories, where computers were used to correct distortions present in images sent by artificial satellites. From these beginnings digital image processing (DIP) has grown enormously, especially in the mid-1980s with the reduction in price and increased potential of computers. Nowadays there exist numerous types of equipment and image analysis and processing progams, ranging from personal computers to powerful workstations, and from general image-analysis programs to specific programs that cover a wide range of applications.

Digital image processing and image analysis have become frequently used tools in a variety of activities—such as robotics, biomedicine, geology, material sciences, management of natural resources, art and so on—where the users of digital image processes are not necessarily experts in DIP. Thus, a training need emerges in the field of image processing for a number of professional groups that traditionally have not had close relations with this type of material.

The Transeuropean Association for Training in Image Analysis (TATIANA), based in the University of Oviedo (Spain), is an association dedicated towards the training and further education of students and personnel in subjects related to and including image analysis. TATIANA was established in September 1992 under the COMETT scheme, with the intention of developing a network of co-operation between universities, companies and European organizations with an interest in these fields of advanced technology. The four main areas of activity in TATIANA are:

- The development of relationships between university institutions and companies with the aim of establishing a permanent structure for a UETP (University–Enterprise Training Partnership).
- The exchange of students/graduates from academia to training placements in industry.
- The exchange of personnel between universities and industry and vice versa.
- The financing of short courses and seminars, and support for the creation of multimedia distance training, including the creation of multimedia products, the issue of books and other types of educational and informative material.

Under the UETP TATIANA programme and with the aim of providing the necessary training in image processing and analysis, it was decided to write a user-interactive computer program which would facilitate the teaching of the fundamentals of DIP and allow familiarization with the principal tasks of image processing.

Initially the progam emerged as a student project at Coventry University (Coventry, UK). Through scholarships within the exchange program of TATIANA, a student from Coventry visited the Image Processing Service at the University of Oviedo where it was decided to continue with the development of the program, examining and debugging existing applications and adding new functions to cover the most important aspects of image processing and analysis.

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The task of writing the program has been carried out by foreign students funded through grants from the Image Processing Service at the University of Oviedo, under the supervision and guidance of the department's personnel. As a result of this co-operation, other objectives of the UETP TATIANA have been achieved, in particular the exchange of students and graduates for practical experience in enterprises and centres of investigation.

HARDWARE AND SOFTWARE

As mentioned in the introduction, a great number of commercial image analysis programs exist, the majority of which specify some hardware requirement that is not always within the reach of all types of users. One of the major advantages of our package is that it can be run independently from normal image-processing hardware, such as frame grabbers and external monitors. It is therefore possible to run this software on a relatively small personal computer.

The following equipment is required:

- an IBM-compatible PC (286 or above).
- VGA card and monitor.
- 649 kbytes RAM.

The program has been written in TurboPascal 6.0 under the Borland package and is intended to be an introduction to DIP.

The algorithms of the functions used are written and set out according to the theories contained in Wintz and Gonzales [1] and Russ [2].

THE DIP PROGRAM

The demonstration model displays a general outline of DIP and illustrates some theories and algorithms for the following tasks:

- Image enhancing.
- Morphological functions.
- Image identification.
- Quantification.

In the first part of the program there is an explanation of the algorithms where the student can learn the theory of image-processing functions (Fig. 1). In the second part (the true program) the student can use the functions with images and see the results.

Program structure

As shown in Fig. 2, the main working screen consists of five windows.

The two upper windows, entitled Active and Temporary, are the windows in which the images are displayed. The processes take place on the image in the Active window; the results are then seen in the Temporary window.

On the right-hand side of the screen is the Histogram window, in which a histogram can be stored.

On the bottom half of the screen are two windows that contain the functions of the program. The functions in the window on the right are self-explanatory and show their results instantly. The image-processing functions are presented in the left-hand window.

File format

The images are stored on disk as .RIC files consisting of 256 × 256 bytes, without any header. In theory this means that there are 256 colours. However, in order to keep the program compatible with simpler hardware, the program reduces these 256 colours to a range of 16. The demonstration images included in the program are acquired with the image-processing software package MIP (Microm España SA). The package stores the images with a header containing information about the

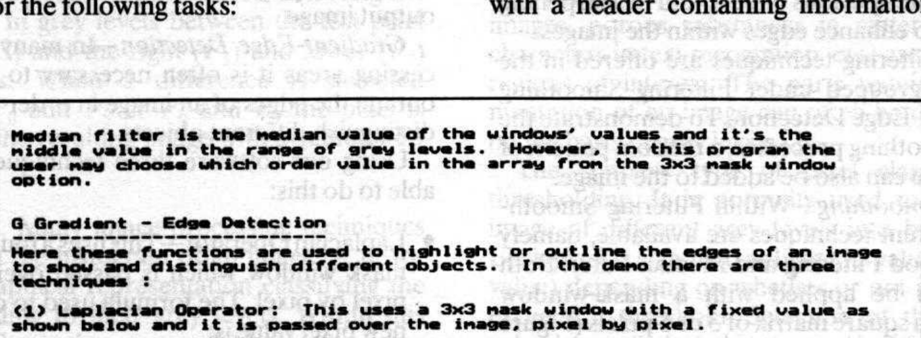

Fig. 1. Part of the explanation of the image-processing algorithms.

Fig. 2. Main working screen.

image such as size and grey levels, followed by the data.

To obtain the images in the right format a program was written to convert these files into .RIC files. In the future it is intended to produce a program that converts .PCX and .TIF files to the required .RIC files.

Functions

Filtering. The principal objective of enhancement techniques is to process a given image so that the result is more suitable than the original image for a specific application [1].

Filters are important features in image smoothing to eliminate spurious effects, and in sharpening as a feature to enhance edges within the images.

Different filtering techniques are offered in the filter menu, grouped under Filtering Smoothing and Gradient-Edge Detection. To demonstrate the different smoothing processes, a random pattern of artificial noise can also be added to the image.

Filtering Smoothing—Within Filtering Smoothing two different techniques are available, namely Neighbourhood Filtering and Median Filter. Both methods can be applied with a mask-window consisting of a square matrix of 3 or 5 pixels (Figure 3).

The Neighbourhood Filter is a low-pass filter based on the mean value of the window, the value of each pixel in the result image is:

$$P'_0 = \frac{1}{9}\sum_{i=0}^{8} P_i$$

The Median Filter is a rank order operator. All points of the matrix are ordered according to their grey level; the median value of these ordered grey levels is displayed as the new central pixel in the output image.

P_1	P_2	P_3
P_4	P_0	P_5
P_6	P_7	P_8

Fig. 3. A 3 × 3 matrix with the relative pixel position represented from P_0 to P_8.

Gradient-Edge Detection—In many image processing areas it is often necessary to highlight or outline the edges of an image in order to show and distinguish different objects.

Using our software three techniques are available to do this:

- Laplacian Operator—This uses a four-neighbour mask window which is passed over the image, pixel by pixel. The formula used to calculate the new pixel value is:

$$P'_0 = (P_2 + P_4 + P_5 + P_7) - 4 \times P_0$$

The result of this kind of filter can be seen in Fig. 4.

- Sobel Operator—This uses two 3 × 3 mask windows, one for the X direction, the other for the Y direction. The result is the addition of the X and Y processes. Although many different matrices can be used, the package uses only two (Fig. 5).

Fig. 4. Original image and the result of the Laplacian operator.

-1	-2	-1		-1	0	1
0	0	0		-2	0	2
1	2	1		-1	0	1

Fig. 5. Sobel operator matrices.

- Global Thresholding—This process is faster than the previous two procedures, detecting the difference in grey levels between the test pixel (P_0) (Fig. 3) and the right (P_5) and lower (P_7) neighbours. When a difference is detected between P_0 and P_5 or P_0 and P_7 the pixel is placed in the resulting image with a value of 15 (white).

Histogram. Many image-processing techniques are based on the histogram of an image. A histogram is a graphical representation classifying the pixels according to their grey levels. Within this section two alternatives are available:

- *Histogram of an Image*—This displays a histogram of the image displayed in the Active window. The histogram can be placed in the Histogram window on the screen for immediate reference (Fig. 6).
- *Histogram Equalization*—The Histogram Equalization technique redistributes a concentrated band of grey levels evenly over the entire scale. The purpose is to improve the contrast of the image.

Combination of images. Addition, subtraction, division and multiplication of the Active and Temporary Image can be performed. Functions like this can be used to highlight the difference between two images. For example, a procedure can be performed on the image in the Active window with the resulting image being displayed in the Temporary window. If subtraction is then performed, the resulting image will be the difference between the two.

Image segmentation/thresholding. Segmentation is the process by which pixels within an image are divided into classes, normally regions of interest and background. Nuclear material in cytological images, porous substances in material sciences, characters in text recognition, etc., are examples of regions of interest. The parts required for segmentation of an image can often be distinguished on the basis of grey levels [3].

The simplest type of pixel classification is thresholding. It is normally used to convert an image of different grey levels into binary image. Each pixel is classified as light (15 value) or dark (0 value) depending on whether or not its grey level exceeds a threshold. Selection of the threshold value is usually based in the study of the grey levels histogram (Fig. 7).

Morphology application. Usually the binary image resulting from the segmentation of the grey-level image does not perfectly represent the regions of interest. This may be due to inherent problems in the original image such as touching objects (Fig. 7), or problems in the image processing, e.g. small areas badly classified.

The two basic morphological applications are erosion and dilation [4]:

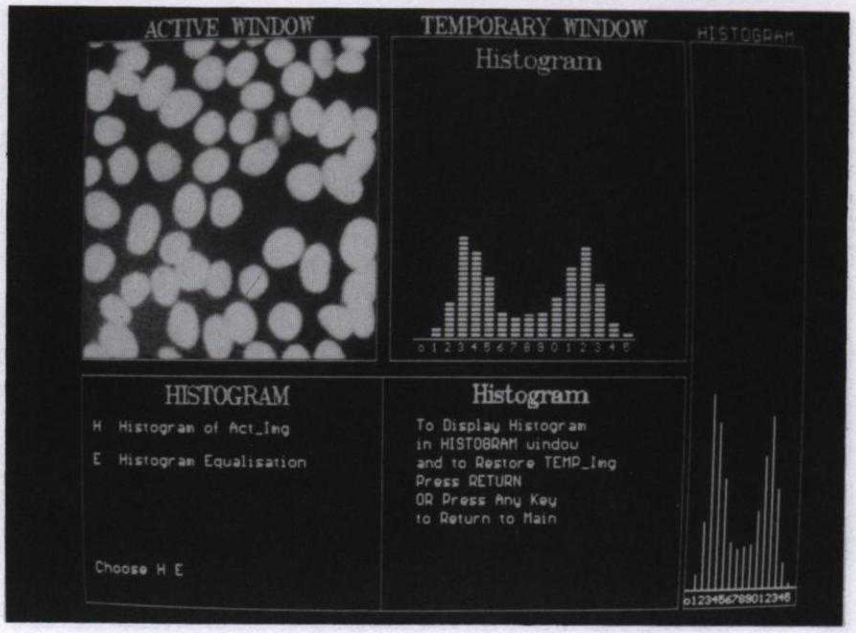

Fig. 6. Histogram of the pixel's grey levels of the image in the active window.

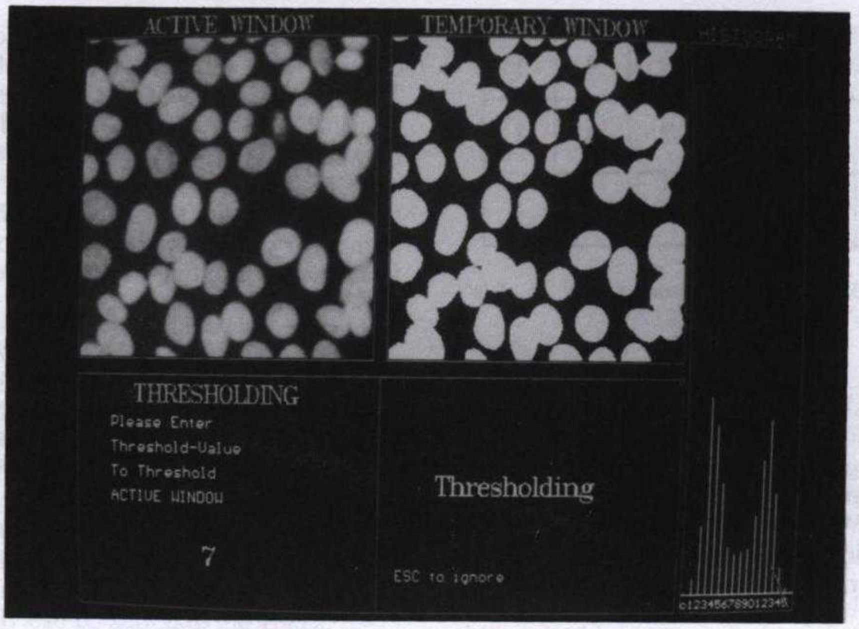

Fig. 7. Classification by thresholding of the image in the active window.

- Erosion consists basically of examining each light pixel and changing it to dark if it has any neighbours that are dark; this causes the contraction of regions around its boundaries.
- Dilation is the opposite of erosion and consists of changing each dark pixel to light if it has at least one light neighbour; this causes the expansion of binary regions around its boundaries.

The result of erosion plus dilation is called opening. This name comes from the tendency of this sequence of operations to open up gaps between touching features, or to open up cavities near the periphery of a feature so that they are not enclosed. The opposite operation (dilation + erosion) is called closing and can be used to connect discontinuous features, to fill in small voids and so forth.

Our program includes different possibilities of erosion, dilation, opening and closing as a function of the number of iterations and the structuring elements (four or eight neighbours) used to perform these operations.

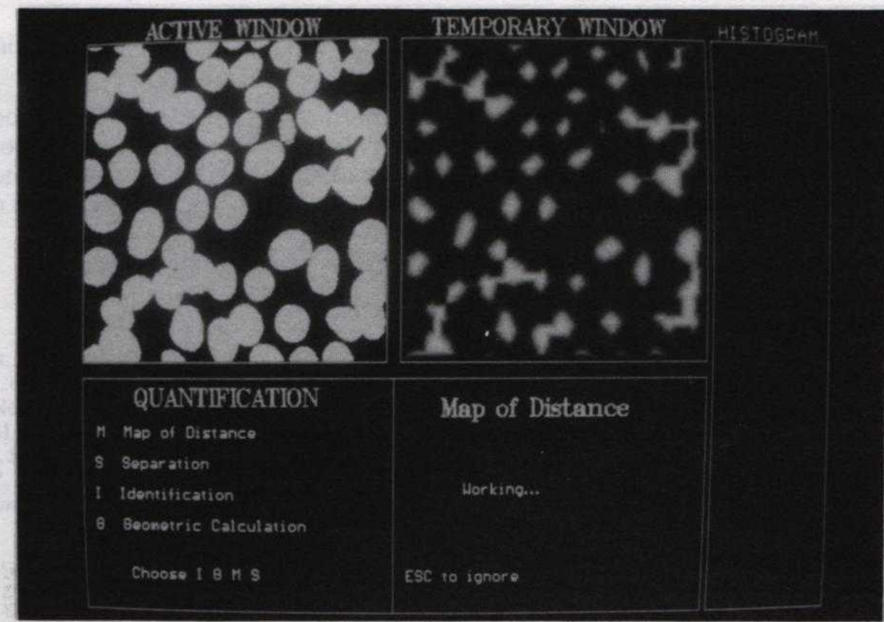

Fig. 8. Map of distances of the image in Fig. 7.

Quantification. The quantification of objects present in images is a task that investigators from different scientific fields habitually have to face. The doctor or biologist needs to know the precise size and number of cells present in a tissue sample; the geologist may need to determine the size of grain and the percentages of the mineral constituents of a rock; and so on.

Before being able to do these kinds of calculations, it is necessary to identify each different feature. Where features are touching or overlapping each other, the result would be that the measurements are calculated on one feature where in reality more than one exists.

Although the majority of image-processing software does not offer the option of disconnecting touching and overlapping features, it was decided to build this function into our package to show the capabilities of image processing.

Map of Distance—This function is necessary as the separation works from this map. The function creates a map of distance of the image in the Active window. In the map of distance each pixel of an object is replaced with a value which corresponds to its distance from the edge of the object (Fig. 8).

To create the map of distance the image is passed from top to bottom and from left to right, with the rule that a pixel's value may not have a value of more than one higher than its lowest neighbour. This process is then repeated from bottom to top and from right to left. The result can be interpreted as a height-coded image where the bright pixels in the centre of regions are mountains and the watersheds are the valleys between the mountains. The separation line of two touching features will be the watershed line (Fig. 9).

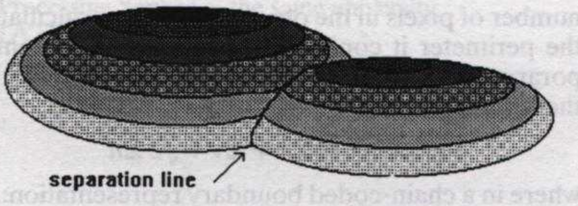

Fig. 9. Examples of separation of two touching features along the 'watershed' line between their peaks in the distance map. (From Russ [1].)

Separation—This option separates the touching and overlapping objects of the image using the watershed technique. The objects are rebuilt from the map of distance growing from the peaks. In the watersheds the objects stay separated.

The growing occurs step by step. Starting from a user-selected height, each pixel with a value that is at least the same as the stated height is a candidate for growing. These pixels remain as feature pixels as long as they do not create new junctions between any neighbouring pixels. The effect of Map Distance + Separation can be observed in Fig. 10, where in the Active window there are touching regions and in the Temporary window these are separated.

Identification—After each feature is perfectly represented in a binary image it is possible to begin its quantification. The computer must first identify the feature, and can then calculate the parameters.

When this option is chosen the program takes the objects one by one from the Active window and calculates their area and perimeter. The objects are then shown with their measurements in the Temporary window.

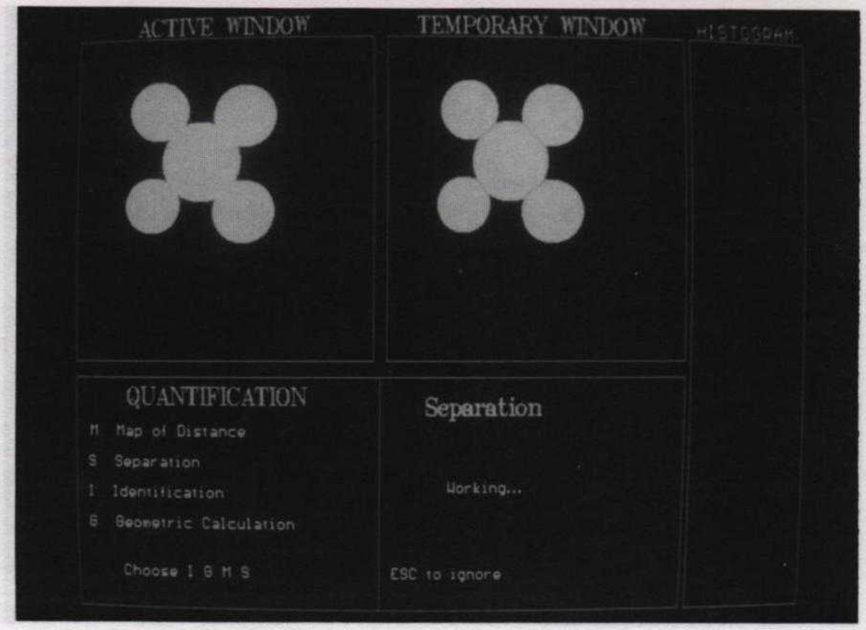

Fig. 10. Separation example.

To calculate the area the software counts the number of pixels in the object. In order to calculate the perimeter it copies the boundary to the temporary window and measures the perimeter with the formula [5]:

$$\text{Perimeter} = \Sigma h + \Sigma v + \sqrt{2}\,\Sigma d$$

where in a chain-coded boundary representation:

h = number of horizontal steps
v = number of vertical steps
d = number of diagonal steps

Geometric Calculation—After the identification process it is possible to calculate many different parameters. In the DIP program it is possible to measure the maximum diameter, the angle of this diameter and the breadth of each object. To calculate these values, the program rotates the boundary coordinates of the object in steps of 2.5° with the formula:

$$[X'\,Y'] = [XY] \begin{matrix} \cos\theta \sin\theta \\ -\sin\theta \cos\theta \end{matrix}$$

This process takes 36 steps, and thus the rotation at the end will be 90°. For each rotation the program calculates the maximum distance in the X and Y directions. The maximum distance for all the rotations is the vaaue of the maximum diameter. The angle of this diameter is calculated according to the rules of Pythagoras and the breadth is the maximum distance at 0° (Fig. 11).

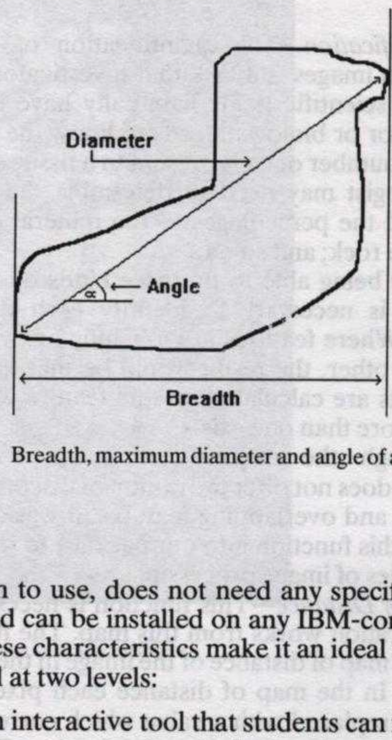

Fig. 11. Breadth, maximum diameter and angle of a feature.

CONCLUSIONS

Our program represents a useful tool for learning the principal concepts of DIP. It is an easy program to use, does not need any specific hardware and can be installed on any IBM-compatible PC. These characteristics make it an ideal teaching material at two levels:

- As an interactive tool that students can install in their own computers and use as a method of learning the principal functions of image analysis.
- As a complement to theory classes, as the program can be installed in a computer room so that students can realize their DIP exercises.

With the development of this program two objectives for the UETP TATIANA have been achieved:

- The development of an educational material for interactive teaching in the field of DIP.

- Professional experience for COMETT-aided students within the transnational exchange project.

Finally, it is important to point out that as a training material the program will be available to users of Internet via anonymous ftp in the 'uniovi' directory of the 'telva-ccu.uniovi.es' server.

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REFERENCES

1. R. C. Gonzalez and P. Wintz *Digital Image Processing*. Addison-Wesley, London (1977).
2. J. C. Russ *Computer-assisted Microscopy: The Measurement and Analysis of Images*. Plenum Press, New York (1990).
3. M. P. Ekstrom, *Digital Image Processing Techniques*. Academic Press, London (1984).
4. J. Serra *Image Analysis and Mathematical Morphology*, Vol. 1. Academic Press, London (1982).
5. Z. Kulpa, Area and perimeter measurement of blobs in discrete binary pictures. *Comput. Graphics Image Process.*, **6**, 434–451 (1977).

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