

ProDIM: Educational Software for Digital Image Processing

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ABSTRACT

We present the educational software package ProDIM, created with the idea of supporting courses on digital image processing techniques. This package was implemented in Visual Basic, which is a visual programming language to create applications in a Windows environment. Operations available in ProDIM include manipulation in the space and frequency domains, such as 2-D convolution, gray-level transformations, linear filtering, histogram equalization, and morphologic filtering. Examples show how the package can be useful as a lecture aid and as a lab assistance tool. The image to be processed can be generated using the editor included, or can be imported using images in a BMP format. A graphical interface allows the user to activate available operations through a menu selection. © 1995 John Wiley & Sons, Inc.

INTRODUCTION

In the last several years there has been a strong development of software to be used in every field of engineering. In the specific case of digital image processing, there is a great variety of professional software, which can be extremely useful for industrial applications as well as for research purposes; however, in many cases this software has sophisticated hardware requirements or needs advanced technology. The educational software package ProDIM, presented in this article was developed for use as a complement of the theory revised in the

course "Digital Image Processing," taught at the Electrical Engineering Department of Universidad de las Américas. This package was implemented in Visual Basic (Microsoft, Inc.), which is a visual programming language to create applications in a Windows environment [1]. It can be used on any 286 or higher personal computer and it does not require

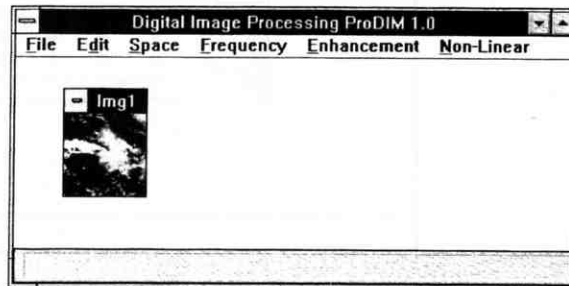


Figure 1 ProDIM main screen.

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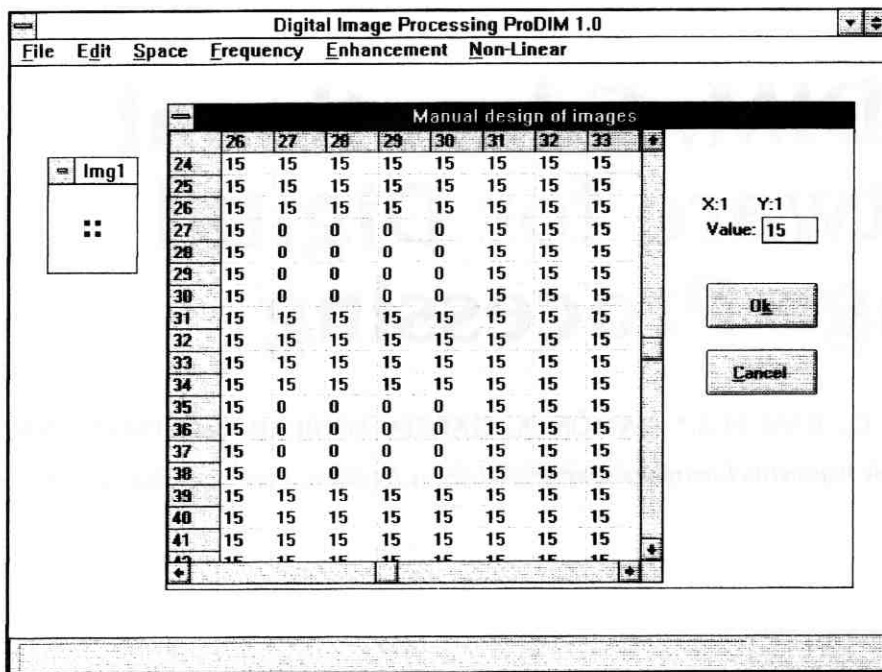


Figure 2 Manual image editor.

math coprocessor, although the use of one improves considerably the execution time. ProDIM is available on request to educators and will be available as a shareware package.

GENERAL PACKAGE DESCRIPTION

This program was conceived with the idea of providing students in this course, with a software tool

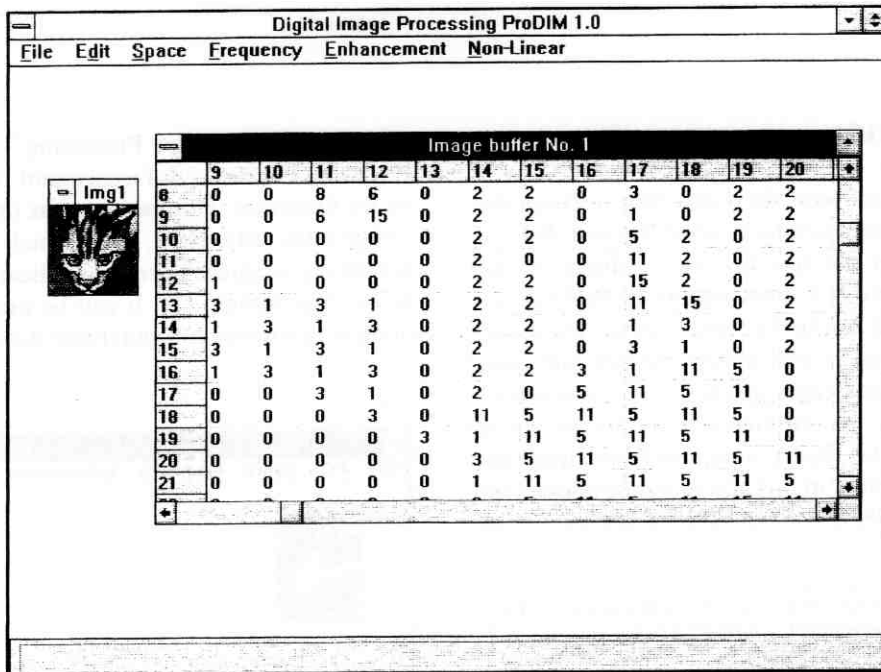


Figure 3 Edition of the selected image.

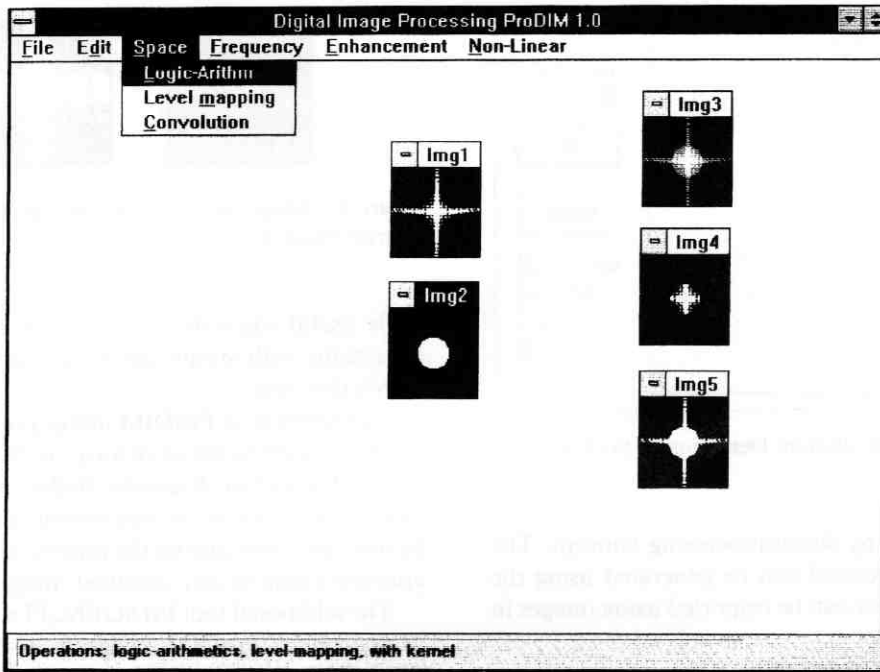


Figure 4 Logic-arithmetic operations.

which could be easy to install, learn, and use on any personal IBM-compatible computer with a 286 or higher processor. Typically, a digital image in the different formats used by professional programs occupies a great amount of memory, and that was something to avoid if the student should store and

print several samples to accomplish scholar assignments. In this package, the images consist of a 64×64 pixel array with 16 gray levels. This size was considered enough to perform, with an educational purpose, most of the operations in the spatial and frequency domains in a reasonable amount of time,

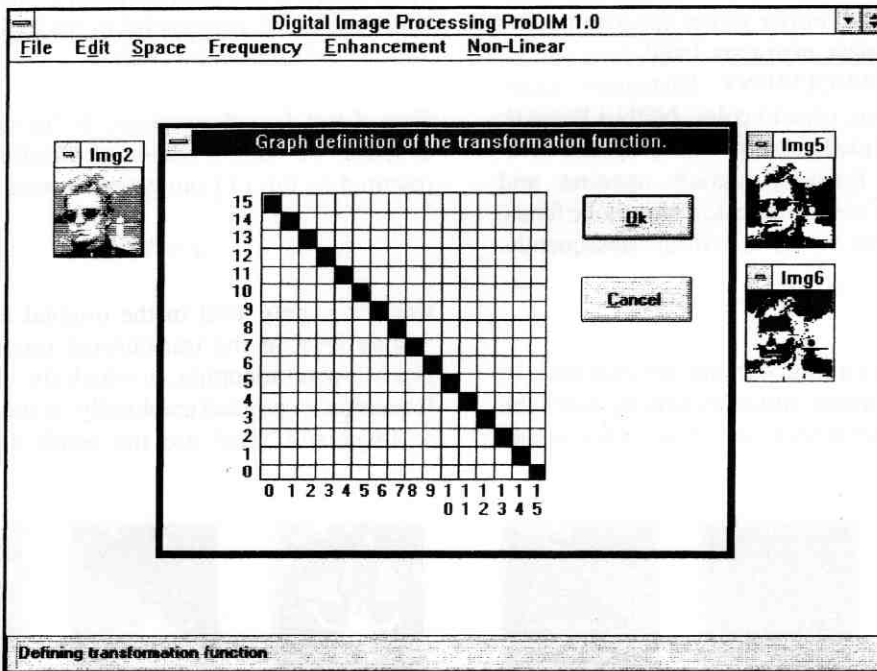


Figure 5 Gray-level transformations.

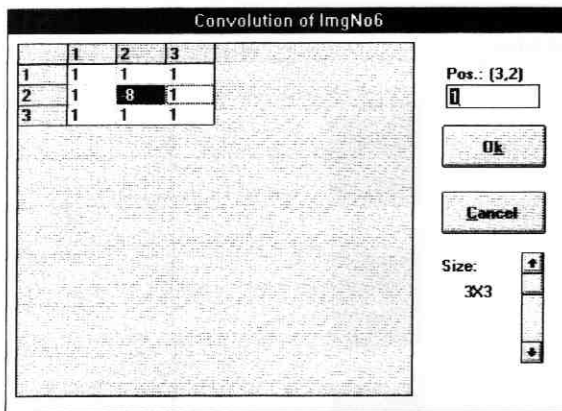


Figure 6 Convolution: Definition of the kernel.

without losing any signal-processing concept. The image to be processed can be generated using the editor included, or can be imported using images in a BMP format.

A graphical interface allows the user to activate different operations through a menu selection. Figure 1 corresponds to the main screen with the different options described as follows: FILE: Basic commands to handle files (open, close, save, exit). EDITION: Examine buffer, edit the selected image, create a new image, copy, paste; access to the utility program to get a window from any BMP image. SPACE: Processing in the space domain (logic-arithmetic operations, gray-level transformations, 2-D convolution). FREQUENCY: Processing in the frequency domain (Fourier power spectrum; ideal linear filters: low-pass, high-pass, band-pass, and reject-band). ENHANCEMENT: Histogram equalization, sharpening, pseudo color. NON-LINEAR: Nonlinear filters (median, homomorphic, and morphologic filters). Erosion, dilation, opening, and closing operations needed to realize morphologic filters.

These options are described in detail subsequently.

Edition

Several ways to get a source image are provided. In the first case, an image editor to directly enter the value of each pixel is included. This editor is spe-

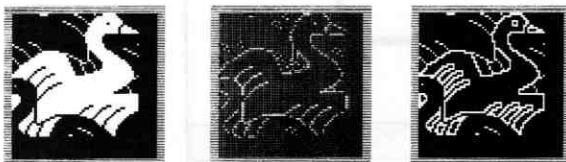


Figure 7 (a) Original image duck. (b) Laplacian of duck. (c) Binarization of Laplacian of duck.

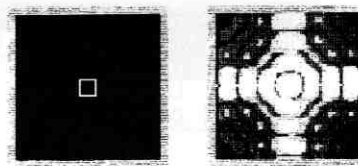


Figure 8 Image square in the spatial domain and its Fourier transform.

cially useful when the user wants to explore some operations with simple geometric forms; Figure 2 shows this case.

Furthermore, a ProDIM image previously saved can be brought to the work area to edit some desired pixels. The option Examine Buffer, which has the same appearance as the one shown in Figure 3, can be used any time during the process to visualize the gray-level map of any obtained image.

The additional tool IMAGEN_PDI was included to generate a ProDIM image from any available BMP. This option is self-explanatory when accessed.

Spatial Domain

Logic-Arithmetic Operations. Processing in the spatial domain is grouped under this category. First, the logic-arithmetic operations between two images can be performed. As shown in Figure 4, the required operation as well as the identification of the involved images is specified. In the example of this figure, *Img3* is the result of adding *Img1* and *Img2*. *Img4* and *Img5* correspond to the logic operations and/or the same input images.

Gray-Level Transformations. In the same category of spatial domain, a gray-level transformation represented by Eq. (1) can be performed.

$$s = T(r), \quad (1)$$

where r = gray level in the original image, and s = gray level in the transformed image. This is a pixel-to-pixel mapping, in which the desired transformation is specified graphically, as shown in Figure 5. *Img5* and *Img6* are the result of applying a



Figure 9 Low-pass filtering of a cat image. (a) Original image. (b) Low-pass, radius 15. (c) Low-pass, radius 10.

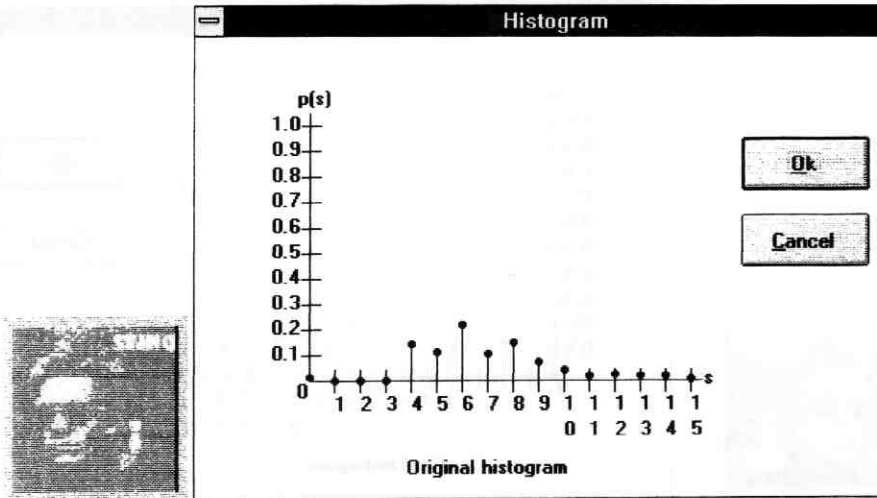


Figure 10 Histogram of a singer's image.

binarization to *Img2*. The transformation function shown in the figure corresponds to an inversion in the gray levels, which has the effect of turning the input into its corresponding negative.

Two-Dimensional Convolution. The last operation included in this category is a 2-D convolution defined by Eq. (2). In a linear system, the output is given by the convolution of the input function with the unit impulse response [2]:

$$g(x, y) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m, n)h(x - m, y - n) \quad (2)$$

In digital image processing, the impulse response is defined as a convolution mask or kernel with a size typically much less than the size of the input image. In this package the size of the convolution mask ranks from 3×3 to 11×11 .

In Figure 6, the convolution kernel of the Laplacian operator is shown with the coefficients entered in the corresponding position. As an example, the Laplacian operator is used on a binary image to perform edge detection. The results obtained are shown in Figure 7.

Frequency Domain

Fourier Transform. In this category, the operations corresponding to ideal linear filtering are included. The mathematical tool which links the space and frequency domains is the 2-D Fourier transform. Because a digital image is represented by a 2-D sampled function, a discrete version of this operation called the discrete Fourier transform (DFT) is used. The DFT is defined as [2,3]:

$$F(u, v) = \frac{1}{N^2} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y)e^{-j2\pi/N}(ux+vy), \quad (3)$$

where (x, y) and (u, v) are coordinates in the spatial and frequency domains, respectively. Figure 8 shows an image $f(x, y)$ in the spatial domain, and its corresponding magnitude spectrum $|F(u, v)|$.

Linear Filtering. A linear filter basically consists of a selective discrimination of frequency spectral components; thus, an ideal low-pass filter keeps only the Fourier coefficients inside a circle of some specific radius, multiplying the remaining ones by zero. The ideal high-pass filter is defined just in the opposite way (i.e., rejecting the frequency components inside a circle and passing the rest), the ratio of the circle defines the cutoff frequency of the filter. Two circles forming a ring are required to implement the

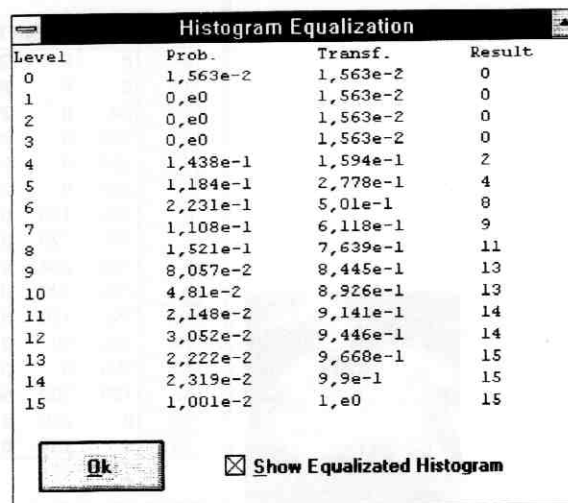


Figure 11 PDF and CDF of the singer image.

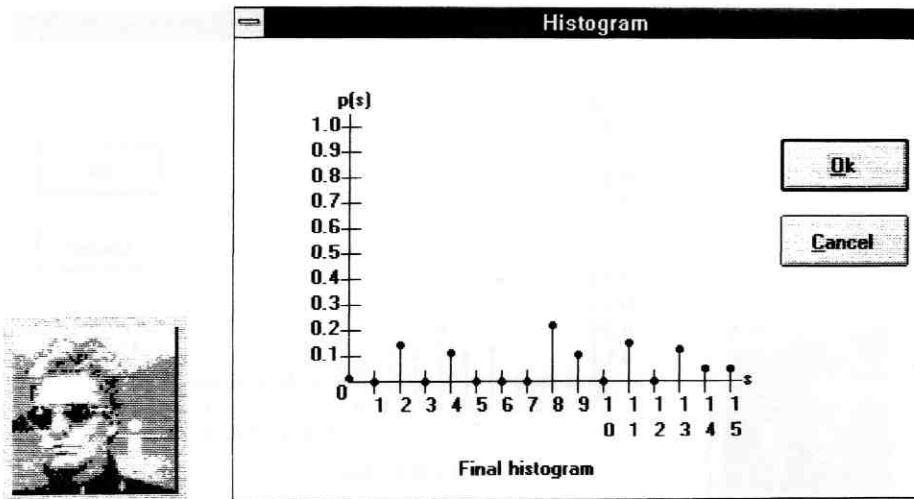


Figure 12 Histogram equalization of the singer image.

band-pass and band-reject ideal filters, passing or rejecting spectral components as required. Figure 9 shows the results obtained after applying ideal low-pass filters with two different cutoff frequencies.

Enhancement

Histogram Equalization. The goal of enhancement techniques is to process a given image so that the result is more suitable than the original image for a specific application. An histogram provides statistical information about the use of the range of gray levels in a digital image (e.g., the histogram of a dark image is concentrated in the lower gray levels). Although visual evaluation of image quality is a

subjective process, it is apparent that a human better perceives the definition of an image when the range of gray levels is completely covered (i.e., when the corresponding histogram tends to be flat). The process of applying a gray-level transformation to some image to optimize the use of the dynamic range is called *histogram equalization* [2,3]. This is achieved when the cumulative distribution function, given by Eq. (4), is used as the transformation function.

$$s = T(r) = \int_0^r r_r(w)dw \quad (4)$$

Figure 10 shows a singer's image and its corresponding histogram.

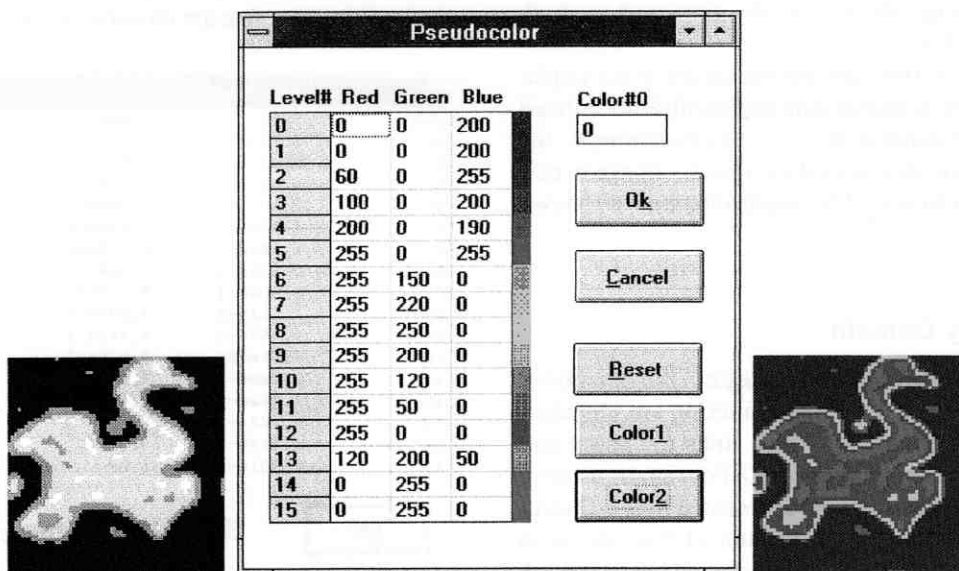


Figure 13 Pseudo color.

Figure 11 shows a table with the PDF obtained from the original histogram, and the CDF which is used as the gray-level transformation function. The new histogram as well as the equalized singer image is shown in Figure 12.

Pseudo Color. The motivation for using color in image processing is provided by the fact that the human eye can discern better color shade and intensities than gray level in a monochrome image [4]. This is specially important in those applications in which a visual examination is crucial, as is the case with medical images and other types of images. The software package ProDIM has an option to assign a color to each gray level by entering the corresponding trichromatic coefficients, as indicated in Figure 13. Two default color assignments are included to provide an initial choice to the user, which can be modified as needed. A monochrome image and its corresponding version in pseudo color are shown in the same figure.

Nonlinear Operations

Morphologic Filters. Morphologic filters are implemented by defining a structurant element B , which operates on the required image A . This structurant element is defined in a similar way to the convolution mask previously described; however, the operations between pixels are performed according to the definitions of mathematic morphology [5]. Erosion and dilation are defined by Eqs. (5) and (6), respectively:

$$C = A \ominus B = \bigcap_{b \in B} A_b \tag{5}$$

$$C = A \oplus B = \bigcup_{b \in B} A_b \tag{6}$$

In these definitions, A_b denotes the translation of the image A by the subelement b .

The techniques included in ProDIM are: erosion, dilation, opening, and closing filters. Figure 14 shows the results obtained when the binary image is dilated with a structurant element given by a 2×2 and 3×3 square, respectively:



Figure 14 (a) Original image. (b) Dilation with a 2×2 square (c) Dilation with a 3×3 square.

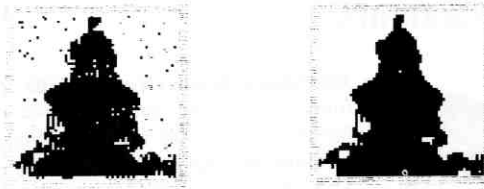


Figure 15 Median filtering of a noisy image.

Median Filtering. In a median filter, the value of each pixel is replaced by the median of the gray levels in a neighborhood of that pixel. This method is particularly effective to remove impulsive noise, and when it is important to preserve edge sharpness. The size of the region in which the statistical analysis is performed is defined by the user. Figure 15 shows the effect of applying median filtering with a small square of size 3×3 to a noisy image.

CONCLUSIONS

The educational software ProDIM, created with the idea to provide a support in the teaching of digital image processing, has been presented. This package was implemented in Visual Basic to be used in a Windows environment, which makes it easy to learn and manipulate by the students from the first attempt. The size of the program as well as the images processed with it make this software easily handled by the students. The theory involved in each topic of the course has been reinforced with the help of this software package. ProDIM is available on request to educators as a shareware package.

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BIOGRAPHIES



Juan Manuel Ramírez received his BS degree from the Instituto Politécnico Nacional, Mexico, in 1979; the MS degree from the Instituto Nacional de Astrofísica, Óptica y Electrónica, Mexico, in 1983; and the PhD degree from Texas Tech. University in 1991, all in Electrical Engineering. From 1986 to 1988 he served as Chairman of the Electrical Engineering and Computer Science Department,

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