Abstract

Title of Thesis: **Image Enhancement and Analysis of Leukocyte Adhesion**

Yee-Ruh Lin, Master of Science in Biomedical Engineering, 1991.

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The image of leukocyte adhesion to microvascular walls in the isolated rat perfused heart model has been observed and processed. Some of the fluorescent labeled leukocytes are barely visible due to microscope focal plane and the motion of objects . The purpose of this thesis is to extract leukocyte from the image of the experimental data using image enhancement and analysis(segmentation) techniques and develop a program to handle automatically counting of leukocytes in a predefined scene.

Image Enhancement and Analysis of Leukocyte Adhesion

by
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Approval Sheet

Title of Thesis: Image Enhancement and Analysis of Leukocyte Adhesion

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1 Introduction

1.1 Biological background

The adhesion of polymorphonuclear leukocytes (PMN's) to endothelium is an essential interaction in inflammatory and immunological responses. The control of these processes in the cell membrane of both endothelium and inflammatory cells is poorly understood. To know the nature of these processes well, the determination of PMN adhesion that after using different treatments, increasing or inhibiting adhesive activity, may evaluate the relative importance of endothelium as a regulator of neutrophil adhesion in an intact microcirculation.

In general, local injury immediately causes an influx of PMN's to the affected area involving a series of complex signaling and recognition processes. Some of the possible causes are local changes in calcium signaling or in membrane potential that may reversibly and instantaneously produce an endothelial pro-adhesive surface for PMN's at the injured site. Calcium entry into endothelium stimulates a variety of activities, such as the release of prostacyclin, ensothelium-derived relaxing factor, Von Willebrand factor, and platelet activating factor. Endothelial contraction and high permeability to macromolecules in microvessel may also induced by calcium entry.

There are some important findings revealed by Paul and Durán (inpreparation)[7] that in high potassium condition, the adhesive activity of endothelium to PMN's is greater than in normal potassium conditions in the coronary microcirculation. Pretreatment of the high potassium heart with calcium ionophore A23187 generates anti-adhesive activity. They proposed that a rapidly synthesized endothelial leukocyte inhibitory molecule (ELAIM) would participate in the balance between adhesion and antiadhesion signal in the normal coronary microcirculation, and would serve as an endogenous anti-inflammatory substance by preventing or decreasing the number of leukocytes adhering to the endothelium. Their findings also suggest that shear rates, coronary resistance, and flow rate in coronary vessels did not change the adhesion significantly, indicating that hemodynamic factors are not important determinants of leukocyte adhesion.

1.2 Objective and Procedure

The objective of this work is the development of suitable image enhancement techniques to deblur and analyze the blured image of fluorescent labeled PMN's. The blur may in the form of sensor noise, microscope misfocus, relative object- microscope motion, and so on. In Paul and Durán's work, the researchers analyzed 40 frames in each heart with the help of a transparent overlay to determine the density of PMN's per unit area. Such kind of work demands great patience and concentration in analyzing the experimental data from the video tape .

The developments in this thesis incorporate software for analyzing the experiment data from videotapes frame by frame to release the uncertainty from scene of the human eye and perseverance of analysis. This software includes techniques of histogram equalization, thresholding, modified interpolation, mathematical morphology and search technique in track to process the segment image. This enhancement process will offer us some important information hidden beneath the rugged surface of the epicardium and yield the PMN's number that appear on a predefined window.

2 Preparation and Experimental System

2.1 General Preparation

Male Wistar-Furth rat hearts were excised and set up as an isolated, perfused preparation. Blood was collected (10 ml/animal) by cardiac puncture in polystyrene tubes containing citrate, and the PMN's were separated from other components. PMN's were fluorescently labeled with 5-carboxy -fluorescein diacetate and infused the heart over 20 min . The number of adhering PMNs/mm^2 reached a plateu within the first 10 minutes. After a 10 min wash out period, the heart was placed on a specially designed lucite chamber and mounted on the stage of a Nikon Optiphot microscope for intravital microscopy observation. To determine the number of adhering PMN's per unit surface area, the entire left anterior surface of heart was scanned using a 6.3× objective following imaginary lines drawn between the left circumflex artery and apex. [7]

2.2 Experimental System

The fluorescent labeled PMN's were epilluminated through the microscope object using a 100 W mercury arc lamp with 488 um excitation filter and 515 barrier filter. The image was transmitted to a video camera (Model COHU 4410 SIT camera) and displayed on a TV monitor and simultaneously transmitted to the memory of a video image digitizer DS20F (Quantex Corp). The output signal from the digitizer can be sent in analog form (EIA standard RS170 video) to a video cassette recorder(Sony 5600) or in digital form over an HP-IB (IEEE 488) bus to a Hewlett-Parkard 1000 series A-900 computer. Video frames in the digitizer can be controlled both manually and by computer.

The DS20F digital video processor provides the capability of digitizing and storing TV images in one field or one frame (33ms) time. Image digitized by the DS20F can originate from any source providing standard RS 170 such as video cameras or video tape recorders. Each video image is resolved into a 512×512 matrix of picture elements. The gray scale range is 8 bits per picture element (256 gray scale). The experimental system is shown on fig.1.[4]

Videotapes of fluorescent label PMN's played back frame by frame through the digitizer memory. Digital images of selected frames are then further processed using several image processing techniques. Program IMAG89 was revised to I2 to provide specific usage for leukocyte adhesion image. Processed image can then be recorded on videotape or stored in digital form on the high speed disk (HP 7958,10 M Bytes) attached to the A-900 computer.

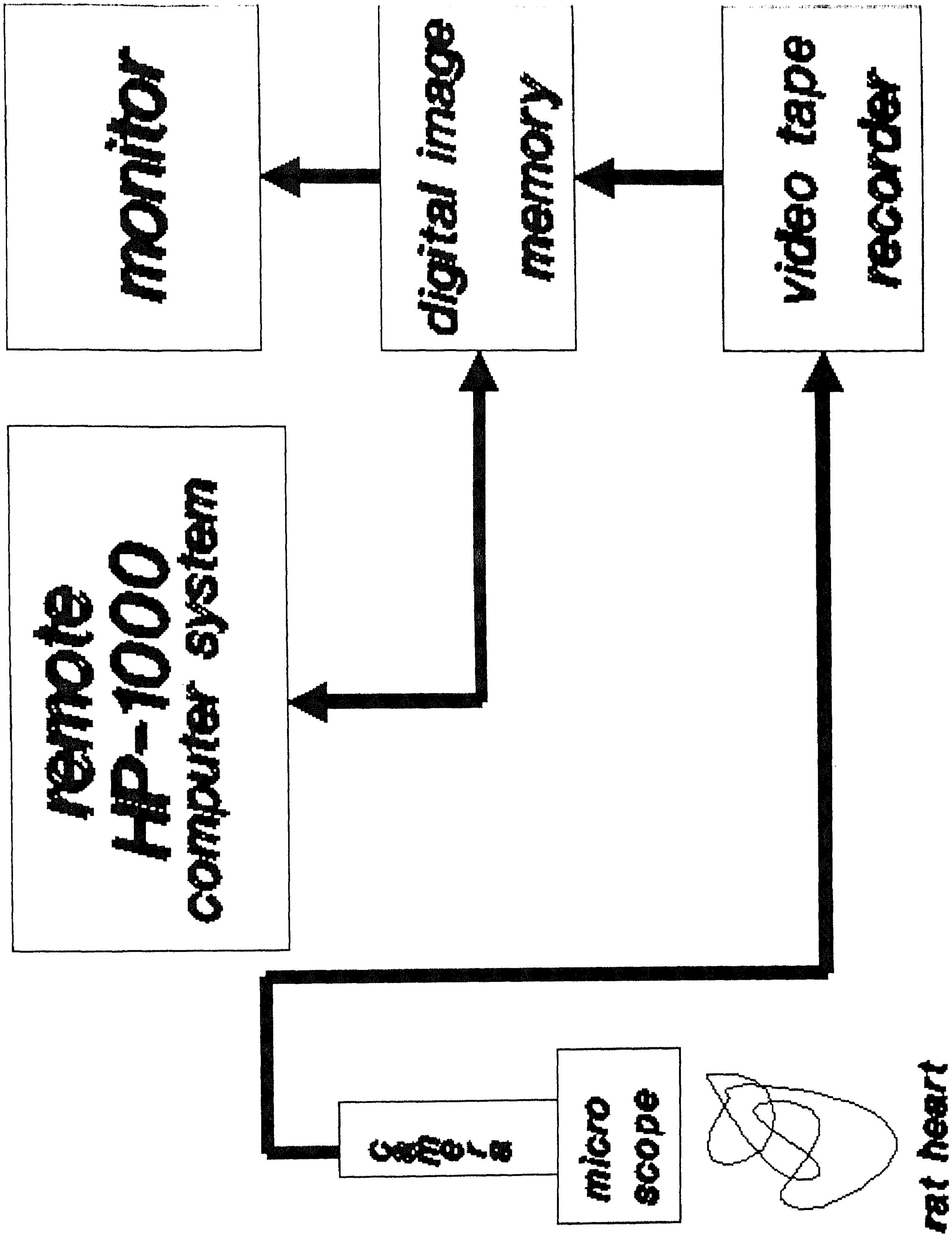


Figure 1: The experimental system

3 Principles, Methods, and Results

3.1 Image Pattern of Leukocyte Adhesion

In image compression or enhancement, the desired output is a picture, an approximation to , or an improved version of, the input picture. Another major branch of picture processing deals with image analysis or scene analysis; here the input is still pictorial, but the desired output is a description of the given picture or scene.[16]

The objective of this work is to use image analysis techniques to develop some software to recognize the fluorescent labeled PMN's on the screen and determine the number of PMN's within a predefined window. The softwares generated description refers to specific objects in the picture; thus, it is necessary to segment the picture of leukocyte adhesion and the background must be "scissored out". In order to extract an object from a picture explicitly after image enhancement and segmentation, the objects needed to be clearly defined to discriminate objects from noise. After completing segmentation and filtering, the standard pattern recognition can be applied to the processed image. Fig.2 shows the procedures to process the image model of leukocyte adhesion.

The following are the principles and concepts of digital image techniques that were applied to this analysis.

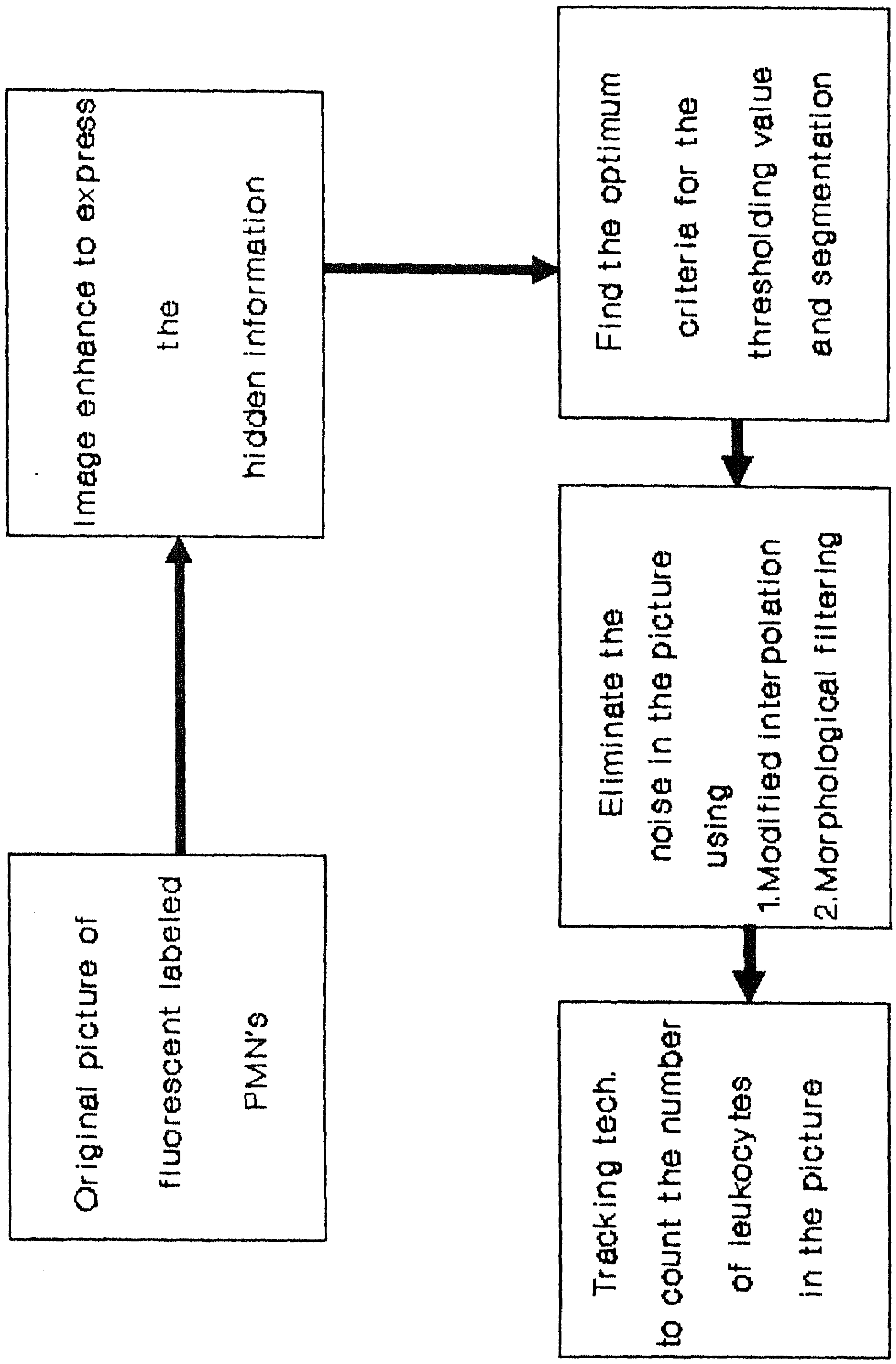


Figure 2: Flow chart of the procedure to enhances images of leukocyte adhesion

3.2 Image Enhancement by Histogram Equalization Technique

Let the variable r represent the gray level of the pixels in the fluorescent labeled PMN's image to be enhanced and they lie in the range

$$0 \leq r \leq 255$$

with r=0 representing black and r=255 representing white in the gray scale. For any r in the interval[0,255], attention will be focused on a transformation of the form

$$s = T(r) \tag{1}$$

which produce a level s for every pixel value r in the original image, and assuming eq(1) satisfies the conditions

(a) T(r) is single-valued and monotonically increasing in the interval $0 \leq r \leq 255$

(b) $0 \leq T(r) \leq 255$ for $0 \leq \mathrm{r} \leq 255$

where condition (a) preserves the order from black to white in the gray scale, and condition(b) guarantees a mapping that is consistent with the allowed range of pixel values.

The inverse transformation from s back to r will be denoted by

$$r = T^{-1}(s) \qquad \text{for } 0 \leq \mathrm{s} \leq 255 \tag{2}$$

where it is assumed that $T^{-1}(s)$ also satisfies conditions (a) and (b) with respect to the variables . The gray levels in an image are random quantities in the interval[0,255]. Assuming for a moment that they are continuous variables, the original and transformed gray levels can be characterized by their probability density function $P_r(r)$ and $P_s(s)$ respectively.

It follows from elementary probability theory that if $P_r(r)$ and T(r) are known, and $T^{-1}(s)$ satisfies condition(a), then the probability density function of the transformed gray level is given by the relation

$$P_s(s) = [P_r(r)\frac{dr}{ds}]_{r=T^{-1}(s)} \tag{3}$$

Now let's consider the transformation function

$$s = T(r) = \int_0^r P_r(w)dw \tag{4}$$

where w is a dummy variable of integration. The rightmost side of eq(4) is recognized as the cumulative distribution function of r. Then from eq(4) the derivative of s with respect to r is given by

$$\frac{ds}{dr} = P_r(r) \tag{5}$$

substituting $\frac{dr}{ds}$ into eq(3)

$$\begin{aligned} P_s(s) &= [P_r(r)\frac{1}{P_r(r)}]_{r=T^{-1}(s)} \\ &= [1]_{r=T^{-1}(s)} \\ &= 1 \qquad\qquad 0 \leq s \leq 255 \end{aligned} \tag{6}$$

which is a uniform density in the interval of definition of the transformed variable s, using a transformation function equal to the cumulative distribution of r produces an image whose gray levels have a uniform density.

In order to be useful for digital image processing, the concept developed above must be formulated in discrete form. For gray levels that assume discrete values we deal with probabilities given by the relation

$$P_r(r_k) = \frac{n_k}{n} \quad 0 \le r_k \le 255 \quad k = 0, \cdots, 255 \tag{7}$$

$P_r(r_k)$ is the probability of kth gray level, n_k is the number of pixels in the image.

The discrete form of eq(1) is given by the relation

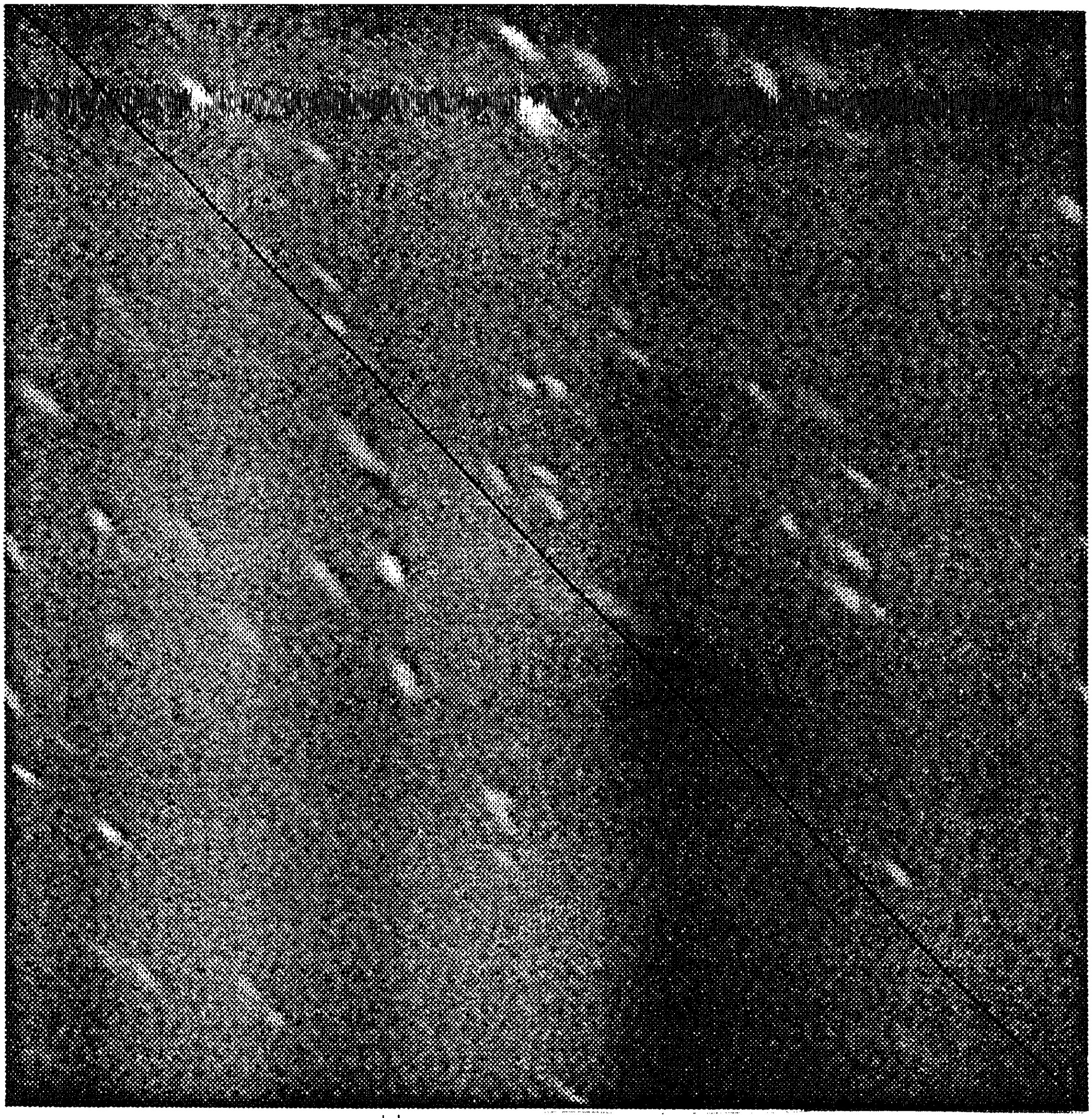
$$s_k = T(r_k) = \sum_{j=0}^{k} \frac{n_j}{n} = \sum_{j=0}^{k} P_r(r_j) \quad 0 \le r \le 255 \quad 0 \le k \le 255 \tag{8}$$

The inverse transformation is denoted by

$$r_k = T^{-1}(s_k) \quad 0 \le s_k \le 255 \tag{9}$$

As a practical illustration of histogram equalization, we applied the subroutine HSTEQ in I2.(see Appendix) Consider the original image of fluorescent labeled PMN's shown in fig. 3(a) which is influenced by microscope misfocus and relative motion, so that some leukocytes are barely visible. The narrow range of values occupied by the pixels of this image is evident in the histogram shown in fig.3(b). The equalized histogram is shown in fig.4(b), and the processed image in fig.4(a); while the equalized histogram is not perfectly flat throughout the full range of gray levels as expected, considerable improvement over the original image was achieved by the spreading effect of the histogram-equalization technique.[9]

The result display explicitly some of the hidden valuable information. With the information of the enhanced image, that offers us a criteria to perform the segmentation.



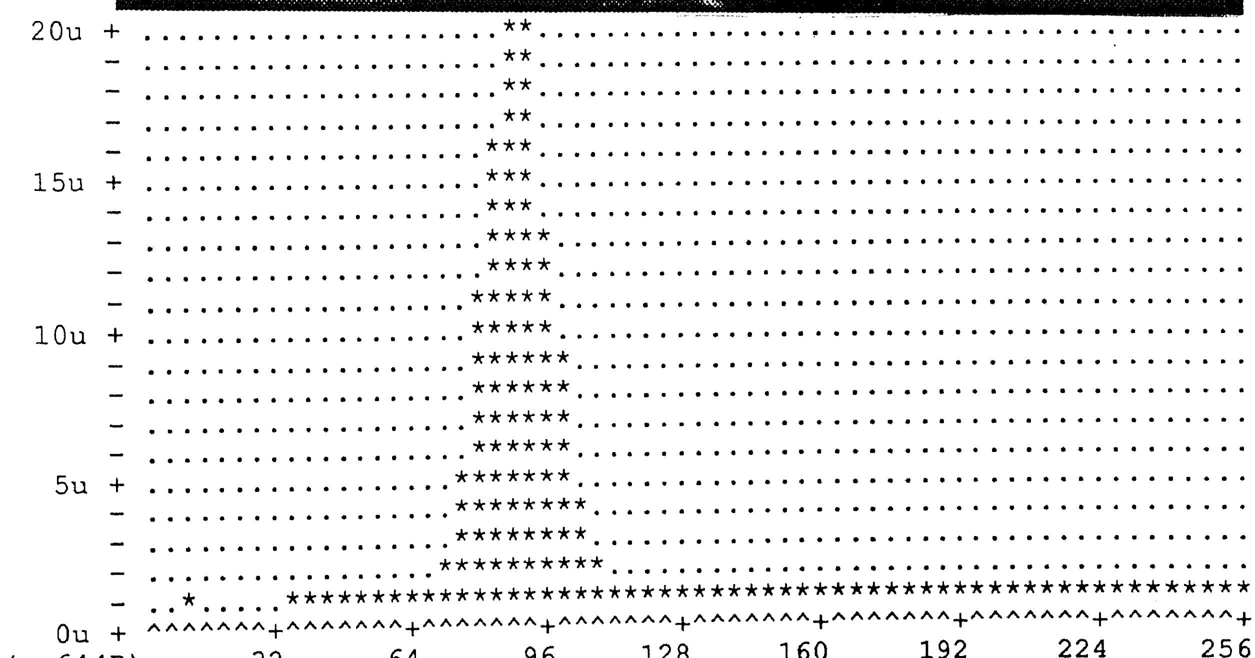


Figure 3: (a) Original picture of leukocyte adhesion in 256 × 256 matrix, some of leukocytes are barely visible result from microscope misfocus and relative motion. (b) The distribution of this histogram is concentrated in one region, from 70 to 110 in gray scale.

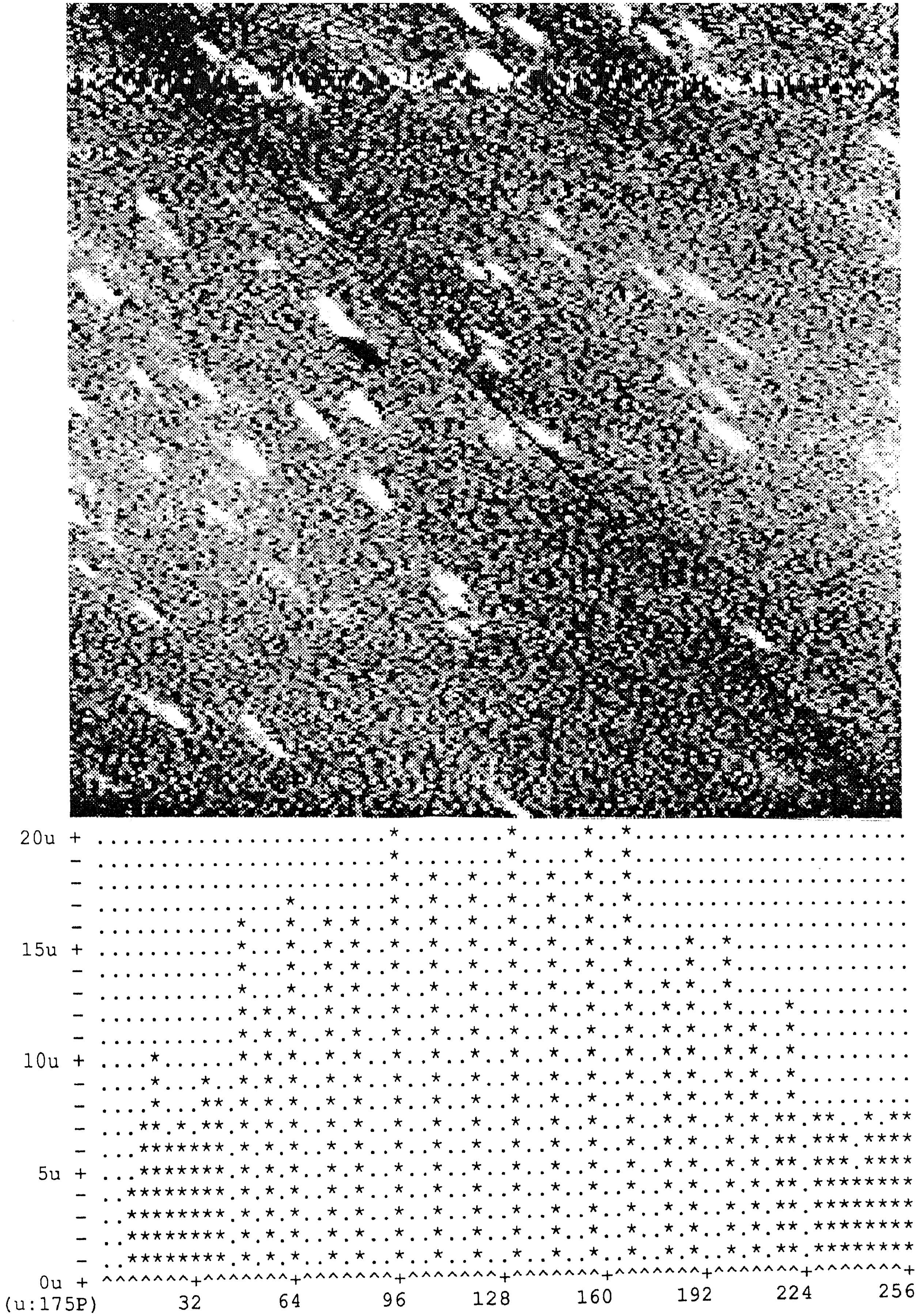


Figure 4: (a) After histogram equalization, the hidden information beneath epithlium are enhanced, simultaneously the noise has been graded up. (b) The equalized histogram is achieved by spreading effect of histogram-equalization techniques.

3.3 Thresholding

The main application of thresholding is the extraction of objects. Simple gray level thresholding is effective in extracting objects when the objects have a characteristic range or set of gray level.[4]

From the image of fluorescent labeled PMN's, the approach to threshold selection is to try a range of thresholds , and choose the one for which the threshold picture has some desired property. After histogram equalization, we can "lock on" some barely visible leukocytes to measure their gray levels and average them, then choose a threshold value adjacent below to this mean value. In image digital image program, subroutine THRH allows the user to assign any gray level range to a specified gray level. For the formula for thresholding

$$f_z(j,i) = \begin{cases} N & \text{if f(j,i) is element of z} \\ unchanged & \text{otherwise} \end{cases} \quad (10)$$

As fig.5 shows, we assign background gray level equal to 0, and objects(leukocytes) and noise lay on the range [105,255]. After the first of segmentation, now the procedure is noise cleaning.

3.4 Noise Filtering

Two major types of image noise dominate the image of leukocyte adhesion. The first type is an electro-optical component associated with the image formation and

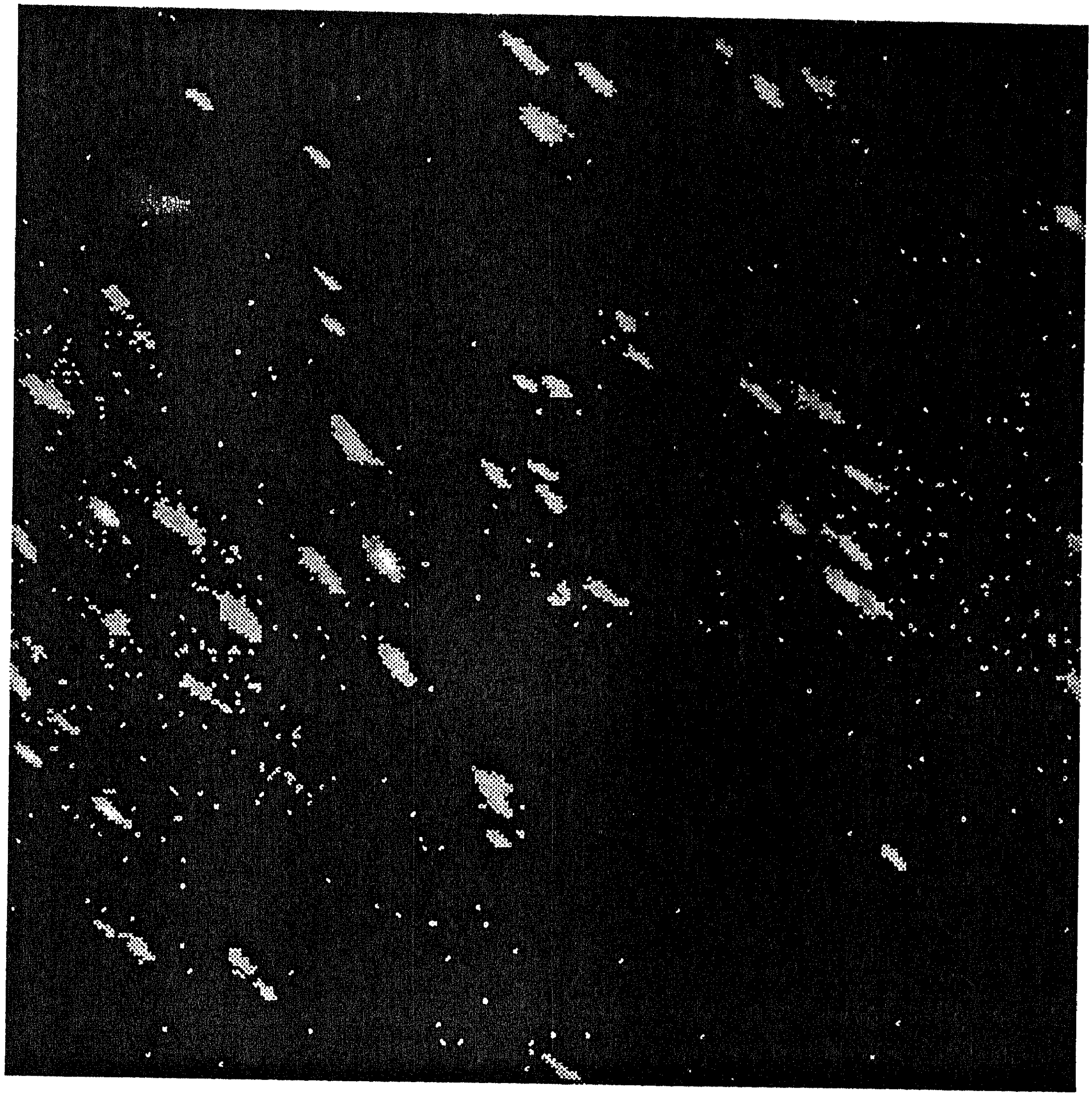


Figure 5: Using the thresholds techniques to define the gray level of background to 0, and leave the leukocytes and noise to old values, such process called semi-thresholding. And the picture show the "salt and pepper" noise caused by electro-optical component in experimental system.

quantization process within the TV camera, videotape recorder and digitizer. The sensed image intensities cannot be recorded without sensor noise. The characteristics of sensor noise are complex function of the sensed intensities. In addition, the characteristics are usually nonlinear so that one cannot assume superposition of signal and noise either in the recorded image or in the reconstruction of the recorded image.

The second type of noise is optical noise due to the experimental system. There are two components of this noise. The first is due to the optical properties of the object observed (the rugged surface of rat heart). The second component is due to the factors associated with lens design and manufacturing, light source, focusing and optical filters. Noise has a distribution over the gray level range 0 to 255.[13]

After optimal thresholding, as shown in fig.5, the techniques for removing "salt-and-pepper" noise in the two value case now can be implemented. In this study, we use two method to remove noise.

3.4.1 Modified interpolation

Before discussing this method we have to define the neighborhood (connectedness) for an object in one certain image. A point P=(j,i) of a digital picture Σ has four horizontal and vertical neighbors, namely the points

$$(j-1,i), \quad (j,i-1), \quad (j,i-1), \quad (j+1,i)$$

We call these points the 4-neighbors of P, and say that they are 4-adjacent to P. In addition, P has four diagonal neighbors , namely

$$(j-1,i-1), \quad (j-1,i+1), \quad (j+1,i-1), \quad (j+1,i+1)$$

These, together with the 4-neighbors are called 8-neighbors of P(8-adjacent to P). Note that if P is on the border of Σ, some of its neighbors may not exist. In the image pattern of leukocyte adhesion, we define the object is 8-adjacent connectedness. A path π of length n from P to Q in Σ is a sequence of points $P = P_0, P_1, ..., P_n = Q$ such that P_i is a neighbor of P_{i-1}, $1 \leq i \leq n$. Thus we can speak of π being 8-path. Let an object be a subset of Σ, and let P,Q be points of object. We say that P is 8-connected to Q in the object if there exists an 8-path from P to Q consisting entirely of points of object. For any P in the object, the set of points that are connected to P in the object is called a connected component of the object.[16] From fig.6 two leukocytes lay down on the x-y plane shown in the form of 8-connected component. The concept concerns the geometric relation of noise and object. When the noise consists of isolated points or group of connected points smaller than the size of leukocyte, we can attempt to detect noise points by comparing each point's gray level z with the level z_i of its neighbors, if z is substantially larger(or smaller) than all, or nearly all, of all z_i, we can classify it as a noise point, and remove it by interpolation, ie. replace z by the background gray level.

As fig.5 shown in "salt and pepper" noise and the given picture is "two valued", zero and nonzero gray levels. Here we detect the noise point by counting the number

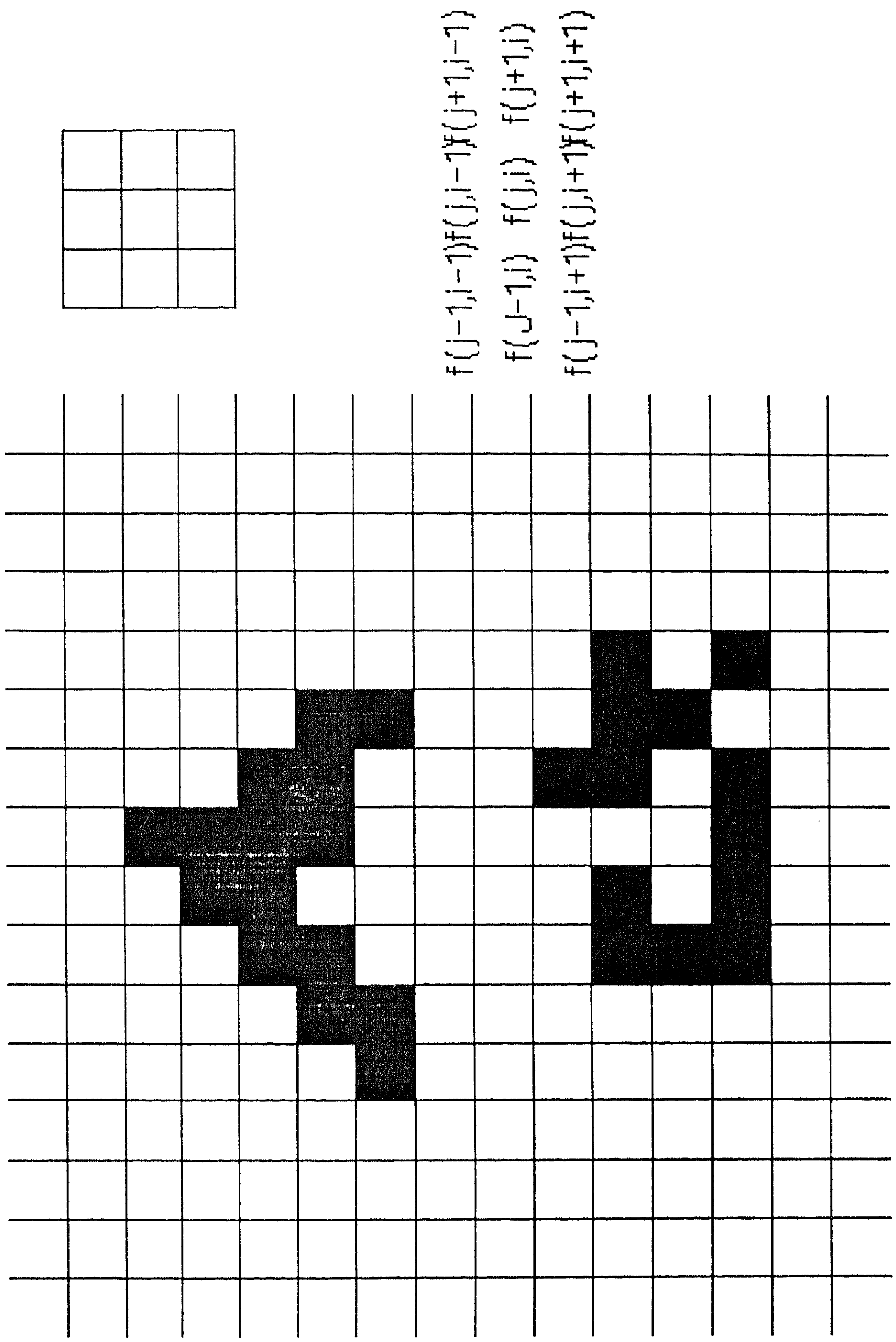


Figure 6: The concept of neighborhood(connectedness)

of their neighbors from which they differ . A white point that has too many ("nearly all") black neighbors can be changed from white to background gray level .

The method makes a forced-choice decision as whether or not the given point is a noise point. If we decide that the point or a group of points is smaller than the size of a leukocyte; in choosing the new gray level for these points, we pay no attention to its old level. On the other hand, if we decide that a group of connected points greater than leukocyte in shape, then we do not change the gray level at all. Using this method to develop the subroutine SMOTH, we can assign the nonzero gray level points to a certain value, further to give the number of neighbors connect to the processing point will delete these points if its'(processing point) neighbors number is smaller than the assign number, for example we assign the gray level to 127 and neighbor number to 4 that the result tell us from fig. 7 means every leukocyte in scene is homogeneous in gray level and "object" smaller than 5-connected component is excluded.

In some cases, if we apply SMOTH subroutine to process sizes of noise or undesired objects, greater than 3×3 matrix, these ones will remain. So we need a second method to give us more flexibility to process the image.

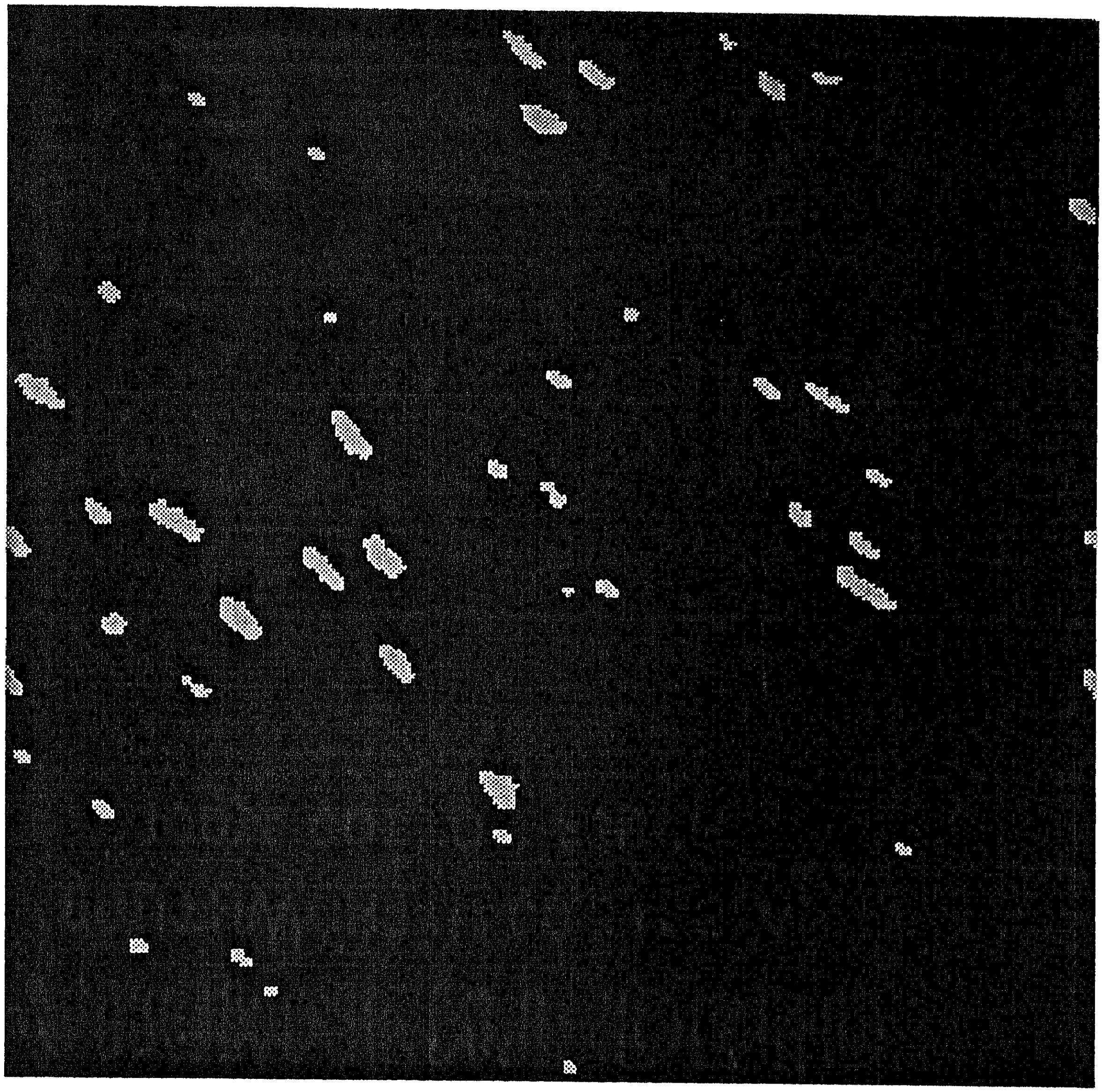


Figure 7: Noise is deleted by modified interpolation, the gray level of leukocytes is assigned to 127, the connected points smaller than 5 are excluded.

3.4.2 Morphological filtering

Digital image processing and analysis in the USA has been developed since the 1960s motivated mainly by problems in remote sensing and scene analysis; its main mathematical tools included classic linear filters, Fourier analysis, and statistical or syntactic pattern recognition. Parallel to, but independent from these ideas, mathematical morphology has evolved in Europe since the 1960s as a set-theoretic method for image analysis, motivated mainly by problems in quantitative microscopy. Its mathematical tools are related to integral geometry and stereology. The theoretical foundations of mathematical morphology which stem from Minkowski set operation, also called morphological filters, are more suitable for shape analysis than are linear filters.[10][11]

Image morphology can be used to reveal the structure of objects by transformation which correspond to shape filtering. An image can be represented by a set of pixels. The morphological operators can be thought to work with two images. The image being processed is referred to as active image and the other image being a kernel is referred to as the structuring element. Each structuring element has a designed shape which can be thought of as a probe or filter of the active image. We can modify the active image by probing it with various structuring elements.

Erosion and dilation are two basic concepts through set operations in morphological filtering.

A. Erosion

Erosion combines two sets using vector subtraction of set elements. If A and B are sets in Euclidean space which elements a and b respectively. $a = (a_1, \cdot, a_n)$ and $b = (b_1, \cdot, b_n)$ being N-tuples of elements coordinates , then the erosion of A by b is the set of all elements x for which x+b ∈ A for every b ∈ B. Erosion $A \ominus_b B$ can be interpreted as the locus of all center c such that the translation B_c is entirely contained within the set A. One should be aware that erosion is different from Minkowski subtraction which is the intersection of translations of A by the elements b ∈ B. Whereas, dilation is identical to Minkowski addition. Some erosion equivalent terms are "shrink" and reduce". The binary erosion of A by B is denoted by $A\ominus_b B$ and is defined as

$$A \ominus_b B = \{x \in E^N \mid x + b \in A \quad for \quad every \ b \in B\} \tag{11}$$

Equivalently, we may write

$$A \ominus_b B = \bigcup_{b \in B} (A)_{-b}. \tag{12}$$

Fig.8 shows the effect of erosion from fig.7. The structuring element is 3×3 matrix is big enough to delete the noise, but shrink some valuable information.

B. Dilation

Dilation is the morphological dual to erosion, and combines two sets using vector addition of set elements, thus the dilation of A by B is the set of all possible vector

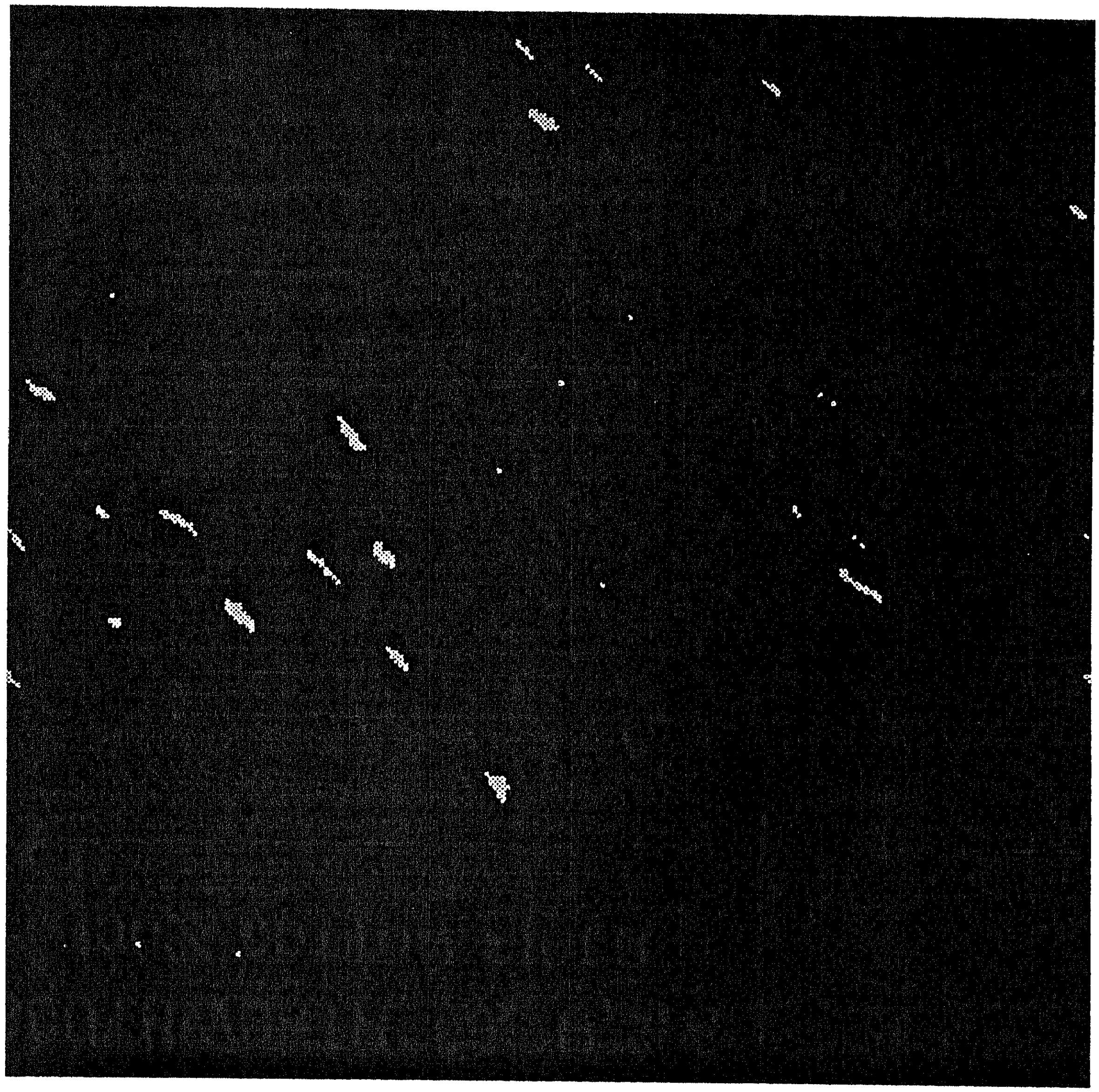


Figure 8: Effect of erosion from the result of fig. 7, show the outlayer of leukocytes are shrink by a 3 × 3 matrix .

sum of pair of elements, one coming from A and the other from B. In dilation, the roles of the sets A and B are symmetric. Dilation has a local interpretation. That is, if we think of each point a of A as a seed that grows the flower B_a (by placing the origin of B at a), and the union of all the flowers is the dilation of A by B. Dilation by disk structuring elements corresponds to isotropic expansion algorithm popular to binary image processing. Dilation by small square (3 × 3) is an 8-neighborhood operation easily implemented by adjacently connected array architectures and is the one known by the name "fill", "expand" or "grow". The binary dilation of A by B is denoted by A $\oplus_b$B and is defined as

$$A \oplus_b B = \{c \in E^N \mid c = a + b \;\; for \;\; some \; a \in A \; and \; b \in B\}. \qquad (13)$$

Equivalently, we may write

$$A \oplus_b B = \bigcup_{b \in B} (A)_b = \bigcup_{a \in A} (B)_a. \qquad (14)$$

From fig.9 the size of leukocyte is expanded using the dilation technique.

Simply speaking in our analysis, suppose that we change all white points to black if they have any white neighbors, and then change all black points to white if they have any white neighbor. The first step shrinks all white region while the second step reexpands them; When the structuring element is set to 3 × 3 matrix, a white object that is two point wide or less will disappear completely at the first step, so that the second step cannot restore it. Thus this process deletes not only isolated points, but

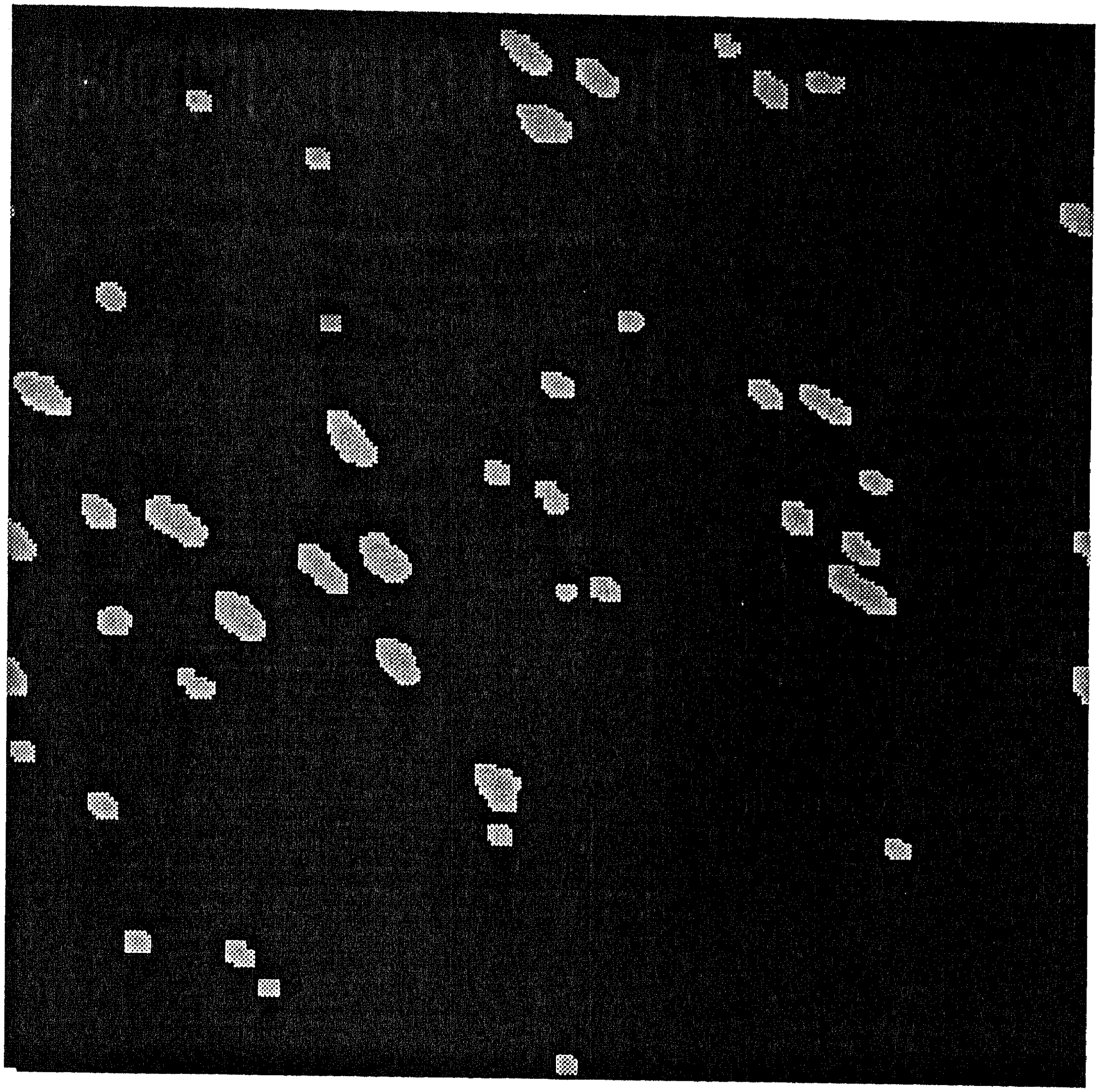


Figure 9: Effect of dilation from the result of fig. 7, show the outlayer of leukocytes are expanded by a 3 × 3 matrix.

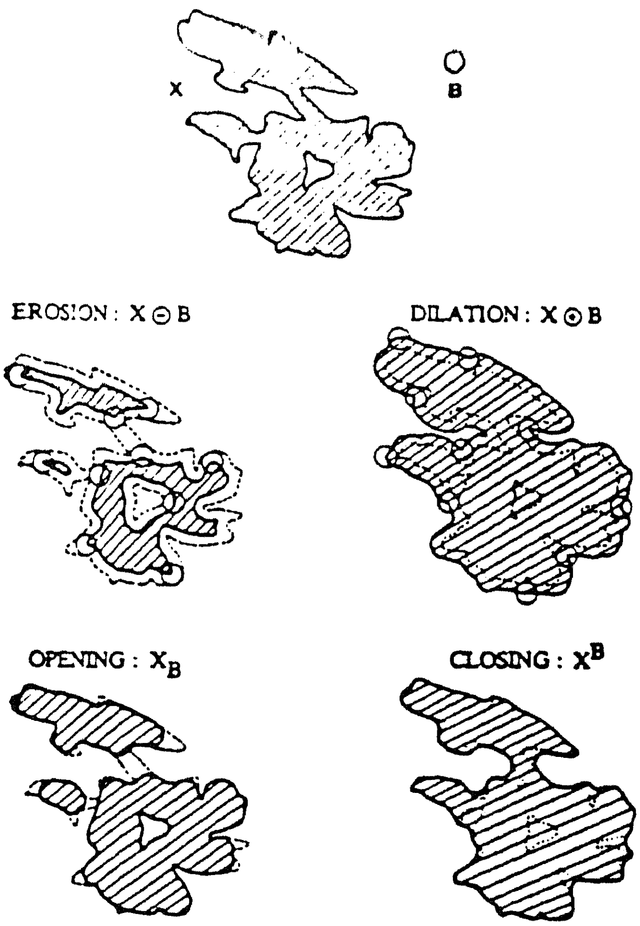


Figure 10: Erosion-dilation pairs show different effects on the morphologic sphere X probed by structuring element B. Left hand side tell X shrinked by B first, and dilated by B following, the structure of X is separated into 3 parts, this process we call it **opening**. Right hand side tell X dilated by B, and shrinked by B in order, the hole in X is filled by B, we call it **closing**.

also thin line, such process we call *opening*, will give us an effect of fig.11 shown. And some morphological shape leukocytes will divide into many parts.

In practical applications, dilation and erosion pairs are used in sequence, either dilation of an image followed by the erosion of the dilated result(opening), or erosion followed by dilation(closing). From fig.10 shown us the basic application of morphological filtering with two processing, opening and closing. In either case, the result of iteratively applied dilations and erosions is an elimination of specific image's detail

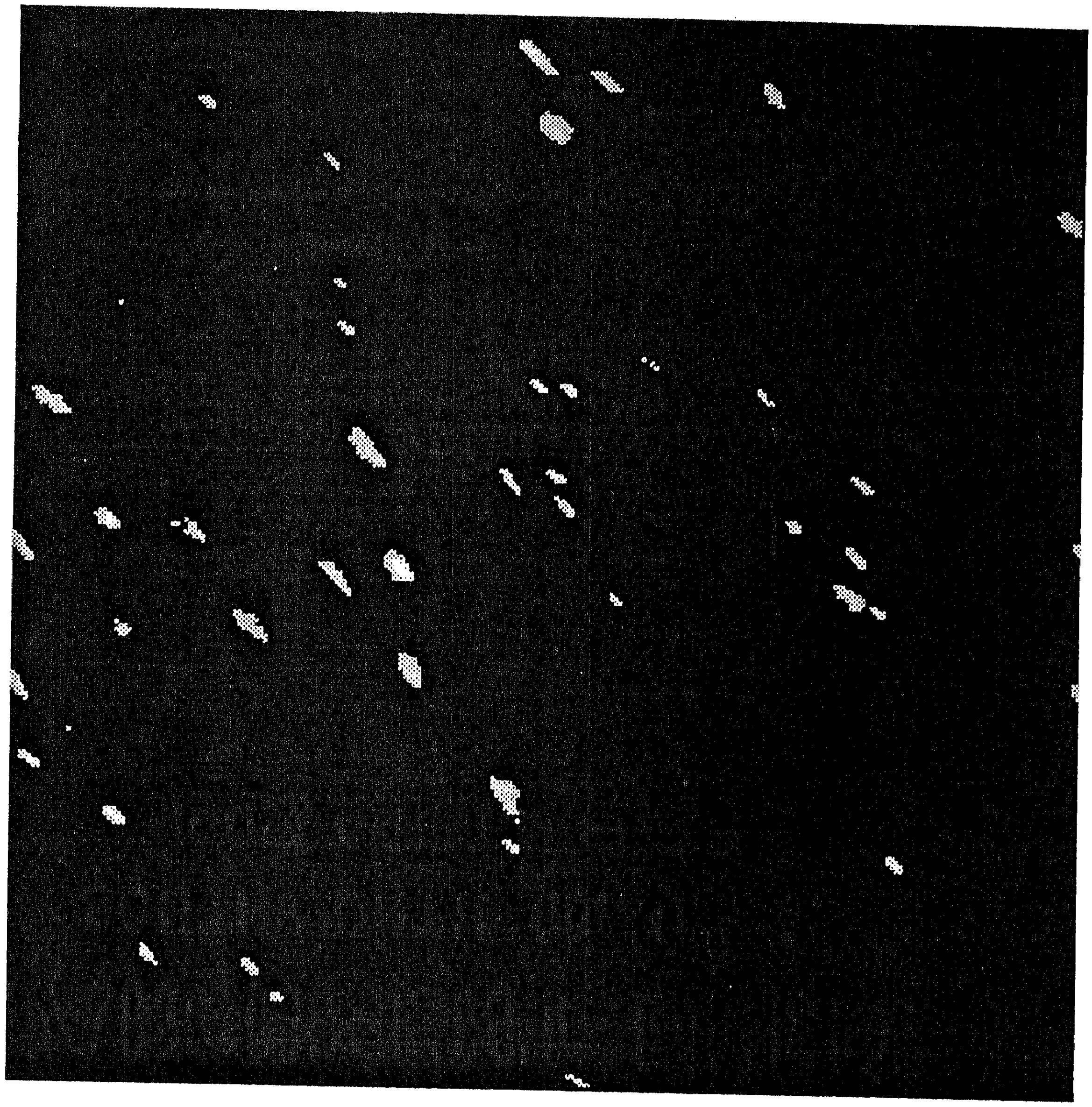


Figure 11: Use the technique of opening to process the result of fig. 5 can delete the noise in the scene, but will give us false information. Compare with the technique of modified interpolation, some leukocytes have critical size are "killed" by structuring element.

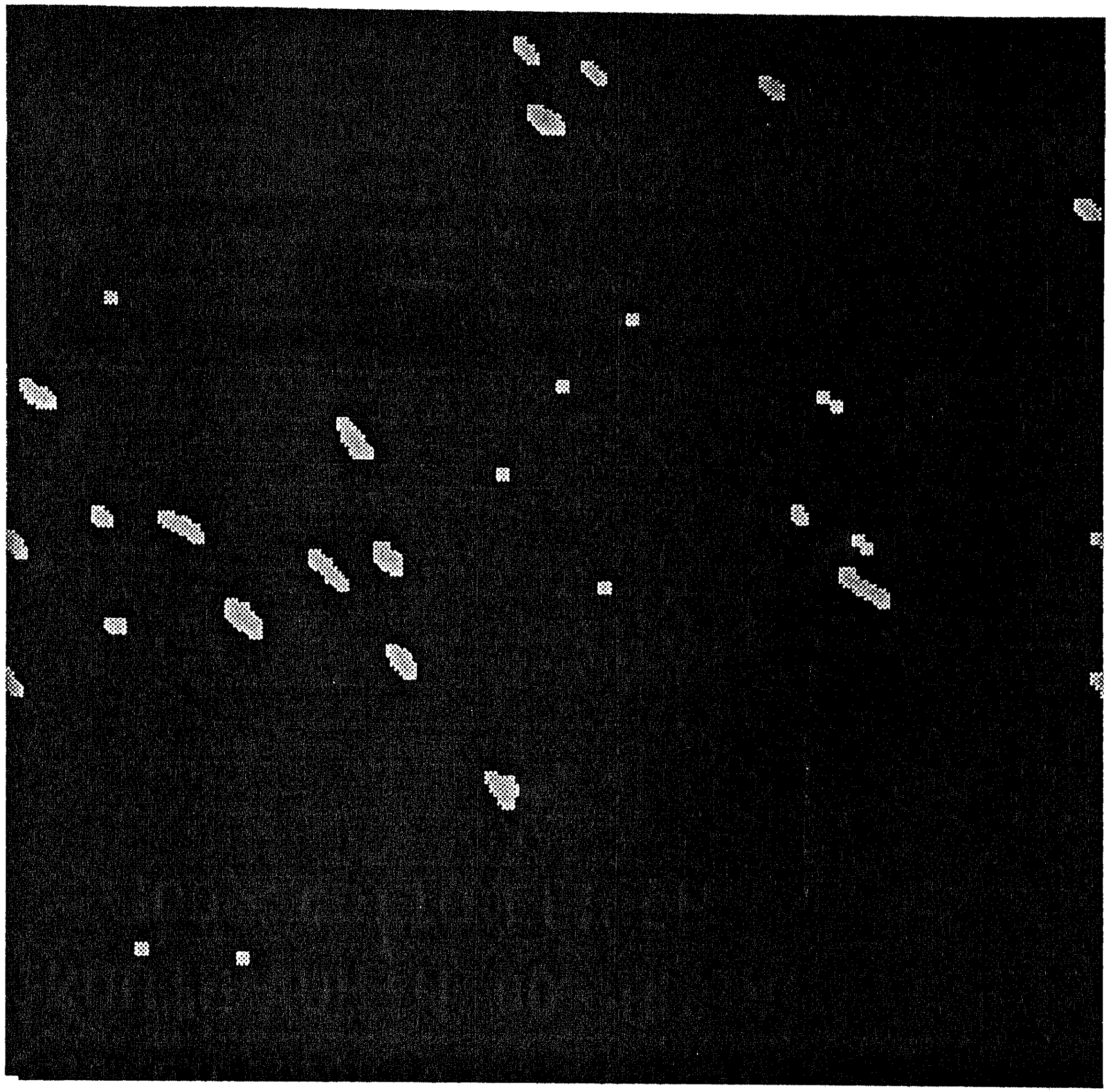


Figure 12: Use the technique of closing to process the result of fig. 5 show the merge effect of separate objects.

smaller than the structuring element without the global geometric distortion of unsuppressed features.[17] In this analysis, from fig.5 known the given picture is" two valued", noise that is smaller than the picture detail can be removed by a process of erosion and dilation. Fig. 12 is the effect of closing comparing with opening that it will merge the nearby spots.

3.5 Tracking Technique

For the purpose of counting the PMN's in a 256 $\times$ 256 window, the image shall turn to bilevel image without noise existing. The image processing techniques we discussed above are for preparing the next procedure.

The basic of this algorithm is from the sequential segmentation, the concept is concerned in processing a point, of the result at previously processed points that is neighborhood (connectedness) base on the same criteria. In these inherently sequential methods, the processing that is performed at a point, and the criteria for accepting it as part of an object, can depend on information obtained from earlier processing of other points, and in particular on the nature and location of the points already accepted as parts of objects.

Using the sequential approach to detect possible object points, once some such points have been detected then more complex computations can be used to track the objects. The detection computations following the processed image can be relatively simple, may have to be performed at every point, since it need only detect every points of object.

The tracking criterion based on gray level and direction can depend in a comparison between the current point(j,i) and its candidate neighbors, so as to discriminate against candidates whose gray levels etc. do not resemble that of (j,i), if desired, in our analysis, we want to accept all candidate points that satisfy the tracking criterion. And we define that leukocyte is an connected(8-adjacent to point(j,i)) components.

The following is the algorithm for the counting technique in the processed image of leukocyte adhesion.

(1) Set up a count main routine to scan the predefined window from the address of (1,1), the raster direction is right and down, accept the first point meeting the detection criterion, and assign this point to be the initial point of a object that is to be tracked.

(2) For each object (leukocyte) currently being tracked, apply the appropriate tracking criterion to the points in its acceptance; adjoin the resulting accepted point to the object, This criterion depends on the gray level of the points, if no new points are accepted into the object, tracking of object has terminated.

(3) Erase the points of object, return to main count routine to add 1, and starting at adjacent pixel of preceding initial point of object to detect the following object.

(4) Repeat procedure (2) and (3).

(5) When the bottom row is reached, the count process is complete, and the description yields the number of PMN in a predefined window.

Fig. 13 displays the counting mechanism in term of the concept of connectedness (8- path) of objects to trace the same criteria using recursive program. This algorithm is effective in counting the numbers in fig.7 and the others processed binary images.

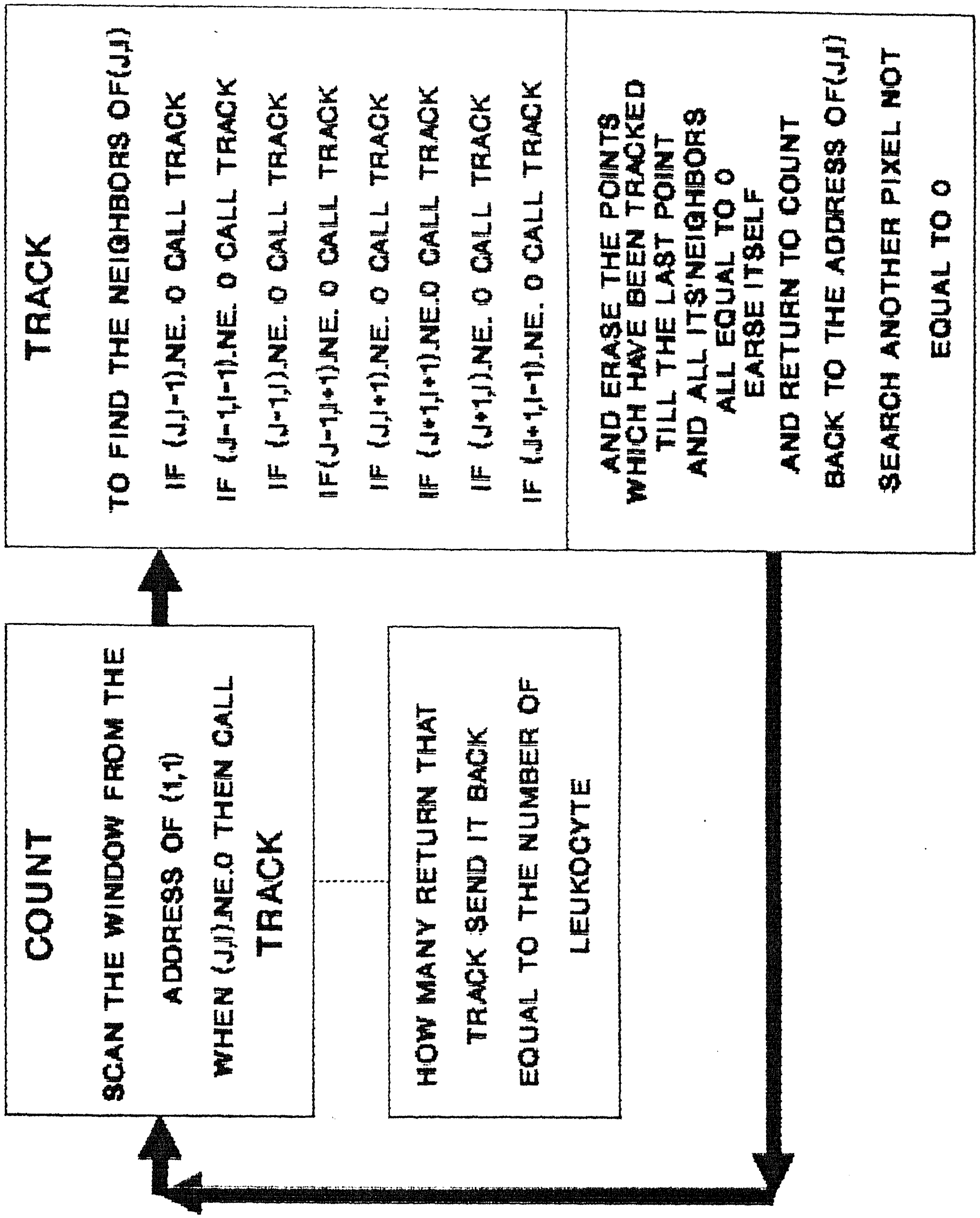


Figure 13: The counting mechanism of leukocyte adhesion

4 Discussion and Conclusion

4.1 Discussion

In our analysis, if it were to be required to define enhancement, it would be particularly difficult because one man's enhancement may be another man's noise. As a rule, enhancement broadly refers to manipulation of imagery to present to the viewer. Nevertheless, since the target object is the leukocyte, then the situation is obvious to process.

As known, broad categories of enhancement techniques might be listed as follows: (a) intensity mappings or point process; (b) edge sharpening or spatial processes; (c) artifact generation. The method of histogram equalization is classified to points processes, and it has many motivating factors. From a practical viewpoint, motivation for the use of this method arise from the simplicity of the operation as well as potential for real time implementation, additional one is that of attempting the removal of monotonic nonlinearities experienced in our image. Turn to statistical motivated point processes, the image histogram becomes particularly significant. The question often arises as to what enhancement techniques can be utilized when the gray levels are not well distributed by quantizing process. This method is most useful when there exists a finely quantized image from which there are an abundant but narrowly distributed number of quantization levels that can be stretched over a broader but fewer number of gray shades. The subtle adjacent-in-gray scale changes which occur most often in the original image are stretched to become more obvious at the expense of losing gray levels that occur less frequently.

There are three general argument in favor of histogram equalization. They are (a) maximum zero order entropy. (b) monotonic nonlinearity compensator. (c) preprocessing normalizer.[1] Maximum zero order entropy means that an equalized image presents to the viewer every gray level in an equally likely mode. This is a maximum entropy mode, but may or may not be a desirable operation as fig.4(a) shows. The motivation provided by monotonic nonlinearity compensator is derived from the fact that, for a large number of bits of quantization, the equalized image will be the same as the equalized object, provided the object was passed through strictly monotonic processes. The third motivation of a preprocessing normalizer that each numeric value occurs equally as often as every other value and, as such, guarantees the same amount of image energy as in any other histogram equalized image. This is a particularly useful property for comparing images as inputs to further data extraction algorithms. as next step in thresholding. It is not necessary to simply stick with histogram equalization as the only statistically motivated point process of interest. Naturally an output image could be generated with any distribution desired. The histogram of an image combined with collateral data may suggest other point process mapping, such as histogram modification.[9]

Definitely, spatial processes applied in the Fourier domain, using ramp or other monotonically increasing functions in the spatial frequency plane is another possible assessment in this analysis.

Obviously, modified interpolation or mathematical morphological filtering, are not suitable for global processes. The greatest advantage of these two noise filtering is that applied together, as in this study, they can be used for any size object, whether it is greater than 3×3 matrix, or smaller than 3×3 matrix. The possible methods to delete the noise have also been introduce by many studies. [13] [14] Image enhancement, smoothing and noise filtering by use of local statics or global information have been developed for many years, and it applied to many complicated computation for individual case (picture). Within the experimental data, 40 frames per rat heart, every picture has its unique characteristic of gray level distribution, and there are many diverse differences between frames. It is difficult to find any optimal global parameter to fit all the 40 frames per rat heart. Differences may be caused by the unstable experimental environment, such as vibration of focal plane, focus sharpness judged by the human eye, temperature influence to vidicon camera to affect system gain during longtime experiment, etc. From inspecting the experimental data, use of any local statics or global statics information to delete noise or smoothing will not give us any significant results.

One of the difficulties we encounter is from the experimental system. In the RTE system, the HP machine only offer FORTRAN 77 to develop software. In our analysis, we need to use recursion to do the tracking techniques, (see appendix: subroutine

COUNT) as we know many commonly used programming languages such as FORTRAN, COBOL do not allow recursive programs. The solution to our experimental problem can be derived and stated quite simply using recursive techniques, and can be programmed in FORTRAN or COBOL by simulating the recursive solution using more elementary operation.[18][2]

In general, a nonrecursive version of a program will execute more efficiently in term of time and space than will a recursive version. Sometimes a recursive solution is the most natural and logical way of solving a problem. The conflict between machine efficiency and programmer efficiency is another interesting topic arise from this software developing.

4.2 Conclusion

Image processing algorithms are presented in this work in order to provide biomedical investigators with tools to get results devoid human uncertainty. Further research in this area is to evaluate the accuracy of the number of fluorescent labeled PMN's experimental data between pre and after processing images. It is also possible to extend the image processing techniques to gray-level morphology method to enhance and extract the object directly.

Appendix

A : Digital image program I2

```
FTN66
$CDS ON
$EMA /A/ ! revision: Jan.15,1991 by LIN, YEE-RUH
$FILES 1,1
      PROGRAM I2
C     ------- ------
C
C     April,1983                                  Wolfgang Braun
C                                                 UMDNJ DEPT.PHYSIOLOGY
C     August,1985                                 Alan J. Stein
C                                                 UMDNJ DEPT.PHYSIOLOGY
C     September,1987                              Arthur B. Ritter
C                                                 UMDNJ DEPT.PHYSIOLOGY
C     Jan,1991                                    Lin Yee-Ruh
C                                                 NJIT DEPT.BIOMED. ENG
C     PROGRAM I2
C ....is a program to interact with the Quantex Digital Image
C     MEMORY. It is a dialog oriented program, designed to ex-
C     plain the functions and ask for necessary inputs and out
C     puts. Emphasis is made on achieving a multiuse modular
C     and self-documenting design. IMAG91 is a merge of the ol
C     IMAG2 and SLAVE programs with the PTOP and FMP calls
C     eliminated and the changes in exec read and write calls
C     the Quantex modified to run on the HP A-900.
C
C
C     Program description:
C     The mainroutine initializes the program to a defined
state.
C     It computes all necessary logical unit numbers on the HP
IB
C     Bus with the given address in the function call. It will
C     check if the power on the digitizer is turned on!
C     While the dimension for the workspace is dynamic (i.e.
C     the dimensions are dependent on loser input) it will ask
for
C     the x-y boundaries.
C     Note: In this program setup the maximum space defined in
C     COMMON /A/ is 256*256!
C     After this initialization process the program starts its
C     guiding menu to lead you through the program.
C     Before stopping the program the ending sequence will clo
C     all opened files.
C
C     The parameters are as follows:
C      IARRY  : workspace accessive for the user
C      IPXL   : reserved project space for picture processing
C      LX,LY  : actual line length,number of lines of the imag
C               residing in the workspace.
C      LSX,LSY: starting address of the residing image
C      LU,LQTX: Logic unit number of the
terminal,Quantex,HP2240A
C        ,I2240
C      IFLAG, : represents the state of a Writefile
```

```
C       IFLGR :        "      "      "    " " Readfile
C                     -1 : not yet logged on
C                      0 : close open files
C                      1 : no file open
C                      2 : NF option was used; no files will be
allowed
C                   > 10 : a file was created and is opened
C      Note: all these parameters are global and passed via
COMMON!
C       JEQT,IEQT,IMENU are local dummy parameters.
C
C      External subroutines:
CONTR,FILER,LOGIN,PROC,MATH,QWRIT,TFMGR
C      Calling procedure   : RU,IMAGXX
C
C
C      ***************************
C      ** M A I N R O U T I N E **
C      ***************************
C
C      This is the main routine of the program.
C      It initializes and guides the user through a mode menu.
C
C      INITIALIZATION
C
       COMPLEX SPECT
       COMMON /A/ IARRY(256,256),IPXL(256,256)
       COMMON LU,LQTX,ISC,JSC,LUBUS
       COMMON /INIT/LX,LY,LSX,LSY,NAPX,NAPY,MAXLY
       COMMON /FLAG/IFLAG,IFLGR
       COMMON /BUFR/ JBUF(128)
       COMMON /STACK/ ISTAK(56),IPTR
       COMMON /HISTO/ IHIST(0:255)
       LU = LOGLU(LU)
       LX = 0
       LY = 0
       IBELL = 3400B
       NAPX = 20
       NAPY = 75
       MAXLY = -1
       IRETR = 0
       IPTR  =  1
       ISWITCH = 0

C->The address of Quantex is set to 4! (Note in LBGET function

       LQTX = LBGET(LU,4,ISC,ISWITCH) ! ISWITCH = 0; RETURN
SELECT CODE

C OF QUALIFYING DEVICE. ISWITCH = 1; FIND QUALIFYING DEVICE
WHOSE
C SELECT CODE MATCHES ISC.

       ISWITCH = 1
```

```
         ENDIF
      ENDIF
      IF (IMENU.EQ.6.AND.IRETR.EQ.1) CALL PROC(IARRY,IRETR)
      IF (IMENU.EQ.7) GOTO 30
      GOTO 20

C->Ending sequence

30    WRITE (LU,32)
32    FORMAT(/" IMAGE:  Ending sequence begun . . .")
      IF (IFLAG.LT.10.AND.IFLGR.LT.10) GOTO 34
      IFLAG = 0
      CALL FILER(0,IARRY)
34    CALL LOGIN
      STOP 0001
      END

      FUNCTION LBGET(LU,IAD,KSC,ISWITCH)
C     -------- ----- -- ---

C->Loop to search for QUANTEX bus number

      DO 10,LLU=7,63
      LBGET = LLU
      CALL EXEC(100015B,LLU,I,J,K)   ! The no-abort option is
used here
      GOTO 10                        ! This line is executed on
error

C->Logical match and fooling the compiler

2     IF (IAND(J,37400B).EQ.17400B.AND.IAND(K,37B).EQ.IAD)THEN
          IF(ISWITCH.EQ.0)THEN
             KSC=IAND(J,77B)
             RETURN
           ELSE
           IF(KSC.EQ.IAND(J,77B))RETURN
           ENDIF
       ENDIF
10    CONTINUE
      LBGET = 0

C->Error message

      WRITE (LU,12) IAD
12    FORMAT(" LU address "I2," cannot be computed on this
bus!")
      RETURN
      END
C
C     **********************
C     ** SUBROUTINE TFMGR  **
C     **********************
C
```

```
C     Transfers a file into memory (or reads from Quantex mem.
C     It is the read supervisor. It asks for necessary info an
C     branches to the requested operation.
C
      SUBROUTINE TFMGR(IARRY)
C     ---------- ----- -----
      EMA IARRY
      COMMON LU
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION IARRY(256,256)
10    WRITE (LU,12)
12    FORMAT(//" Would you like to "/
     1"      1. read from Quantex memory (what's on the
screen),"/
     2"      2. read from an existing data file, or "/
     3"      3. return to main menu ?")
      READ (LU,*,ERR=10) IANS
      IF (IANS.EQ.1) GOTO 20
      IF (IANS.EQ.3) RETURN
      IF (IANS.NE.2) GOTO 10
      CALL FILER(1,IARRY)
      GOTO 40
20    WRITE (LU,22)
22    FORMAT(//" Type 0 to get a screen cursor; type 1000 to
return"/
     1" to the previous menu.")
24    WRITE (LU,26)
26    FORMAT(//" Type your start address (column,row)?  _")
      READ (LU,*,ERR=24) LSX,LSY
      IF (LSX.EQ.1000.OR.LSY.EQ.1000) GOTO 10
      IF (LSX.EQ.0.OR.LSY.EQ.0) CALL CURSR(IARRY)
      IF (LSX.GT.512.OR.LSY.GT.512) GOTO 24
      IF (LSX.EQ.0.OR.LSY.EQ.0) GOTO 24
30    WRITE (LU,32)
32    FORMAT(//" How many columns and rows? _")
      READ (LU,*,ERR=30) LX,LY
      IF (LX.GT.256.OR.LY.GT.256) GOTO 30
      CALL QDIMR(IARRY)
40    RETURN
      END
C
C     ******************************
C     ** SUBROUTINE  Q D I M R    **
C     ******************************
C
C     Quantex Digital Image Memory Read...
C     prepares the array string to set up Quantex for sending
the
C     requested data from a defined location.
C
      SUBROUTINE QDIMR(IARRY)
C     ---------- ----- -----
      EMA IARRY
      COMMON LU,LQTX,ISC,JSC,LUBUS
```

```
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION INTO(10),IARRY(256,256),IBUF(256),NPL(5)
      JCLMN = LSX
      JROW = LSY
      DO 10 I=1,LX
      ICLMN =JCLMN + I-1
      DO 10 J=1,LY
      IROW =JROW +J - 1
      CALL ADRCV(IROW,ICLMN,NPL)

C->NECESSARY ARRAY VARS

      INTO(1) = 00475B
      INTO(2) = 21002B
      INTO(3) = IOR(ISHFT(NPL(1),8),NPL(2))
      INTO(4) = IOR(ISHFT(NPL(3),8),NPL(4))
      INTO(5) = IOR(ISHFT(NPL(5),8),03B)
      CALL ADRCV(0,LX,NPL)
      INTO(6) = IOR(ISHFT(NPL(1),8),NPL(2))
      INTO(7) = IOR(ISHFT(NPL(3),8),NPL(4))
      INTO(8) = IOR(ISHFT(NPL(5),8),017B)
      IX = 1
C->Do not send EOI but require it from Q.

C     CALL EXEC(3,LQTX+2500B,34000B)

C->Send a IFC (interface clear) to get Q. attention
C
      CALL EXEC(3,LUBUS+5100B)
      CALL EXEC(2,LQTX+2100B,INTO,8)
      CALL EXEC(1,LQTX+100B,IBUF,IX)
 10   IARRY(J,I)=IBUF(1)
      CALL EXEC(3,LUBUS+5100B)
      CALL SEPAR(IARRY)
C->Separate the compressed workspace
      RETURN
      END
C
C     ************************************
C     **   SUBROUTINE QWRIT             **
C     ************************************
C
C ...is a control unit for most output functions.
C
      SUBROUTINE QWRIT(IARRY)
C     ---------- ----- -----
      EMA IARRY
      COMMON LU,LQTX,ISC,JSC,LUBUS
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION IARRY(256,256)
      IBELL = 3400B
10    WRITE (LU,12)
12    FORMAT(///" You want to write into Quantex memory."/
     1 " To do so I need more information."//
```

```
     2 "    1. Read in an image first."/
     3 "    2. Utilize an available test pattern."/
     4 "    3. Use the data we already have in the program's
memory."/
     5 "    4. Go back into main menu."//
     6 " Please type the number of your request (1-4)?  _")
      READ (LU,*,ERR=10) IREQ
      IF (IREQ.EQ.1) GOTO 1111
      IF (IREQ.EQ.2) GOTO 2222
      IF (IREQ.EQ.3.AND.LX.GT.0) GOTO 3333
      IF (IREQ.EQ.3.AND.LX.EQ.0) WRITE (LU,14) IBELL
      IF (IREQ.EQ.4) RETURN
      GOTO 10
14    FORMAT(A1,"There isn't any data in the program's
memory!")

C->Branch to the appropriate request.

1111  CALL TFMGR(IARRY)
      IF (LX.GT.0) GOTO 3333
      GOTO 10

2222  WRITE (LU,30)
30    FORMAT(//"    Choose one of the following test
patterns:"//
     1"  1.Black dot in white area "/
     2"  2.Vertical line"/
     3"  3.Two dots"/
     4"  4.Dotted square"//
     5"    Your selection?  _")
      READ (LU,*,ERR=2222) INUM
      IF (INUM.EQ.1000) GOTO 10
      IF (INUM.LT.1.OR.INUM.GT.4) GOTO 2222
      CALL TPAT(IARRY,INUM)

C-> Now definitely have an image

3333  WRITE (LU,42)
42    FORMAT(//' Now we have something to write!'/
     1 ' Select one of the following possibilities:'//
     2 '    1. Write the image beginning at the predefined
location.'/
     3 '    2. Write the image into a defined window.'/
     4 '    3. Use the automatic placement routine.'/
     5 '    4. Store the image in a file.'/
     6 '    5. Use the cursor to find the best location for the
image.'/
     7 '    6. Go back to menu.              _'/)
      READ (LU,*,ERR=3333) ISELC
      IF (ISELC.LT.1.OR.ISELC.GT.6) GOTO 2222
      IF (ISELC.EQ.1) CALL WQTX(IARRY)
      IF (ISELC.EQ.2) CALL WINDW(IARRY)
      IF (ISELC.EQ.3) CALL AUTO(IARRY)
      IF (ISELC.EQ.4) CALL FILER(0,IARRY)
```

```
      IF (ISELC.EQ.5) CALL CURSR(IARRY)
      IF (ISELC.EQ.4.OR.ISELC.EQ.5) GOTO 3333
      RETURN
      END

      SUBROUTINE TPAT(IARRY,INUM)
C     ---------- ---- ----- ----
      EMA IARRY
      COMMON /INIT/LX,LY
      DIMENSION IARRY(256,256)
      LX = 64
      LY = 64
      DO 10 I=1,64
      DO 10 J=1,64
10    IARRY(I,J) = 200

C-> Choose which to do

      GOTO (100,200,300,400) INUM

100   DO 120 I=30,35
      DO 120 J=30,35
120   IARRY(I,J) = 0
      RETURN

200   DO 220 I=31,33
      DO 220 J=10,54
220   IARRY(J,I) = 0
      RETURN

300   DO 320 I=14,18
      DO 320 J=30,35
      IARRY(J,I) = 0
320   IARRY(J,I+32) = 0
      RETURN

400   DO 420 I = 17 , 47 , 6
      DO 420 J = 17 , 47 , 6
      IF (I.EQ.17.OR.I.EQ.47.OR.J.EQ.17.OR.J.EQ.47) THEN
          IARRY(I,J) = 0
          IARRY(I,J+1) = 0
          IARRY(I+1,J) = 0
          IARRY(I+1,J+1) = 0
      ENDIF
420   CONTINUE
      RETURN
      END
      SUBROUTINE AUTO(IARRY)
C     ---------- ---- -----
      EMA IARRY
      COMMON LU
      COMMON /INIT/ LX,LY,LSX,LSY,NAPX,NAPY,MAXLY
      COMMON /STACK/ ISTAK(56),IPTR
      DIMENSION IARRY(256,256)
```

```
C->Initilize

      ILFT = 20
      IRT = 450
      ITOP = 75
      IBTM = 475
      IFLAG = 0

C->If NAPX & NAPY (20,75) then just go to 400 (write to left
top)

      IF (NAPX.EQ.20.AND.NAPY.EQ.75) GOTO 400

C->Menu

10    WRITE (LU,12)
12    FORMAT(//"    Auto Placement Menu"//
     1" 1. Place the image in the top left corner of the
screen."/
     2" 2. Overwrite the previous image."/
     3" 3. Write the image to the next free area on the
screen."/
     4" 4. Overwrite one of the other preceding images."/)
      READ (LU,*,ERR=10) IANS
      IF (IANS.LT.1.OR.IANS.GT.4) GOTO 10
      GOTO (100,200,400,300) IANS

C->   Clear stack

100   IPTR = 1
      NAPX = ILFT
      NAPY = ITOP
      GOTO 400

C-> Pop one, write to that location

200   CALL POP (NAPX,NAPY)
      GOTO 400

C-> Pop until correct one found, overwrite

300   WRITE(LU,302)
302   FORMAT(/"Which image, counting in the order in which the
were"/
     1"put up?   _")
      READ (LU,*) IANS
      KOUNT = (( IPTR - 1) / 2) - IANS + 1
      DO 310 I=1,KOUNT
310   CALL POP (NAPX,NAPY)


C->Check to see if new row needed
```

```
400   NN = NAPX + LX
      IF (NN.GT.IRT) THEN
                    NAPX = ILFT
                    NAPY = NAPY + MAXLY + 5
      ENDIF

C->Check to see if bottom out of range

      NN = NAPY + LY
      IF (NN.GT.IBTM) THEN
                    ISLY = LY
                    LY = IBTM - NAPY
                    IFLAG = 1
      ENDIF

C->Store old values of LSX,LSY; write to screen

      ISLSX = LSX
      ISLSY = LSY
      LSX = NAPX
      LSY = NAPY
      CALL WQTX(IARRY)

C->Restore old values

      NAPX = LSX
      NAPY = LSY
      LSX = ISLSX
      LSY = ISLSY
      IF (IFLAG.EQ.1) LY = ISLY
      CALL PUSH (NAPX,NAPY)

C->Compute new NAPX

      NAPX = NAPX + LX + 5

C->Check for new MAXLY

      IF (LY.GT.MAXLY) MAXLY = LY
      RETURN
      END

      SUBROUTINE PUSH(IVAL,JVAL)
C     ---------- ---- ---- ----
      COMMON /STACK/ ISTAK(56),IPTR
      ISTAK(IPTR) = IVAL
      IPTR = IPTR + 1
      ISTAK(IPTR) = JVAL
      IPTR = IPTR + 1
      RETURN
      END

      SUBROUTINE POP(IVAL,JVAL)
C     ---------- --- ---- ----
```

```
      COMMON /STACK/ ISTAK(56),IPTR
      IPTR = IPTR - 1
      JVAL = ISTAK(IPTR)
      IPTR = IPTR - 1
      IVAL = ISTAK(IPTR)
      RETURN
      END
C
C     ******************************
C     **  SUBROUTINE  W Q T X     **
C     ******************************
C
C     Write to Quantex memory
C ...initializes the Quantex for write procedures.
C
C     It sets up the outputstring in Quantex "NIBBLE" format
C     then it puts out the dimensioned IARRY.
C
      SUBROUTINE WQTX(IARRY)
C     ---------- ---- -----

      EMA IARRY
      COMMON LU,LQTX,ISC,JSC,LUBUS
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION NPL(5),INTO(5),ITEMP(128),IARRY(256,256)
C
C->Convert the workspace into a compressed output field
C  and set up the address string.

      CALL COMB(IARRY)
      ICLMN = LSX
      JROW = LSY
      NLX=INT((LX+1)/2.)
      DO 10 J=1,LY
      IROW = JROW + J - 1
      CALL ADRCV(IROW,ICLMN,NPL)
      INTO(1) = 00461B
      INTO(2) = 21002B
      INTO(3) = IOR (( ISHFT (NPL(1),8)) , NPL(2))
      INTO(4) = IOR (( ISHFT (NPL(3),8)) , NPL(4))
      INTO(5) = IOR (( ISHFT (NPL(5),8)) , 0017B)
C
      DO 5 J1=1,LX,2
      JJ=INT((J1+1)/2.)
      ITEMP(JJ)=IARRY(J,J1)
 5    CONTINUE
C
C->EXEC will cause a Interface Clear -) the only way
C  to get Quantex attention!
C
      CALL EXEC(3,LUBUS+5100B)
      CALL EXEC(2,LQTX+2100B,INTO,5)
 10   CALL EXEC(2,LQTX+2100B,ITEMP,NLX)
C 10  WRITE (LQTX) (INTO(I),I=1,5),(IARRY(J,J1),J1=1,LX,2)
```

```
      CALL SEPAR(IARRY)
      RETURN
      END
C
C     ***************************
C     ** SUBROUTINE  W I N D W **
C     ***************************
C
C     Description:
C     window replaces the dormant workspace to any defined
C     position in the memory(==screen).
C
      SUBROUTINE WINDW(IARRY)
C     ---------- ----- -----

      EMA IARRY
      COMMON LU
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION IARRY(256,256)

C->Store the original window

      ISLX = LX
      ISLY = LY
      ISLSX = LSX
      ISLSY = LSY

C->Dialog, and do the window

10    WRITE (LU,12)
12    FORMAT(" Type your new start address (column,row)? _")
      READ (LU,*,ERR=10) LSX,LSY
      IF (LSX.EQ.1000) RETURN
      IF (LSX.GT.512.OR.LSY.GT.512) GOTO 10
20    WRITE (LU,22)
22    FORMAT(" Type length of field (x,y)? _")
      READ (LU,*,ERR=20) LX,LY
      IF (LX.GT.256.OR.LY.GT.256) GOTO 20
      CALL WQTX(IARRY)
      WRITE (LU,24)
24    FORMAT(" Would you like to save this image? _")
      READ (LU,26) IANSW
26    FORMAT(A1)
      IF (IANSW.EQ.1HY) CALL FILER(0,IARRY)

C->Restore the original window

      LX = ISLX
      LY = ISLY
      LSX = ISLSX
      LSY = ISLSY
      RETURN
      END
C     *****************************
```

```
C      ** SUBROUTINE  C U R S R   **
C      ****************************
C
C      Description:
C       Cursor display on the monitor. A dot on the monitor, at
C      the defined position, will appear. After typing G (go)
C      the cursor is removed and the original data is written
C      back.
C
       SUBROUTINE CURSR(IARRY)
C      ---------- ----- -----
       EMA IARRY
       COMMON LU
       COMMON /INIT/LX,LY,LSX,LSY
       DIMENSION IRST(3,3),IARRY(256,256)
       ISLSX = LSX
       ISLSY = LSY
       LX = 10
       LY = 10
       ISLX = LX
       ISLY = LY

C->Save the IARRY contents of the cursor position

C      DO 2 I=1,LY
C      DO 2 J=1,LX
C 2    ISAVE(I,J) = IARRY(I,J)
C
10     WRITE (LU,12)
12     FORMAT(/" Type the cursor address (column,row)? _")

C->Read the cursor position and store the memory contents in
IRST.

       READ (LU,*,ERR=10) LSX,LSY
       IF (LSX.EQ.1000) RETURN
       CALL QDIMR(IARRY)
       ICC = 0
       IF (IARRY(1,1).LT.128) ICC = 255
       LX=3
       LY=3
       DO 20 I=1,LX
       DO 20 J=1,LY
       IRST(J,I) = IARRY(J,I)
20     IARRY(J,I) = ICC

C->Write the cursor to monitor

       CALL WQTX(IARRY)
       WRITE (LU,30)
30     FORMAT(" Hit any key and <return> to continue! _")
32     READ (LU,34) IANSW
34     FORMAT(A1)
       IF (ITLOG(IANSW).EQ.0) GOTO 32
```

```
C->Restore the monitor greycolours & orig. IARRY values

      DO 40 I=1,LX
      DO 40 J=1,LY
40    IARRY(J,I) = IRST(J,I)
      CALL WQTX(IARRY)
C
C     DO 50,I=1,LY
C     DO 50,J=1,LX
C 50  IARRY(I,J) = ISAVE(I,J)

C->Restore the original window

      LX = ISLX
      LY = ISLY
      LSX = ISLSX
      LSY = ISLSY
      RETURN
      END
      SUBROUTINE SCALR(IARRY,IPXL)
C     ---------- ----- ----- ----

      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION IARRY(256,256),IPXL(3,256)
      ISLSX = LSX
      ISLSY = LSY
      ISLX = LX
      ISLY = LY
      IANS = 1HX
1     LX = 170
      LY = 1
      J1 = 0
      ICC = 300

C->Let's open our textbooks to page 1, class . . .

10    WRITE (LU,12)
12    FORMAT(/"Input row number:   _")
      READ (LU,*,ERR=10) LSY
      IF (LSY.EQ.1000) RETURN
      IF (LSY.LT.1.OR.LSY.GT.512) GOTO 10
14    IF (IANS.NE.1HX) GOTO 19
      WRITE (LU,16)
16    FORMAT(/"White or black line (W/B) :   _")
      READ (LU,18) IANS
18    FORMAT(A1)
19    IF (IANS.EQ.1HW) ICC = 170
      IF (IANS.EQ.1HB) ICC = 30
      IF (ICC.GT.255) THEN
          IANS = 1HX
          GOTO 14
```

```
      ENDIF

C->Here we go Quantex, here we go!! (knock wood)

      DO 22 I=1,3
      LSX = 2 + 170 * (I - 1)
      CALL QDIMR(IARRY)
      DO 20 J=1,170
      J1 = J + 170 * (I - 1)
      IPXL(I,J) = IARRY(1,J)
      IARRY(1,J) = ICC
      RJ1 = FLOAT(J1)
      IF (J1 / 5.EQ.RJ1 / 5.0) IARRY(1,J) = 100 - IDIM(50,ICC)
      IF (J1 / 50.EQ.RJ1 / 50.0) IARRY(1,J) = 250 * IDIM(31,IC
20    CONTINUE
      CALL WQTX(IARRY)
22    CONTINUE
      WRITE (LU,30)
30    FORMAT(/"Right row (Y/N) :   _")
      READ (LU,18) JANS
      IF (JANS.EQ.1HY) GOTO 50

C->Wheah yu thin yu goin wit dat!

40    DO 44 I=1,3
      LSX = 2 + 170 * (I - 1)
      DO 42 J=1,170
      IARRY(1,J) = IPXL(I,J)
42    CONTINUE
      CALL WQTX(IARRY)
44    CONTINUE
      IF (JANS.EQ.1HY) GOTO 70
      GOTO 1

C->He likes it - hey Mikey!

50    WRITE (LU,52)
52    FORMAT(/"Please locate the scalar nearest to your"/
     1"starting point; count the number of markers and input
(Note:"/
     2"the lightest/darkest markers occur at 10,20,30,etc.")
      READ (LU,*,ERR=50) IPT
      ICOL = 5 * IPT + 1
54    WRITE (LU,56)
56    FORMAT(/"Please type in whether your starting point is"/
     1" 1. Far Left"/
     2" 2. Near Left"/
     3" 3. Center"/
     4" 4. Near Right"/
     5" 5. Far Right"/
     6"Enter the corresponding number :   _")
      READ (LU,*,ERR=54) IEXCT
      ICOL = ICOL + IEXCT - 3
```

```
C->You tell 'em---No,you(!) tell 'em!

      WRITE (LU,60) ICOL,LSY
60    FORMAT(/"The address of your starting pixel is
("I3,",","I3,").""/
     1"Take the starting point of your window accordingly!")
      GOTO 40

C->I'us dard as a dooornail, but he ressuurreecctteed me!

70    LSX = ISLSX
      LSY = ISLSY
      LX = ISLX
      LY = ISLY
      RETURN
      END
C
C
C     ************************
C     ** SUBROUTINE GRAB     **
C     ************************
C
C
      SUBROUTINE GRAB
C     ---------- ----

      COMMON LU,LQTX,ISC,JSC,LUBUS
      COMMON /INIT/ LX,LY,LSX,LSY,NAPX,NAPY,MAXLY
      DIMENSION INTO(2)

C->Reset NAPX & NAPY for new screen

      NAPX = 50
      NAPY = 75
      MAXLY = -1

C->Necessary array vars for quantex

      INTO(1) = 00442B
      INTO(2) = 07777B
      CALL EXEC(3,LUBUS+5100B)
      CALL EXEC(2,LQTX+2100B,INTO,-3)
      CALL EXEC(3,LUBUS+5100B)
      RETURN
      END

C     ****************************
C     ** SUBROUTINE  L O G I N   **
C     ****************************
C
      SUBROUTINE LOGIN
C     ---------- -----

C
```

```
C->This subroutine,'LOGIN', just prints a header and a closing
C  statement on logging off.
C
      COMMON LU
      COMMON /FLAG/IFLAG,IFLGR
      IF (IFLAG.EQ.-1) GOTO 30

C->Logging off

      WRITE (LU,2)
2     FORMAT(" IMAGE:  Logging off now . . . bye!"//)
      RETURN

C->Logging on

30    WRITE (LU,32)
32    FORMAT(//////" IMAGE:  A data acquisition and processing
program"/
     1" servicing the Quantex digital image memory in
communication "/
     2" with the Hewlett-Packard 1000 computer system."///)
      CALL EXEC(12,0,2,0,-1)  !  wait 1 sec, then continue
      IFLAG = 1
      IFLGR = 1
      RETURN
      END
C
C     ******************************
C     ** SUBROUTINE  A D R C V    **
C     ******************************
C
      SUBROUTINE ADRCV(IRW,ICLMN,NPL)
C     ---------- ----- --- ----- ---
C
C     Address Conversion takes a given row and column, and cal
C     calculates the Quantex memory address or pixelcount.
C     As output a array in nibble QUANTEX format is provided.
C
C     Remark: the Quantex memory has a 18 Bit address. Since w
C       are working on a 16 Bit integer base we prevent overfl
C       by dividing the row into blocks of 128 lines.
C      If the row number is )512 the program will print a erro
C      message and terminate the program!
C      Input  : IRW,ICLMN
C      Output : NPL(1-5)
C
      COMMON LU
      COMMON /FLAG/IFLAG,IFLGR
      DIMENSION NPL(5)
      IROW = IRW
      DO 10,I=1,4
      J = I-1
      IF (IROW.LE.128) I = 4
      IROW = IROW - 128
```

```
10    CONTINUE
      NPL(5) = J + 000140B
      IROW = IROW + 128
      IF (IROW.LE.128) GOTO 20
      WRITE (LU,12)
12    FORMAT("Row too big!!!")
      IFLAG = 0
      CALL LOGIN

C->Calculate the 16 Bit address and combine the 4 Bit data wit
C  4 Bit Quantex control data (2-6).

20    IF (IROW.EQ.0) IROW = 1
      IADR = ((IROW-1) * 512) + ICLMN
      ISHRG = IADR
      DO 30 I=1,4
      J = I + 1
      NPL(I) = IAND (ISHRG,017B)
      JJ = ISHFT(J,4)
      NPL(I) = IOR (NPL(I),JJ)
      ISHRG = IADR
      ISHRG = ISHFT (ISHRG,-4)
      IADR = ISHRG
30    CONTINUE
      RETURN
      END
C
C     *************************
C     ** SUBROUTINE COMBINE  **
C     *************************
C
C     combines 2 adjacent integers in a 16 bit word (2n-1
spaced)
C
C      Input  : IARRY containing 0 to 255 integers
C      Output : IARRY  with compressed  contents.
C
      SUBROUTINE COMB(IARRY)
C     ---------- ---- -----
      EMA IARRY
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION IARRY(256,256)
      DO 111 I=1,LY
      DO 111 J=1,LX
      J1 = J+1
111   IARRY(I,J) = IOR (ISHFT (IARRY(I,J),8) , IARRY(I,J1))
      RETURN
      END
C
C     **************************
C     ** SUBROUTINE SEPARATE  **
C     **************************
C
C     Separates the two compressed pixelintegers (16 bit)
```

```
C
C      Input  : IARRY containing a 2*8bit information in the
C                (2n-1) field location.
C      Output : IARRY containing 0 to 255 integers.
C
C
       SUBROUTINE SEPAR(IARRY)
C      ---------- ----- -----
       EMA IARRY
       COMMON /INIT/LX,LY,LSX,LSY
       DIMENSION IARRY(256,256)
       DO 111 I=1,LY
       DO 111 J=1,LX,2
       ISAVE = IARRY(I,J)
       J1 = J+1
       IARRY(I,J) = ISHFT (IARRY(I,J) , -8)
       IARRY(I,J1) = IAND (ISAVE,0377B)
111    CONTINUE
       RETURN
       END
C      ******************************
C      ** SUBROUTINE  F I L E R    **
C      ******************************
C
C      Description:
C      does all filehandling in a dialog mode. It keeps track o
C      opened files with FLAG and IFLGR, and allows only one op
C      file at a time.
C
C        A data compression is done to save memory(see COMB).
C      call proc. : CALL FILER(IRQST,IARRY)   &  COMMON's
C
       SUBROUTINE FILER(IRQST,IARRY)
C      ---------- ----- ----- -----
C
       EMA IARRY
       COMMON LU
       COMMON /INIT/LX,LY,LSX,LSY
       COMMON /FLAG/IFLAG,IFLGR
       COMMON /BUFR/JBUF(128)
       DIMENSION INBUF(64),IARRY(256,256),JTIME(15),LBUF(128)
       DIMENSION IHEAD(16),ITIME(5)
       DATA IHEAD/16*1H /
       CALL LGBUF(JBUF,128)

C->control to read or write sections

       IF (IRQST.EQ.1) GOTO 500

C->write section

       IF (IFLGR.GT.10) CLOSE
(88,IOSTAT=IERR,ERR=999,STATUS='KE')
```

```
      IF (IFLAG.GT.10) GOTO 100   ! file is already open,ready
be written
      IF (IFLAG.EQ.0) GOTO 200    ! file needs to be closed

C->dialog with loser

      IFLAG = IFLAG + 10
      WRITE (LU,2)
2     FORMAT(//////"IMAGE:  Program Filer"//)
      WRITE (LU,4)
4     FORMAT(/"Please input file namr:  _")
      READ (LU,6) (INBUF(I),I=1,64)
6     FORMAT(64A2)

C->open file

      OPEN(88,IOSTAT=IERR,ERR=999,FILE=INBUF,STATUS='UN')
      WRITE (LU,8)
8     FORMAT(/"IMAGE:  file opened successfully"/)

C->puts header on file

      WRITE (88,10,IOSTAT=IERR,ERR=999)
10    FORMAT(1X,10HIMAGE FILE)
      CALL FTIME(JTIME)
      WRITE (88,12,IOSTAT=IERR,ERR=999) (JTIME(I),I=1,15)
12    FORMAT(15A2)

C->get system time; store msecs with size of image

      CALL EXEC(11,ITIME)
100   ENCODE(32,102,IHEAD) ITIME(2),LX,LY,LSX,LSY
102   FORMAT(5I4)
      WRITE (88,104,IOSTAT=IERR,ERR=999) (IHEAD(I),I=1,16)
104   FORMAT(16A2)
      WRITE (LU,106)
106   FORMAT(/"IMAGE:  parameters written to file"/)

C->compress data; write to file one line at a time

      CALL COMB(IARRY)
      IFLAG = 11
      NEWLX = (LX + 1) / 2
      DO 110 I=1,LY
      DO 108 J=1,LX,2
108   LBUF((J + 1) / 2) = IARRY(I,J)
110   WRITE (88,112,IOSTAT=IERR,ERR=999 (LBUF(K),K=1,NEWLX)
112   FORMAT(128A2)
      WRITE (LU,114)
114   FORMAT(/"IMAGE:  data written to file  "/)

C->separate data

      CALL SEPAR(IARRY)
```

```
C->close file

200    CLOSE(88,IOSTAT=IERR,ERR=999,STATUS='KE')
       WRITE (LU,202)
202    FORMAT(/"IMAGE:  file closed successfully"/)
       IF (IFLAG.GT.10) IFLAG = IFLAG-10
       IF (IFLGR.GT.10) IFLGR = IFLGR-10
       RETURN

C->READ SECTION
C  ---- -------

500    IF (IFLAG.GT.10) CLOSE(88,IOSTAT=IERR,ERR=999,STATUS='KE
       IF (IFLGR.GT.10) GOTO 600 !   file is open already
       IF (IFLAG.EQ.0) GOTO 200  !   close up & get out

C->open file

       IFLGR = IFLGR+10
       WRITE (LU,2)
       WRITE (LU,4)
       READ (LU,6) (INBUF(I),I=1,64)
       OPEN (88,IOSTAT=IERR,ERR=999,FILE=INBUF,STATUS='OL')

C->read header

       WRITE (LU,8)
600    READ (88,602,IOSTAT=IERR,ERR=999) (IHEAD(I),I=1,16)
602    FORMAT(16A2)
       WRITE (LU,602) (IHEAD(I),I=1,16)
       READ (88,602) (IHEAD(I),I=1,16)
       WRITE (LU,602) (IHEAD(I),I=1,16)

C->assign file data to LX,LY,etc.

       READ (88,604,IOSTAT=IERR,ERR=999)(IHEAD(I),I=1,10)
604    FORMAT(10A2)
       DECODE (32,606,IHEAD) ITIME(2),LX,LY,LSX,LSY
606    FORMAT(5I4)

C->read file data

       NEWLX = (LX + 1) / 2
       DO 610 I=1,LY
       READ (88,112,IOSTAT=IERR,ERR=999) (LBUF(J),J=1,NEWLX)
       DO 608 J=1,LX,2
608    IARRY(I,J) = JBUF((J + 1) / 2)
610    CONTINUE

C->separate workspace

       CALL SEPAR(IARRY)
       WRITE (LU,612)
```

```
612   FORMAT(/"IMAGE:  file read successfully"/)
      GOTO 200

C->if error occurs, call FIERR routine

999   CALL FIERR(IERR)
      RETURN
      END
      SUBROUTINE FIERR(IERR)
C     ---------- ----- ----
      COMMON LU

      IF (IERR.EQ.462.OR.IERR.EQ.506) THEN
          WRITE (LU,10)
      ELSE IF (IERR.EQ.459.OR.IERR.EQ.508) THEN
          WRITE (LU,11)
      ELSE IF (IERR.EQ.502) THEN
          WRITE (LU,12)
      ELSE IF (IERR.EQ.507) THEN
          WRITE (LU,13)
      ELSE IF (IERR.EQ.514) THEN
          WRITE (LU,14)
      ELSE IF (IERR.EQ.515) THEN
          WRITE (LU,15)
      ELSE IF (IERR.EQ.532) THEN
          WRITE (LU,16)
      ELSE IF (IERR.EQ.533) THEN
          WRITE (LU,17)
      ELSE IF (IERR.EQ.546) THEN
          WRITE (LU,18)
      ELSE
          WRITE (LU,19) IERR
      ENDIF

10    FORMAT(/"IMAGE: File not found")
11    FORMAT(/"IMAGE: File already open")
12    FORMAT(/"IMAGE: Duplicate file name")
13    FORMAT(/"IMAGE: Wrong security code")
14    FORMAT(/"IMAGE: Directory full")
15    FORMAT(/"IMAGE: Illegal file name")
16    FORMAT(/"IMAGE: Cartridge not found - probably not
mounted")
17    FORMAT(/"IMAGE: No room on cartridge")
18    FORMAT(/"IMAGE: File has too many extents")
19    FORMAT(/"IMAGE: File handling error "I3," occured.")

      WRITE (LU,100)
100   FORMAT(/"Would you like to continue with the program,"/
     1"or stop here?    _")
102   READ (LU,104) IANS
104   FORMAT(A1)
      IF (IANS.EQ.1HC) RETURN
      IF (IANS.NE.1HS) THEN
          WRITE (LU,106)
```

```
106         FORMAT(/"Please answer with a C or S    _")
            GOTO 102
        ENDIF

        IFLAG = 0
        CALL LOGIN
        STOP 0005
        END

        SUBROUTINE PROC(IARRY,IRETR)
C       ---------- ---- ----- -----

        COMPLEX SPECT
        EMA IARRY,IPXL,SPECT
        COMMON LU
        COMMON /INIT/LX,LY
        DIMENSION
ITAG(20),IARRY(256,256),IPXL(256,256),SPECT(256,256)
        DIMENSION IOFF(36)
        IBELL = 3400B
        ITAG(4) = LX
        ITAG(5) = LY
        ITAG(10) = 0
        IF (LX.EQ.0.OR.LY.EQ.0) WRITE (LU,10)
10      FORMAT(//" Warning !!!! there is no workspace defined.")
20      WRITE (LU,22)
22      FORMAT(///" Here are the goodies for picture processing!
     1" The following routines work on your given workfield"/
     2" Note: Some of the routines will change the picture"/
     3"       information. If you want to keep your original"/
     4"       it is recommended to go back to menu and store"/
     5"       the workfield first!")
24      WRITE (LU,26)
26      FORMAT(" Choose one of the following: "/
     1"    1. Neighborhood Enhancement-Background spot
elimination. "/
     2"    2. Expand/Compress the graycolor range of the image.
     3"    3. Histogram equalization."/
     4"    4. Smoothing by average filtering."/
     5"    5. Enhancment for more edge contrast.  "/
     6"    6. Enhancing with laplacian."/
     7"    7. Kirsch Edge Detection Algorithm."/
     8"    8. Butterworth high-pass filter."/
     9"    9. Homomorphic filtering."/
CC   &"   10. Power Spectrum equalization."/
CC   1"   11. Weiner filtering."/
     2"   12. Signal Averaging."/
     3"   13. Subtraction of two windows."/
     4"   14. Threshold filtering."/
     5"   15. Display the histogram."/
     6"   16. Percentage of image in grayscale range."/
     7"   17. Pause."/
     8"   18  Smooth the noise."/
     9"   19. Count the number of leukocyte adhesion."/
```

```
     1"  20. Erosion."/
     2"  21. Dialation."/
     3"  22. Back to main menu.")

      WRITE (LU,28) IBELL      ! Ring bell
28    FORMAT(A1)
      READ (LU,*,ERR=24) ITAG(1)
      IF(ITAG(1).EQ.22) GOTO 999
      IF (ITAG(1).GT.20.OR.ITAG(1).LT.1) GOTO 20
      IF (IRETR.EQ.2.AND.ITAG(1).LT.14) GOTO 24
      IF(ITAG(1).GE.2) GOTO 40
30    WRITE (LU,32)
32    FORMAT(/"Please enter lower & upper threshold boundaries
_")
      READ (LU,*,ERR=30) ILTB,IUTB
      IF (ILTB.EQ.1000) GOTO 24
      IF (ILTB.LT.0.OR.IUTB.GT.255.OR.ILTB.GT.IUTB) GOTO 30
      ITAG(2) = ILTB
      ITAG(3) = IUTB
      CALL NGHBR(IARRY,IPXL,ILTB,IUTB)
      GOTO 24

40    IF(ITAG(1).NE.2) GOTO 50
C->Get old maximum value; store in ITAG(2)

      WRITE (LU,42)
42    FORMAT(/"Please enter the desired maximum graycolor  _")
      READ (LU,*,ERR=40) MAXGCL
      IF (MAXGCL.EQ.1000) GOTO 24
      IF (MAXGCL.LE.0.OR.MAXGCL.GT.255) GOTO 40
      ITAG(2) = MAXGCL
      CALL EXPND(IARRY,MAXGCL)
      GOTO 24

50    IF(ITAG(1).EQ.3) CALL HSTEQ(IARRY)
      IF(ITAG(1).EQ.4) CALL FILTR(IARRY,IPXL)
      IF(ITAG(1).EQ.5) CALL LAPL(IARRY,IPXL)
      IF(ITAG(1).EQ.6) CALL HOLPL(IARRY,IPXL)
      IF(ITAG(1).EQ.7) CALL KIRSH(IARRY,IPXL)
      IF(ITAG(1).GE.12) GOTO 70
      IF(ITAG(1).LE.7) GOTO 24
C->Here user decides which transform to use

60    WRITE (LU,62)
62    FORMAT(/"Which transform would you like to use:"//
     1"        1- Fourier Transform"/
     2"        2- Walsh Transform"/
     3"        3- I don't know what the fuck you're talking
about."//)
      READ (LU,*,ERR=60) ITAG(3)
      ITAG(2) = ITAG(1)   ! This lets SHELL know which routine
use.
      IF (ITAG(3).GE.1.AND.ITAG(3).LE.2) GOTO 68
      WRITE (LU,64)
```

```
64     FORMAT(/"Unfortunately, the filter you've chosen uses a
pro-"/
     1"cedure known as a Fast Fourier Transform.  This process
is"/
     2"wonderfully efficient when using an image whose size is
     3"a power of two (e.g., 64x64 or 128x128), but horrible
for"/
     4"other sizes.  If your image is not a power of two in
size,"/
     5"please don't try this filter.  This program wil die a
slow,"/
     6"painful death and your picture will be lost forever.")
       CALL EXEC (12,0,2,0,-5)      !  Give user a few seconds t
       GOTO 24                      !  digest the bad news
C->Store old values of LX and LY

68     LX1 = LX
       LY1 = LY
       IF(ITAG(1).GE.8.AND.ITAG(1).LE.11) CALL
SHELL(IARRY,SPECT,ITAG)
       GOTO 24

C->Here we take care of all the interactive routines

70     IF (ITAG(1).EQ.12) CALL SAVRG(IARRY)
       IF (ITAG(1).EQ.13) CALL SDIFF(IARRY)
       IF (ITAG(1).EQ.14) CALL THRH(IARRY)
       IF (ITAG(1).EQ.15) CALL HIST(IARRY)
       IF (ITAG(1).EQ.16) CALL PCT(IARRY)
       IF (ITAG(1).EQ.17) CALL EXEC(7)
       IF (ITAG(1).EQ.18) CALL SMOTH(IARRY)
       IF (ITAG(1).EQ.19) CALL COUNT(IARRY)
       IF (ITAG(1).EQ.20) CALL ERSON(IARRY,IPXL)
       IF (ITAG(1).EQ.21) CALL DATON(IARRY,IPXL)
       GOTO 24

C->Pause routine

80     PAUSE 1
       GOTO 24

999    RETURN
       END
       SUBROUTINE SAVRG(IARRY)
C      ---------- ----- -----

       EMA IARRY,IPXL
       COMMON LU
       COMMON /INIT/LX,LY,LSX,LSY
       COMMON /FLAG/ IFLAG
       DIMENSION IARRY(256,256),IPXL(256,256)
       IMAX = 0
       IMIN = 255
```

```
C->Feh!

10     WRITE (LU,12)
12     FORMAT(/"All windows must be of same size and saved in "
      1"data files for signal averaging - like to continue (Y/N
_")
       READ (LU,14) IANS
14     FORMAT(A1)
       IF (IANS.EQ.1HN) RETURN

C->Get count here

20     WRITE (LU,22)
22     FORMAT(/"How many windows will be averaged?  _")
       READ (LU,*,ERR=20) KOUNT
       IF (KOUNT.LT.2) GOTO 20

C->CALL THE PLUMBER,DEAR! (Seriously, call FILER to get LX & L

       CALL FILER(1,IARRY)

       DO 5 I = 1,LX
       DO 5 J = 1,LY
       IPXL(J,I) = IARRY(J,I)
5      CONTINUE
C
C NOW GET THE OTHER ARRAY
C
       DO 40 I = 2, KOUNT
       WRITE (LU,32) I
32     FORMAT (/"Please repeat for file # "I2)
       IFLAG = 1
       CALL FILER(1,IARRY)
       DO 25 J = 1 , LY
       DO 15 I2= 1 , LX
       IPXL(I2,J) = IPXL(I2,J) + IARRY(I2,J)
15     CONTINUE
25     CONTINUE
40     CONTINUE
C
C  NOW WE DIVIDE BY KOUNT
C
       DO 30 I=1,LX
       DO 30 J=1,LY
       IARRY(J,I) = IPXL(J,I) / KOUNT
       IF (IARRY(J,I).GT.IMAX) IMAX = IARRY(J,I)
       IF (IARRY(J,I).LT.IMIN) IMIN = IARRY(J,I)
30     CONTINUE
C->Wanna store this shit?

60     WRITE (LU,62)
62     FORMAT(/"Would you like to store this image in a file no
_")
       READ (LU,14) IANS
```

```
      IF (IANS.EQ.1HN) RETURN
      IFLAG = 1
      CALL FILER(0,IARRY)
      RETURN
      END
      SUBROUTINE SDIFF(IARRY)
C     ---------- ----- -----
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/LX,LY,LSX,LSY
      COMMON /FLAG/ IFLAG
      DIMENSION IARRY(256,256),IPXL(256,256)
      IMAX = 0
      IMIN = 255

C->Make sure loser has prepared to use this routine

10    WRITE (LU,12)
12    FORMAT(/"IMAGE:  This image sutraction routine requires
that"/
     1"both images involved must be the same size, and stored"
     2"in data files."//
     3"Is it ok to continue at this point?   _")
      READ (LU,14) IANS
14    FORMAT(A1)
      IF (IANS.EQ.1HN) RETURN

C->Here we get the first file

20    WRITE (LU,22)
22    FORMAT(/"This program will now ask you for the two
filenames - "/
     1"Please keep in mind that you may put either one in
first,"/
     2"since the program will take the absolute value of the"/
     3"difference."///)
      IFLAG = 1
      CALL FILER(1,IARRY)

C STORE THE FIRST ARRAY
      DO 8 I=1,LX
      DO 8 J=1,LY
      IPXL(J,I)=IARRY(J,I)
8     CONTINUE

C->Now we do the second file

      IFLAG = 1
      CALL FILER(1,IARRY)
50    WRITE (LU,52)
52    FORMAT(/"Crunch, crunch, crunch...")
C
      DO 30 I=1,LX
      DO 30 J=1,LY
```

```
      IARRY(J,I)=IABS(IARRY(J,I)-IPXL(J,I))
      IF (IARRY(J,I).GT.IMAX) IMAX = IARRY(J,I)
      IF (IARRY(J,I).LT.IMIN) IMIN = IARRY(J,I)
30    CONTINUE

C->Files?

70    WRITE (LU,72)
72    FORMAT(/"Would you like to store this image in a file no
_")
      READ (LU,14) IANS
      IF (IANS.EQ.1HN) RETURN
      IFLAG = 1
      CALL FILER(0,IARRY)
      RETURN
      END
      SUBROUTINE SAERR(IERR,ITAG)
C     ---------- ----- ---- ----

      LU = LOGLU(LU)
      IFUNC = ITAG(8)
      WRITE (LU,10) IERR,IFUNC
10    FORMAT(/"IMAGE:  Signal Averaging error "I6," occured."/
     1"The function was "I2," .  This can be deciphered by"/
     2"looking at the slave program"/
     3"Would you like to continue with the program, or stop"/
     4"here?  _")
11    READ (LU,12) IANS
12    FORMAT(A1)
      IF (IANS.EQ.1HC) RETURN
      IF (IANS.EQ.1HS) STOP 0007
      WRITE (LU,14)
14    FORMAT(/"Please answer the question with C or S    _")
      GOTO 11
      END
      SUBROUTINE THRH(IARRY)
C     ---------- ---- -----

      EMA IARRY
      COMMON LU
      COMMON /INIT/LX,LY
      DIMENSION
IARRY(256,256),ISTGC(10),ISUTL(10),ISLTL(10),ISCNT(10)
      DATA IQM,IEM/1H?,1H!/
      DO 111,LN=1,10
10    WRITE (LU,12)
12    FORMAT(/" *** Program THRESHOLD *** "//
     1" ? : prints an explanation of the thresholding
procedure;"/
     2" ! : will display your executed operations;"/
     3" G : will go back to the signal processing menu;"/
     4" <return> continues the program.")
      WRITE (LU,14)
14    FORMAT("*_")
```

```
      READ (LU,201) ISERV
      IF (ISERV.EQ.IQM) CALL EXPL(LU)
      IF (ISERV.EQ.IEM) THEN
          CALL DISPL(LN,ISTGC,ISUTL,ISLTL,ISCNT,LU)
          GOTO 10
      ENDIF
      IF (ISERV.EQ.1HG) RETURN

C->Initialization

      ICNT = 0
      ILTL = 0
      IUTL = 255

C->Loser input

20    WRITE (LU,22)
22    FORMAT(/" Type your Upper Threshold Limit (UTL):  _"/)
      READ (LU,*,ERR=20) IUTL
24    WRITE (LU,26)
26    FORMAT(/" Type your Lower Threshold Limit (LTL):  _"/)
      READ (LU,*,ERR=24) ILTL
28    WRITE (LU,30)
30    FORMAT(/" To which graycolour value should your given"/
     1" range be assigned?    _"/)
      READ (LU,*,ERR=28) ITGCV

C->LOSER INPUT CHECK

      FLAG = 0
      IF (IUTL.LT.0.OR.IUTL.GT.255) FLAG = 1
      IF (ILTL.LT.0.OR.ILTL.GT.255) FLAG = 1
      IF (ITGCV.LT.0.OR.ITGCV.GT.255) FLAG = 1
      IF (FLAG.NE.1) GOTO 333
      WRITE (LU,106)
106   FORMAT(//" Input out of range!! "//)
      LN = LN-1
      GOTO 10
333   IF (IUTL.EQ.0) IUTL = 255
      ISTGC(LN) = ITGCV
      ISUTL(LN) = IUTL
      ISLTL(LN) = ILTL

C->Thresholding

      DO 222 LM=1,LY
      DO 222 N1=1,LX
      IF (IARRY(N1,LM).LT.ILTL.OR.IARRY(N1,LM).GT.IUTL) GOTO 2
      IARRY(N1,LM) = ITGCV
      ICNT = ICNT+1
222   CONTINUE
      ISCNT(LN) = ICNT
111   CONTINUE
201   FORMAT(A1)
```

```
      RETURN
      END

      SUBROUTINE EXPL(LU)
C     ---------- ---- --
      WRITE (LU,101)
101   FORMAT(" THRH EXPLANATION !"/
     1" Program THRH works with the following algorithm "/
     2"          fz(x,y)= / 1 if f(x,y) is ELEMENT of z"/
     3"                     0 otherwise"/
     4" This formula provides 3 different ways of operation:"/
     5"      1. If a upperthreshold limit is set "/
     6"         and the lower thrh. limit is default "/
     7"         then all greycolour values between 0"/
     8"         and utl. are changed to your given"/
     9"         greycolour value."/
     &"      2. If the ltl is set and default on the"/
     1"         utl.; greycolour values between ltl."/
     2"         and 255 are changed."/
     3"      3. If ltl. and utl. are set all values"/
     4"         in between are changed."/
     5"  combination of 1.,2. and 3. is called semi-"/
     6"  thresholding. 1. is used to extract objects"/
     7"  from background or noise. 2. removes sharp"/
     8"  contrasts. 3. enhances greycolour ranges(if"/
     9"  known exactly), which can be used for edge"/
     &"  detection."//)
      RETURN
      END

      SUBROUTINE DISPL(L,ISTGC,ISULT,ISLTL,ISCNT,LU)
C     ---------- ----- - ----- ----- ----- ----- --
C   ...displays the range and assigned graycolour value
C   of the THRH process including the number of changed
C   pixels.
      DIMENSION ISLTL(10),ISULT(10),ISTGC(10),ISCNT(10)

      DO 111,I=1,(L-1)
      WRITE (LU,101) I,ISLTL(I),ISULT(I),ISTGC(I),ISCNT(I)
101   FORMAT(I2". RANGE:"I3,"-"I3," CHANGED TO:"I3," # OF
CP:"I8)
111   CONTINUE
      WRITE (LU,102)
102   FORMAT(//)
      RETURN
      END

      SUBROUTINE HIST(IARRY)
C     ---------- ---- -----

C->Initialization

      EMA IARRY
      COMMON LU
```

```
      COMMON /INIT/LX,LY
      COMMON /HISTO/ IHIST(0:255)
      DIMENSION IARRY(256,256),IFT(130),ISAVE(17)
      DATA ICHAR/1H+/

C->Reset the IHIST array

      DO 555,I = 0,255
555   IHIST(I) = 0
      MAX = 0
      IOFFS = 0

C->Default group for histogram display.

      LM = 15
      SUM = 0
C->Sort greyc. values
1     DO 111,LN=1,LY
      DO 111,L=1,LX
      INDX = IARRY(LN,L)
      SUM = SUM + IARRY(LN,L)
111   IHIST(INDX) = IHIST(INDX)+1

C->Reset the first 17 ISAVE vars

      DO 666,I=1,17
666   ISAVE(I) = 0

C->Print header

2     WRITE (LU,101)
101   FORMAT(//"   #   N     I            frequency"/
     1"-- 0 --------I---------------------",
     2"--------------------------------------")

C->Grouping and scaling

      DO 222,J=1,17
      DO 333,I=1,LM
      JJ = (IOFFS+((J-1)*LM)+I)
      ISAVE(J) = ISAVE(J)+IHIST(JJ)
333   CONTINUE
222   IF (ISAVE(J).GT.MAX) MAX = ISAVE(J)

C->Normalize the histogram frequency

      DIV = 50./FLOAT(MAX)

C->Output

      DO 444,I=1,17
      II = IOFFS+(LM*I)
      LN = INT(DIV*ISAVE(I))
```

```
C->No 0A1 format possible -) LN must be >0

      IF (LN.LT.1) LN = 1
      ENCODE (130,102,IFT) LN
      WRITE (LU,IFT) II,ISAVE(I),(ICHAR,ICONT=1,LN)
102   FORMAT('(I4,I8," I",'I3,'A1)')
444   CONTINUE

C->The option (zooooom)
      WRITE(LU,1007) SUM
1007  FORMAT(/"  IOD for the selected window   ",I12)
      WRITE (LU,105)
105   FORMAT(/" Would you like to see a more detailed histogra
_")
      READ (LU,201) IANS
201   FORMAT(A1)
      IF (IANS.EQ.1HN) RETURN
      WRITE (LU,107)
107   FORMAT(/" Type your new range (low,high): _")
      READ (LU,*) NR1,NR2

C->Calculate (and correct) the new group size

      LM = INT (IABS ( (NR2 -NR1) / 17) + 0.5)
      IF ((17 * LM).LT.(MAX0 (NR1 , NR2))) LM = LM + 1

C->Reset the old ISAVE array

      DO 777,I=1,17
777   ISAVE(I) = 0
      IOFFS = NR1
      IF (NR2.LT.NR1) IOFFS = NR2
      GOTO 2
      END
      SUBROUTINE PCT(IARRY)
C     ---------- --- -----
      EMA IARRY
      COMMON LU
      COMMON /INIT/ LX,LY
      COMMON /HISTO/ IHIST(0:255)
      DIMENSION IARRY(256,256)

C-> Set IHIST array to zero

      DO 2 I=0,255
2     IHIST(I) = 0

C-> Sort graycolors (perform histogram operation)

10    DO 20 I=1,LY
      DO 20 J=1,LX
      IDUM = IARRY(J,I)
20    IHIST(IDUM) = IHIST(IDUM) + 1
```

```
C-> Loser input

30     WRITE (LU,32)
32     FORMAT(/" Please input graycolor range, low to high  _")
       READ (LU,*,ERR=30) ILOW,IHIGH
       IF (ILOW.EQ.1000) RETURN
       IF (ILOW.LT.0.OR.IHIGH.GT.255.OR.ILOW.GT.IHIGH) GOTO 30

C-> Compute size, sum pixels in range, compute percentage

       ISIZE = LX * LY
       ISUM = 0
       DO 40 I=ILOW,IHIGH
40     ISUM = ISUM + IHIST(I)

       PERCT = ( FLOAT (ISUM) / FLOAT (ISIZE) ) * 100.0

C-> Give user result

       WRITE (LU,50) PERCT
50     FORMAT(/" This range of graycolors makes up "F5.2,"
percent"/
      1" of the image"/)
       RETURN
       END
C
       SUBROUTINE EXPND(IARRY)    !  EXPAND RANGE ROUTINE FOR
SLAVE
C      ---------- ------ -----    !  8/10/84  AJS
       EMA IARRY
       COMMON LX,LY,MAX
       DIMENSION IARRY(256,256)
       IOLD = -1

C->Search for old maximum

       DO 10 I=1,LY
       DO 10 J=1,LX
       IF (IARRY(J,I).GT.IOLD) IOLD = IARRY(J,I)
10     CONTINUE

C->Now we have old maximum and desired new maximum,
C  so we can compute a conversion factor.

       RMULT = FLOAT (MAX) / FLOAT (IOLD)

C->Do it!

       DO 20 I=1,LY
       DO 20 J=1,LX
       IARRY(J,I) = IARRY(J,I) * RMULT
20     CONTINUE

C->Done!
```

```
      RETURN
      END
      SUBROUTINE HSTEQ(IARRY)
C     ---------- ----- -----
      EMA IARRY
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256),IR(256),S(256),IG(256)
      INTEGER K,M
      REAL XS,YS
C->Set IR and S to zero, get total number of points for divisi
5     WRITE(LU,15)
15    FORMAT(//'Please input the size of picture'/
     1'How many columns and rows?_')
      READ (LU,*,ERR=5) XS,YS
      IF (XS.GT.256.0.OR.YS.GT.256.0)  GOTO 5

      DO  10 K=0,255
      IR(K) = 0.0
      S(K) = 0.0
10    CONTINUE
      A=DBLE(XS*YS)

C->Get histogram (Note K+1 because R(1) <-> gray level 0)

      DO 20 I=1,LY
      DO 20 J=1,LX
      K = IARRY(J,I)
      IR(K) = IR(K) + 1.0
20    CONTINUE
      DO 70 K=0 ,255
      PRINT *,'NUM',IR(K),A
70    CONTINUE

C->Get S's (just a summation, or density function)
      S(0) = DBLE(IR(0) /A)
      DO 30 K=1,255
      S(K)=DBLE(IR(K)/A)+DBLE(S(K-1))
30    CONTINUE
      DO 1 K=0,255
      A=DBLE(XS*YS)
      PRINT*,'S(',K,')=',S(K),'IR(',K,')=',IR(K),A
1     CONTINUE
C->Now multiply by 256 & truncate to get 256 distinct levels

      DO 40 M=0,255
      IG(M)=INT (S(M)*256.0)-1
40    CONTINUE
      DO 60 M=0 ,255
      A=DBLE(XS*YS)
      PRINT *,'S(',M,')=',S(M),'IG(',M,')=',IG(M),A
60    CONTINUE
```

```
C->Map new values into IARRY

      DO 50 I=1,LY
      DO 50 J=1,LX
      M=IARRY(J,I)
      IF(IARRY(J,I).EQ.M) IARRY(J,I) =INT (IG(M))
50    CONTINUE
      RETURN
      END
C     ****************************
C     ** SUBROUTINE  F I L T R  **
C     ****************************
C
C-----------------------------------------------------------------
---
C  ...applies a digital filter (F) to a time domain array.
C    (smoothing by averaging)
C     method: takes the average of the 8 surrounding (adjacent
C             pixels and assigns it to the center.
C-----------------------------------------------------------------
---
C     Ext.: none
C     call: CALL FILTR(IARRY,IPXL)   &   COMMON's
C-----------------------------------------------------------------
---
C     Inp. to outp chngs: IARRY
C
      SUBROUTINE FILTR(IARRY,IPXL)
C     ---------- ----- ----- ----
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION F(3,3) , IARRY(256,256) , IPXL(256,256)
      DATA F/.125,.125,.125,.125,0.,.125,.125,.125,.125/
      LYS = LY - 1
      LXS = LX - 1
      DO 111 I=2,LYS
      DO 111 J=2,LXS
      P=0.
      DO 222 K=1,3
      DO 222 L=1,3
      P = P + F(K,L) * IARRY(J + K - 2 , I + L - 2)
222   CONTINUE
      NP = INT (P + .5)
      IF (NP.LT.0) NP = 0
      IF (NP.GT.255) NP = 255
      IPXL(J,I) = NP
111   CONTINUE
      DO 333 I=2,LYS
      DO 333 J=2,LXS
      IARRY(J,I) = IPXL(J,I)
333   CONTINUE
```

```
      RETURN
      END
C     ********************************
C     ** SUBROUTINE  L A P L       **
C     ********************************
C
C-------------------------------------------------------------
---
C  ...applies the LAPLACIAN method to enhance the picture.
C      (2nd. order gradient)
C   I am using a laplacian divider of (1/5) to get a
C   continuously weighted result rather than a black/
C   white contrast.
C     method:  0  1  0
C              1 -4  1
C              0  1  0
C the result of the multiplication matrix is divided by 5.
C-------------------------------------------------------------
---
C     ext. subs: none
C     call proc: CALL LAPL(IARRY,IPXL)   &   COMMON's
C-------------------------------------------------------------
---
C     Inp. to outp chngs: IARRY
C
      SUBROUTINE LAPL(IARRY,IPXL)
C     ---------- ---- ----- ----
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION F(3,3) , IARRY(256,256) , IPXL(256,256)
      DATA F/0.,1.,0.,1.,-4.,1.,0.,1.,0./
      LYS = LY - 1
      LXS = LX - 1
      DO 111 I=2,LYS
      DO 111 J=2,LXS
      P = 0.
      DO 222 K=1,3
      DO 222 L=1,3
      P = P + F(K,L) * IARRY(I + K - 2 ,J + L - 2)
222   CONTINUE

C   Use divider!

      NP = INT (.5 + (P / 5.))
      IPXL(J,I) = NP
111   CONTINUE
      DO 333 I=2,LYS
      DO 333 J=2,LXS
      IARRY(J,I) = IARRY(J,I) - IPXL(J,I)
      IF (IARRY(J,I).LT.0) IARRY(J,I) = 0
      IF (IARRY(I,J).GT.255) IARRY(I,J) = 255
333   CONTINUE
      RETURN
```

```
      END
C
C     ********************************
C     ** SUBROUTINE  H O L P L     **
C     ********************************
C
C-------------------------------------------------------------
---
C  ...applies the LAPLACIAN method to enhance the picture.
C       (N-th. order gradient)
C  k1=1st neighbour field
C  k2=2nd neighbour field
C   method:
C     *******-K2
C     * ,K1 *
C     * *** *
C     * *X* *
C     * *** *
C     *     *
C     *******
C-------------------------------------------------------------
-----
C     ext. subs.: none
C     call proc.: CALL HOLPL(IARRY,IPXL)  & COMMON's
C-------------------------------------------------------------
---
C     Inp. to outp. chngs: IARRY
C
      SUBROUTINE HOLPL(IARRY,IPXL)
C     ---------- ----- ----- ----
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/  LX,LY
      DIMENSION IARRY(256,256) , IPXL(256,256)
C initialisation
      K1 = 3
      K2 = 7
C calculation of the laplacian
C inner boundary
      DO 111 K = 4 , LY - 3
      DO 111 L = 4 , LY - 3
      P=0.
      DO 222 I = 1 , K1
      DO 222 J = 1 , K1
      IF (J.EQ.1.OR.J.EQ.K1) GOTO 10
      IF (I.EQ.1.OR.I.EQ.K1) GOTO 10
      GOTO 222
10    P = P + IARRY (I + K - 2 , J + L - 2)
222   CONTINUE
      SK1 = P
C  outer boundary
      P=0.
      DO 333 I=1,K2
      DO 333 J=1,K2
```

```
      IF (J.EQ.1.OR.J.EQ.K2) GOTO 20
      IF (I.EQ.1.OR.I.EQ.K2) GOTO 20
      GOTO 333
20    P = P + IARRY(I + K - 4 , J + L - 4)
333   CONTINUE
      SK2 = P
      IPXL(K,L) =INT ((SK1/(K1*K1)) - ((SK2-SK1) / ((K2*K2) -
(K1*K1))))
111   CONTINUE
C  normalisation to 0-255
      DO 444 I=1,LY
      DO 444 J=1,LX
      IARRY(J,I) = IARRY(J,I) - IPXL(J,I)
      IF (IARRY(J,I).LT.0) IARRY(J,I) = 0
      IF (IARRY(J,I).GT.255) IARRY(J,I) = 255
444   CONTINUE
      RETURN
      END
C     *****************************
C     **  SUBROUTINE  K I R S H  **
C     *****************************
C
C---------------------------------------------------------------
---
C  ...applies the KIRSCH operator method for edge detection.
C  (the K-op. method is a 1st order x-y difference equation)
C     method: subtracts the sum of the left 3 pixels
C        from the right 3 pixels,then subtrcts the sum
C        from the upper 3 pxls from the lower 3 pxls.
C       finally it takes the maximum of this two subtractions.
C---------------------------------------------------------------
---
C     ext.sub's: none
C     call proc: CALL KIRSH(IARRY,IPXL)    &  COMMON's
C---------------------------------------------------------------
---
C     Inp. to outp. chngs: IARRY
C
      SUBROUTINE KIRSH(IARRY,IPXL)
C     ---------- ----- ----- ----
C initialisation
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256) , IPXL(256,256)
      LYS = LY - 1
      LXS = LX - 1
C calculation of the k-op.
      DO 111 I = 2 , LYS
      DO 111 J = 2 , LXS
      IPXL(J,I) = 0
      ILFT = IARRY (J-1,I-1) + IARRY(J-1,I) + IARRY(J-1,I+1)
      IUP = IARRY(J-1,I-1) + IARRY(J,I-1) + IARRY(J+1,I-1)
      IDWN = IARRY(J-1,I+1) + IARRY(J,I+1) + IARRY(J+1,I+1)
```

```
      IRGT = IARRY(J+1,I-1) + IARRY(J+1,I) + IARRY(J+1,I+1)
      IPXL(J,I) = MAX0 (IABS (IRGT - ILFT) , IABS (IUP - IDWN)
/ 3
111   CONTINUE
      DO 333 I = 2 , LYS
      DO 333 J = 2 , LXS
      IARRY(J,I) = IPXL(J,I)
      IF (IARRY(J,I).LT.0) IARRY(J,I) = 0
      IF (IARRY(J,I).GT.255) IARRY(J,I) = 255
333   CONTINUE
      RETURN
      END
      SUBROUTINE NGHBR(IARRY,IPXL)
C     ---------- ----- ----- ----
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256) , IPXL(256,256)
C
C->TILT!
C
      DO 20 I=1,LX
      DO 20 J=1,LY
      IPXL(J,I) = IARRY(J,I)
20    CONTINUE
C
C->MAY THE FORCE BE WITH YOU!
C
      DO 111 I = 3 ,LY-2 , 2
      DO 111 J = 3 ,LX-2 , 2
      IF (IARRY(J,I).GT.IUTB.OR.IARRY(J,I).LT.LTB) GOTO 111
C
      DO 222 I1 = I-2 , I+2
      DO 222 J1 = J-2 , J+2
      I2 = IABS (I1-I)
      J2 = IABS (J1-J)
      IF (I2.LT.2.AND.J2.LT.2) GOTO 222
      IF (IABS (IARRY(J1,I1) - IARRY(J,I)).GT.3) GOTO 222
C
      I3 = INT (.5 * (I1 + I))
      J3 = INT (.5 * (J1 + J))
      IPXL(J3,I3) = INT (.5 * (IARRY(J,I) + IARRY(J1,I1)))
      IF ((I2+J2).NE.3) GOTO 222
      I3 = I3 + 1
      J3 = J3 + 1
      IPXL(J3,I3) = INT (.5 * (IARRY(J,I) + IARRY(J1,I1)))
222   CONTINUE
111   CONTINUE
C
C->SILLY RABBIT, TRIX ARE FOR KIDS!
C
      DO 30 I=1,LX
      DO 30 J=1,LY
      IARRY(J,I)=IPXL(J,I)
```

```
30     CONTINUE
       RETURN
       END
C      SUBROUTINE SVGCR(IARRY,IPXL,ITAG)
C      ---------- ----- ----- ----
C      EMA IARRY,IPXL
C      COMMON LX,LY,IMAX,IMIN
C      DIMENSION IARRY(256,256),IPXL(256,256),ITAG(20)


C      SUBROUTINE SDFCR(IARRY,IPXL,ITAG)
C      ---------- ----- ----- ----
C      EMA IARRY,IPXL
C      COMMON LX,LY,IMAX,IMIN
C      DIMENSION IARRY(256,256) ,IPXL(256,256),ITAG(20)
C->The first thing we have to do is store the first array

       SUBROUTINE SHELL (IARRY,SPECT,ITAG)
C      ---------- -----  ----- ----- ----
       COMPLEX SPECT
       EMA IARRY,SPECT
       COMMON /INIT/ LX,LY
       DIMENSION IARRY(256,256) , SPECT(256,256) , ITAG(20)

C->Transform to frequency domain
       CALL FWD2D (IARRY,SPECT,ITAG)

C->Choose filter

       IF (ITAG(1).EQ.8) CALL BHPF(SPECT,ITAG)
       IF (ITAG(1).EQ.9) CALL HMPHC (SPECT)
CC     IF (ITAG(1).EQ.10) CALL POWER (SPECT)
CC     IF (ITAG(1).EQ.11) CALL BLIND (SPECT)

C->Now transform back to time domain

       CALL INV2D (IARRY,SPECT,ITAG)
C->Go back to image processing menu

       RETURN
       END

       SUBROUTINE FWD2D(IARRY,SPECT,ITAG)
C      ---------- ----- ----- -----
       EMA IARRY,SPECT
       COMPLEX SPECT,TEMP
       COMMON/INIT/ LX,LY
       COMMON /BUFRS/ TEMP(256)
       DIMENSION IARRY(256,256) , SPECT(256,256),ITAG(20)

C->Store one row at a time into buffers TEMPA and TEMPB, do on
C  dimensional transform, store in temporary arrays

       DO 6 I=1,LY
```

```
      DO 2 J=1,LX
      DMY = FLOAT (IARRY(J,I)) + 0.01  ! The .01 is so log (0)
doesn't happen
      IF(ITAG(1).EQ.9) DMY = LOG (DMY)  ! Homomorphic needs lo
first !
2     TEMP(J) = CMPLX (DMY,0.0)
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LX)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LX)
      DO 4 J=1,LX
4     SPECT(J,I) = TEMP(J) * FLOAT(LX)
6     CONTINUE

C->Do transform on each column of transformed data

      DO 12 J=1,LX
      DO 8 I=1,LY
8     TEMP(I) = SPECT(J,I)
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LY)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LY)
      DO 10 I=1,LY
10    SPECT(J,I) = TEMP(I)
12    CONTINUE
      RETURN
      END
      SUBROUTINE INV2D (IARRY,SPECT,ITAG)
C     ---------- -----  ----- ----- -----
      EMA IARRY,SPECT
      COMPLEX SPECT,TEMP
      COMMON/INIT/ LX,LY
      COMMON /BUFRS/ TEMP(256)
      DIMENSION IARRY(256,256) , SPECT(256,256),ITAG(20)

C->Have to put each column into temporary buffers, take comple
C  conjugate of data to make forward FFT into inverse

      DO 6 J=1,LX
      DO 2 I=1,LY
2     TEMP(I) = CONJG (SPECT(J,I))
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LY)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LY)
      DO 4 I=1,LY
4     SPECT(J,I) = TEMP(I)
6     CONTINUE

C->Now do inverse transform on each row; Since we only had a
real
C  function to start with, take the real part and mult. by LX.

      DO 12 I=1,LY
      DO 8 J=1,LX
8     TEMP(J) = SPECT(J,I)
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LX)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LX)
      DO 10 J=1,LX
```

```
      IARRY(J,I) = LX * REAL ((TEMP(J)))
      IF (ITAG(1).EQ.9) IARRY(J,I) = IFIX (EXP (FLOAT
(IARRY(J,I))))
10    CONTINUE
12    CONTINUE
      RETURN
      END
      SUBROUTINE BHPF(SPECT,ITAG)          ! Butterworth high-
pass filter
C     ---------- ---- ----- ----           ! with high-frequenc
emphasis
      EMA SPECT
      COMPLEX SPECT,TEMP
      COMMON LU
      COMMON/INIT/ LX,LY
      COMMON /BUFRS/ TEMP(256)
      DIMENSION SPECT(256,256) , ITAG(20)
      REAL * 8  C

C-> Set Do to 1/8 of distance
5     WRITE (LU,12)
12    FORMAT('Please input the length of x size:_')
      READ (LU,*,ERR=5) XS
      IF (XS.GT.256) GOTO 5
      DZERO = DBLE (XS) * SQRT (2.0) / 8.0

C-> Set n to 3

      N=3

C-> Compute D(u,v), then H

      DO 10 I=1,LX
      DO 10 J=1,LY
          C = DBLE (REAL (I ** 2)) + DBLE (REAL (J ** 2))
          D = DBLE (DSQRT (C))
          BLOB = (( (DZERO/D) ** (2*N)) * 0.414)
          H = ( (2+BLOB) / (1+BLOB) )
10        SPECT(J,I) = SPECT(J,I) * H
      RETURN
      END
      SUBROUTINE HMPHC(SPECT)
C     ---------- ----- -----
      EMA SPECT
      COMPLEX SPECT,TEMP
      COMMON /INIT/ LX,LY
      COMMON /BUFRS/TEMP(256)
      DIMENSION SPECT(256,256)
      REAL * 8  C
C
      DO 10 I=1,LX
      DO 10 J=1,LY
          C = DBLE (FLOAT (I ** 2)) + DBLE (FLOAT (J ** 2))
          D = SNGL (DSQRT (C))
```

```
            H = (2.0 * EXP (-.1 * FLOAT(LX) / D))      ! This set
upper to 2
10          SPECT(J,I) = SPECT(J,I) * H
      RETURN
      END
      SUBROUTINE FFT(F,N)
C     ---------- --- - -
      COMPLEX F(256),U,W,T,CMPLX
      PI=3.141593
      DO 1 LN=1,9                           !  512 Largest image  !
      IDUM=2**LN
      IF (IDUM.EQ.N) GOTO 2
1     CONTINUE
      STOP 0007
2     NV2=N/2
      NM1=N-1
      J=1
      DO 5 I=1,NM1
          IF (I.GE.J) GOTO 3
          T=F(J)
          F(J)=F(I)
          F(I)=T
3         K=NV2
4         IF (K.GE.J) GOTO 5
          J=J-K
          K=K/2
          GOTO 4
5         J=J+K
      DO 7 L=1,LN
          LE=2**L
          LE1=LE/2
          U=(1.0,0.0)
          W=CMPLX(COS(PI/LE1),-SIN(PI/LE1))
          DO 7 J=1,LE1
              DO 6 I=J,N,LE
              IP=I+LE1
              T=F(IP)*U
              F(IP)=F(I)-T
6             F(I)=F(I)+T
7         U=U*W
      DO 8 I=1,N
8         F(I)=F(I)/FLOAT(N)
      RETURN
      END

      SUBROUTINE FWT(CF,N)
C     ---------- --- -- -
      COMPLEX CF(256)
      DIMENSION F(256)
      DO 10 LN=1,9
      IDUM=2**LN
      IF (IDUM.EQ.N) GOTO 20
10    CONTINUE
      STOP 0010
```

```
20     DO 30 I=1,128
30     F(I)=REAL(CF(I))
       NV2=N/2
       NM1=N-1
       J=1
       DO 3 I=1,NM1
           IF (I.GE.J) GOTO 1
           T=F(J)
           F(J)=F(I)
           F(I)=T
1          K=NV2
2          IF (K.GE.J) GOTO 3
           J=J-K
           K=K/2
           GOTO 2
3          J=J+K
       DO 5 L=1,LN
           LE=2**L
           LE1=LE/2
           DO 5 J=1,LE1
               DO 4 I=J,N,LE
                   IP=I+LE1
                   T=F(IP)
                   F(IP)=F(I)-T
4                  F(I)=F(I)+T
5              CONTINUE
       DO 6 I=1,N
6          CF(I)=CMPLX((F(I)/FLOAT(N)),0.0)
       RETURN
       END


       SUBROUTINE SMOTH(IARRY,IPXL)
C*****************************************************
C This subprogram is to define the size of leukocyte
C It is the powerful tool to eliminite noise which
C small than the defined size
C******************************************************
       EMA IARRY
       COMMON LU
       COMMON /INIT/ LX,LY
       DIMENSION IARRY(256,256)
       INTEGER COUNT,OUTGREY,NEB
       OUTGREY=255
       NEB=0
C      This part is to make bigrey level
21     WRITE (LU, 22)
22     FORMAT(//'Please input the grey level you want:_')
       READ (LU,*,ERR=21) OUTGREY
C      To define the size of noise
30     WRITE(LU,32)
32     FORMAT(//'Please input the neberhor of pls:_')
       READ (LU,*,ERR=30) NEB
       IF (OUTGREY .GT. 255 .OR. OUTGREY .LT.0) GOTO 21
```

```
      IF (NEB .GT. 8 .OR. NEB .LT.0) GOTO 30
C     This portion can cancel the spot which smaller than some
C     certain vaules
      DO 10 J=1,LX
      DO 10 I=1,LY
      IF (IARRY(J,I).NE.0)THEN
           COUNT=0
           IF (IARRY(J-1,I).NE.0) COUNT=COUNT+1
           IF (IARRY(J,I-1).NE.0) COUNT=COUNT+1
           IF (IARRY(J+1,I-1).NE.0) COUNT=COUNT+1
           IF (IARRY(J+1,I).NE.0) COUNT=COUNT+1
           IF (IARRY(J-1,I-1).NE.0) COUNT=COUNT+1
           IF (IARRY(J+1,I+1).NE.0) COUNT=COUNT+1
           IF (IARRY(J-1,I+1).NE.0) COUNT=COUNT+1
           IF (IARRY(J,I+1).NE.0) COUNT=COUNT+1
      IF (COUNT .LT. NEB) THEN
           IARRY(J,I)=0
      ELSE
C     Give spot a certain grey level vaule
           IARRY(J,I)=OUTGREY
          IF (IARRY(J-1,I).NE.0) IARRY(J-1,I)=OUTGREY
          IF (IARRY(J,I-1).NE.0) IARRY(J,I-1)=OUTGREY
          IF (IARRY(J+1,I-1).NE.0) IARRY(J+1,I-1)=OUTGREY
          IF (IARRY(J-1,I-1).NE.0) IARRY(J-1,I-1)=OUTGREY
          IF (IARRY(J,I+1).NE.0)  IARRY(J,I+1)=OUTGREY
          IF (IARRY(J+1,I+1).NE.0) IARRY(J+1,I+1)=OUTGREY
          IF(IARRY(J-1,I+1).NE.0) IARRY(J-1,I+1)=OUTGREY
          IF(IARRY(J+1,I).NE.0)  IARRY(J+1,I)=OUTGREY
      END IF
      END IF
10    CONTINUE
      RETURN
      END

      SUBROUTINE COUNT(IARRY)
C************************************************************
C The subroutine is to use the properity of connectivity
C to define an indivadual spot. Within the program existing
C a TRACK subprogram to caculate and search the connective
C pixel with the same grey level. After searching, the TRACK
C will erase the intact spot , and go back to COUNT to tell
C that it has already find one spot and earse it,then
C COUNT will add the number of spot
C************************************************************
      EMA IARRY
      COMMON/INIT/ LX,LY
      DIMENSION IARRY(256,256)
      INTEGER ICOUNT
      ICOUNT=0
      DO 10 I=1,LY
      DO 10 J=1,LX
      IF (IARRY(J,I) .NE.0) THEN
C     Now the route can trace the connective pixel to define
C     a complete spot
```

```
         CALL TRACK(IARRY,J,I)
         ICOUNT=ICOUNT+1
      END IF
10    CONTINUE
      PRINT *,'THE NUMBER OF COUNTER: ',ICOUNT
      RETURN
      END


      SUBROUTINE TRACK(IARRY,J,I)
C*************************************************************
C The purpose of the subprogram is to find the adjectant pixel
C which exist a certain number of grey level,and determine the
C relation of connectivity to define an intact leukocyte
C*************************************************************
      EMA IARRY
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256)
      INTEGER PTR,STACK(10000),ADDR
C     Using a simulating method to do the recursive program
      PTR=1
10    IARRY(J,I)=0
      IF (IARRY(J-1,I).NE.0) THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=1
      PTR=PTR+3
      J=J-1
      GOTO 10
      END IF
1     IF(IARRY(J-1,I+1).NE.0) THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=2
      PTR=PTR+3
      J=J-1
      I=I+1
      GOTO 10
      END IF
2     IF (IARRY(J,I+1).NE.0) THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=3
      PTR=PTR+3
      I=I+1
      GOTO 10
      END IF
3     IF( IARRY(J+1,I+1).NE.0) THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=4
      PTR=PTR+3
      J=J+1
```

```
      I=I+1
      GOTO 10
      END IF
4     IF( IARRY(J+1,I).NE.0)  THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=5
      PTR=PTR+3
      J=J+1
      GOTO 10
      END IF
5     IF (IARRY(J+1,I-1).NE.0) THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=6
      PTR=PTR+3
      J=J+1
      I=I-1
      GOTO 10
      END IF
6      IF (IARRY(J,I-1).NE.0)THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=7
      PTR=PTR+3
      I=I-1
      GOTO 10
      END IF
7     IF(IARRY(J-1,I-1).NE.0) THEN
      STACK(PTR)=J
      STACK(PTR+1)=I
      STACK(PTR+2)=8
      PTR=PTR+3
      J=J-1
      I=I-1
      GOTO 10
      END IF
8     IF (PTR.EQ.1) RETURN
      ADDR=STACK(PTR-1)
      I=STACK(PTR-2)
      J=STACK(PTR-3)
      PTR=PTR-3
      IF (ADDR.EQ.1) GOTO 1
      IF (ADDR.EQ.2) GOTO 2
      IF (ADDR.EQ.3) GOTO 3
      IF (ADDR.EQ.4) GOTO 4
      IF (ADDR.EQ.5) GOTO 5
      IF (ADDR.EQ.6) GOTO 6
      IF (ADDR.EQ.7) GOTO 7
      GOTO 8
      END


      SUBROUTINE ERSON(IARRY,IPXL)
```

```
C*************************************************************
C Use mathematical morphlogy to erase the noise,meanwhile it
C will erose the outer layer of leukocyte
C**************************************************************
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256),IPXL(256,256),ST(10,10)
      INTEGER SX,SY,SX2,SY2
C     SAM is the gray level of struture element
      SAM=80
C     Now  set the size of strutrue element and assign its' gr
level
      SX=2
      SY=2
      SX2=(SX-1)/2
      SY2=(SY-1)/2
      DO 10 N=1,SY
      DO 10 M=1,SX
      ST(M,N)=SAM
10    CONTINUE

      DO 20 J=1+SX2,LX-(SX-SX2)+1
      DO 20 I=1+SY2,LY-(SY-SY2)+1
      DO 30 N=1,SY
      DO 30 M=1,SX
C     Now the formula of erosion

      VALUE=IARRY(J+M-SX2-1,I+N-SY2-1)-ST(M,N)
      SAM =MIN(SAM,VALUE)
      IF (SAM.LT.0) SAM=0
30    CONTINUE
      IPXL(J,I)=SAM
20    CONTINUE
      DO 50 J=1+SX2,LX-(SX-SX2)+1
      DO 50 I=1+SY2,LY-(SY-SY2)+1
      IARRY(J,I)=IPXL(J,I)
50    CONTINUE
      RETURN
      END


      SUBROUTINE DATON(IARRY,IPXL)
C**********************************************************
C The Dialation will add an outer layer to the leukocyte
C it is the power tool to fill the hollow hole within the
C leukocyte
C**********************************************************
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256),IPXL(256,256),ST(10,10)
      INTEGER SX,SY,SX2,SY2
C     Set the struture element gray level
```

```
      LAG=0
C     The size of struture element
      SX=2
      SY=2
      SX=(SX-1)/2
      SY=(SY-1)/2
      DO 10 M=1,SX
      DO 10 N=1,SY
      ST(M,N)=LAG
10    CONTINUE

      DO 20 J=1+SX2,LX-(SX-SX2)+1
      DO 20 I=1+SY2,LY-(SY-SY2)+1
      LAG=0
      DO 30 M=1,SX
      DO 30 N=1,SY
C     The formula of dialtion
      VALUE=IARRY(J+M-SX2-1,I+N-SY2-1)+ST(M,N)
      IF (LAG.LT.VALUE) LAG=VALUE
      IF (LAG.GT.255) LAG=255
30    CONTINUE
      IPXL(J,I)=LAG
20    CONTINUE
      DO 50 J=1,LX
      DO 50 I=1,LY
      IARRY(J,I)=IPXL(J,I)
50    CONTINUE
      RETURN
      END
```

B : References

References

[1] H.C. Andrew , "Monochromo Digital Image Enhancement", Applied Optics , February 1976, p494-503.

[2] Alfred V. Aho, John E. Hopcroft, Jeffery D. Uli. Man,"Data Structures and Algorithms", Addison-Wesley Publishing Company, 1983.

[3] Dana H. Ballard , Christopher M. Brown, "Computer Vision", 1982 Prentice-Hall Inc.

[4] Wolfgang Braun, "An experimental System for Observation of the Rat Coronary Microcirculation Using Digital Image Processing", 1983.

[5] Nils Aslund Kjell Calsson, Lars Olsson and Fredrik Lund, " Digital Image Analysis of Fluorescein Angiogram" 10th Euro Conf Microcirculation, Caglian 1978 Biblthca anat no 18 ,p328-332.

[6] Edward R. Dougherty, " Image Processing Cintinuous to Discrete Volume 1", Prentice-Hall Inc. 1987

[7] Jeffrey Paul , Walter N. Durán,"Inhibition of Endothelial- Leukocyte Adesion in the Coronary Microcirculation" 1989.

[8] J.sklansky. P.V. Sankar and R.J. Walter JR, "Handbook of Pattern Recognition and Image Processing -Biomedical Image Analysis ", Editor: King Sun Fu, Tzay Y. Young, 1986.

[9] Rafael C. Gonzalez, Paul Wintz, "Digital Image Processing second edition" Addison -Wesley Publishing Company Inc. 1987.

[10] Charles R. Giardina , Edward R. Dougherty, "Morphlogical Methods in Image and Signal Processing", Prentice Hall Inc. ,1988.

[11] Robert M. Haralick, Stanly R. Sternberg, Xinhua Zhuang, "Image Analysis Using Mathematical Morphology", IEEE Transaction on Pattern Analysis and Machine Intellgence, vol PAME 9 No4, July 1987.

[12] Anil K. Jain, "Fundamentals of Digital Image Processing", Pretice-Hall Inc.,1989.

[13] J.S. Lee, "Digital Image Enhancement and Noise Filtering by Use of Local Statistics.", IEEE Transactions on Pattern Analysis and Machine Intelligence, March 1980, p-165-168.

[14] P.M. Narendra, "A Separable Median Filter for Image Noise Smoothing", IEEE Transaction on Pattern Analysis and Machine Intelligence, January 1981 p20-29.

[15] Theo Pavlidis, " Graphics and Image Processing ", Computer Science Press Inc. 1982.

[16] Azriel Rosenfeld and Avinash C. Kak, "Digital Picture Processing"," 2nd edtion", Prentice-Hall International 1982.

[17] Frank Shih, Hon-son Don, "Machine Tools Recognition by Image Morphology", "International Computer Symposium", Taiwan, 1988.

[18] Aron M Tenenbaum and Moshe J, Augenstein, "Data Structures Using Pascal", Prentice-Hall International, 1986.