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(6) THRESHOLD SELECTION USING QUADTREES

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ABSTRACT

The quadtree representation of binary arrays can be generalized to a quadtree approximation for images. A block is subdivided if its gray level standard deviation is greater than (e.g.) half of the global standard deviation. As a result, small blocks will tend to occur near region borders, and suppressing these blocks deepens the valleys on the image's histogram, thus making it easier to select a threshold for extracting objects from their background in the image.

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1. Introduction

Recent research on using quadtrees, trees of out degree 4, to represent binary images has produced interesting results in several areas of image processing [1-19]. For a 2^n by 2^n binary image, its quadtree is constructed by successively dividing the array into quadrants until square blocks (possibly single pixels) of uniform color (consisting of entirely 0's or 1's) are obtained. The root node of the tree represents the entire image, the four sons of a nonterminal node represent its four quadrants, and the terminal nodes (leaves) correspond to the uniformly colored blocks of the array for which no further subdivision is needed. A simple example of a binary image and its quadtree representation is shown in Figure 1.

The quadtree construction process can be generalized to arbitrary images. Requiring perfect uniformity (each pixel has the same gray level) in each terminal node will almost certainly produce a complete quadtree for a gray image. Thus some less rigid criterion for homogeneity should be used to determine whether to subdivide a block. For example, one can compute the mean and standard deviation of the gray levels of the pixels in a block and subdivide it if the standard deviation is high. When this is done, the leaves close to the root correspond to large homogeneous blocks which are in the interiors of regions. The small leaves correspond to pixels on or near the borders between regions. The number of leaves depends on the homogeneity criterion; see Table 1.

Quadtree approximations of images can be used in many ways as aids in image processing and segmentation. This note describes their use in connection with threshold selection.

2. Threshold selection

Many images are composed of two types of regions, e.g., of objects on a background. The objects in such images can be extracted from the background by thresholding--pixels with gray level darker than the threshold value are mapped into black and the lighter ones into white. Choosing the proper threshold is not always an easy task. A variety of threshold selection techniques have been proposed [20-25]. Some methods are based on the analysis of modification of the frequency distribution of the gray levels in the image, some use local property statistics to compute the threshold, and some methods use different thresholds for different parts of the image.

Threshold selection is relatively easy if the gray level ranges occupied by the objects and background are sufficiently well separated, i.e., the gray level histogram of the image is strongly bimodal with the two peaks comparable in size and separated by a deep valley. In this case, using the gray level of the bottom of the valley as the threshold would minimize the misclassification error. In general the two peaks may differ greatly in size and/or may lie close together. The histogram may then be unimodal with one side of the peak being a shoulder or not as steep as the other, making it difficult to define a threshold separating the two populations. Figures 2-4 show three images and their corresponding gray level histograms.

Various methods can be used to produce a transformed histogram in which the valley is deepened. One of the methods involves looking at the points on the object/background border. In general these points have gray levels intermediate between those of the object and background. Hence they contribute to the shoulders or the high broad valleys of the histogram. Thus if we construct a gray level histogram of the nonborder points only, it should have better separated peaks. Equivalently, a gray level histogram of the border points only should have a single peak at a gray level intermediate between those of the object and background [24,25], and the mean of this histogram should be a good threshold value.

In the gray quadtree of an image, the small leaves should correspond to pixels on the object/background border. Thus the gray level histogram when these points are eliminated should have a more pronounced valley, and the gray level mean of these points only should be a good threshold.

3. Experiments

For each of the pictures in Figures 2-4, a gray quadtree was built using the standard deviation of each block's gray level as a measure of homogeneity. A block is subdivided if its standard deviation exceeds a tolerance value (half of the global standard deviation was used to produce the results in Figures 5-7). From this quadtree, a "Q-image" is obtained by replacing each pixel's gray level with the average gray level of the terminal node it belongs to. The Q-image and its gray level histogram are shown in part (b) of Figures 5-7. Part (c) is the modified-Q-image which results from deleting the smallest size leaves, together with its gray level histogram. Part (d) shows the histogram of the deleted leaves. Part (e) is the thresholded picture when the mean of the gray levels of the deleted small leaves is used as the threshold value.

The results for all three pictures are very reasonable. It is interesting to note that the Q-image histogram of the tank has two well separated peaks, which is a remarkable improvement from the original histogram. An improvement is also seen in the case of the cloud cover picture. The modified Q-image histogram shows two better separated peaks for the tank and separates the objects from the background for the cloud cover. The original chromosome picture is bimodal and the object/background boundaries are already quite distinct. The Q-image is very blocky and only part of the border belongs to the small leaves. However, following the same entire procedure as for the other pictures still gives a threshold producing an excellent picture of the chromosome.

The standard deviation tolerahce value for homogeneity used for Figures 5-7 is half of the global standard deviation. Too large a tolerance value resulted in gray quadtrees with very large terminal blocks whose gray levels can vary greatly. Thus many border points would be considered as interior points. Too low a tolerance value results in quadtrees consisting mostly of small (single pixel) leaves and thus many interior points would be considered as border points. Figures 8 and 9 show the results of using too large (=3.6) and too small (=1.6) a value on the tank picture.

4. Concluding remarks

This note makes use of a simple generalization of the quadtree representation scheme to gray images. It demonstrates how to use the gray quadtree to help select a threshold for extracting objects from a background. The mean gray level of the small leaves is a good threshold value. In some cases, the gray level histogram of the Q-image shows noticeable improvement (peaks more separable) over that of the original image. The problem of selecting an appropriate measure to decide when to subdivide a block in the gray quadtree construction is also addressed; it was found that splitting a block when its standard deviation is greater than half of the global standard deviation works satisfactorily.

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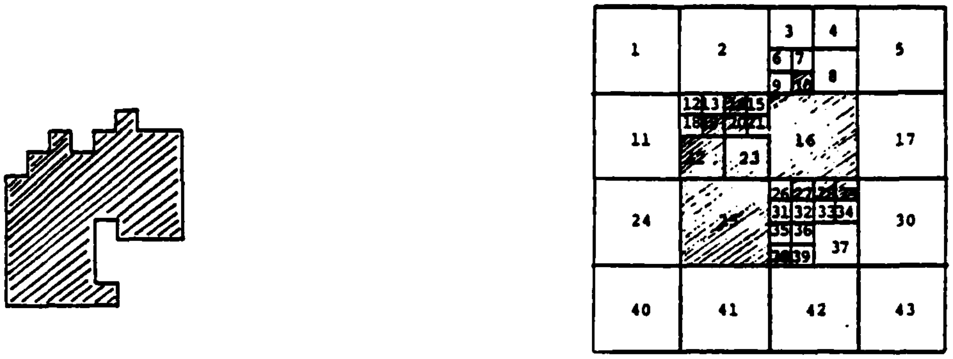
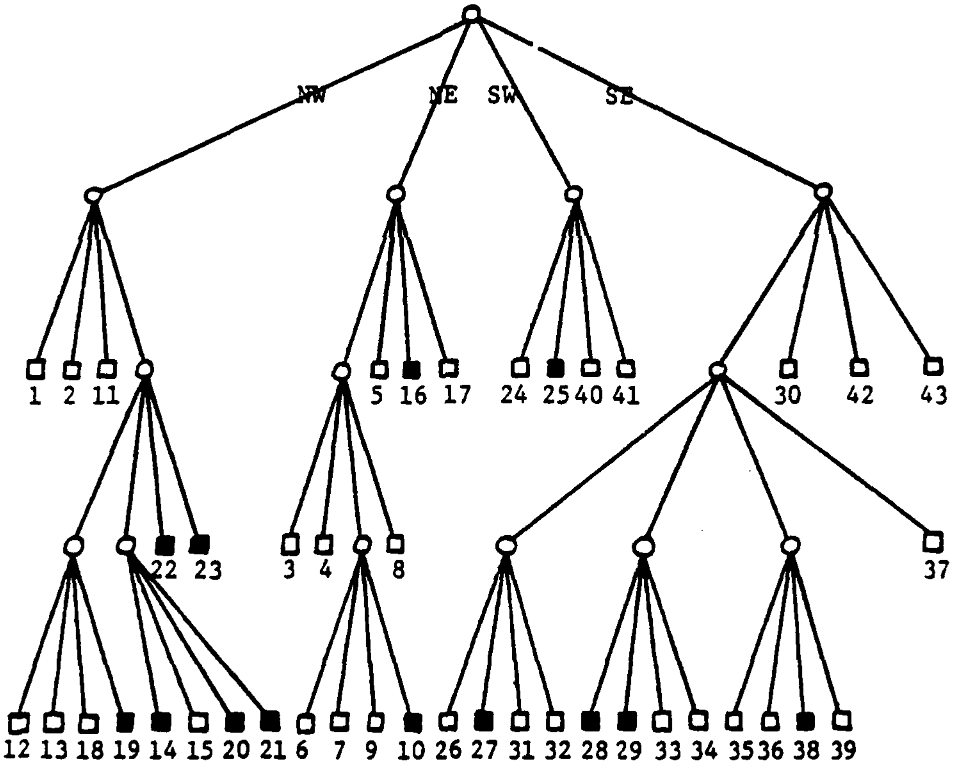
Standard deviation tolerance	Number of leaves						
	32x32	16x16	8x8	4x4	2x2	1x1	Total
1.6	0	0	2	37	326	2072	2437
2.6	0	8	9	27	126	536	706
3.6	1	8	2	32	54	168	265

Table 1. Number of leaves of various sizes for different standard deviation tolerances for the 64x64 tank picture of Figure 2.



a. Region.

b. Block decomposition of the region in (a).



c. Quadtree representation of the blocks in (b).

Figure 1. A region, its maximal blocks, and the corresponding quadtree. Blocks in the region are shaded, background blocks are blank.

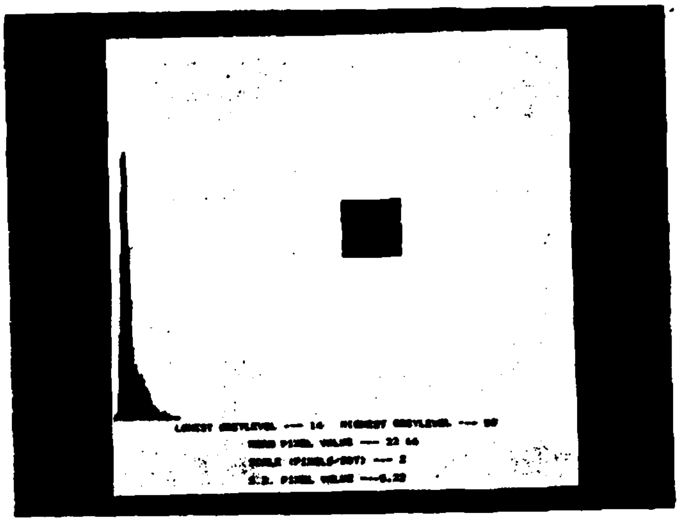


Figure 2. Tank and its gray level histogram.

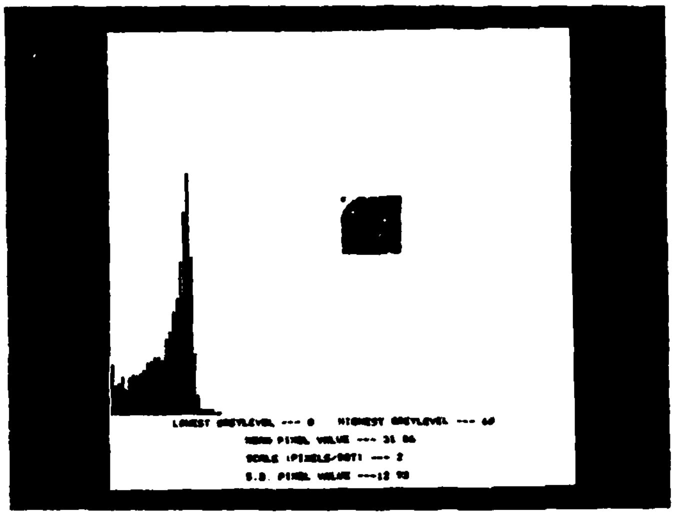


Figure 3. Cloud cover and its gray level histogram.

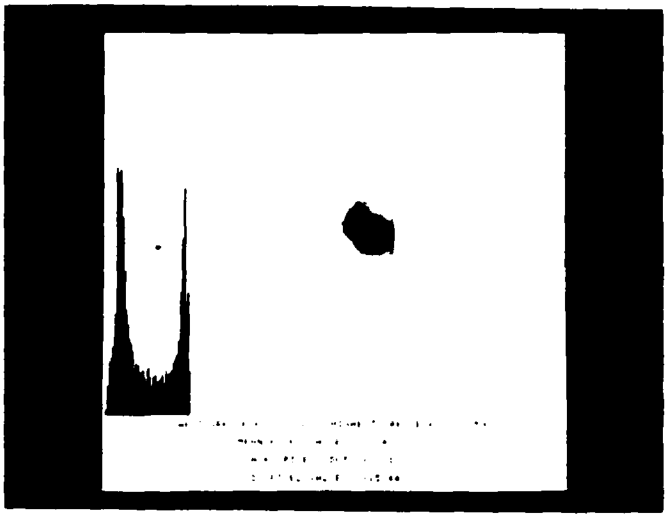


Figure 4. Chromosome and its gray level histogram.

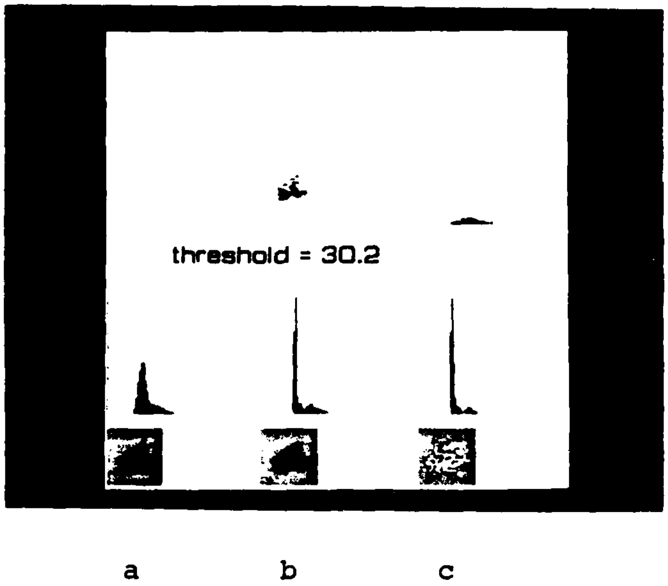


Figure 5. Tank
Standard deviation tolerance = 2.6
Counterclockwise from lower left:

- a. Original image and histogram
- b. Q-image and histogram
- c. Modified Q-image (all small leaves deleted) and histogram
- d. Histograms of the leaves deleted in (c)
- e. Result of thresholding

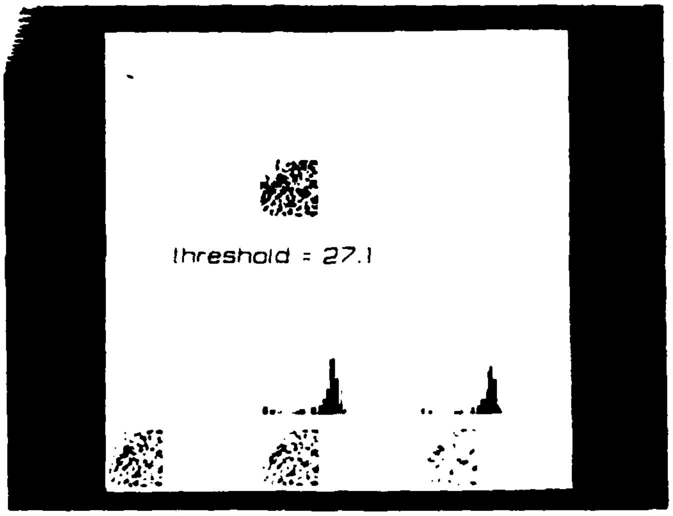


Figure 6. Same as Figure 5 for cloud cover; standard deviation tolerance = 6.5.

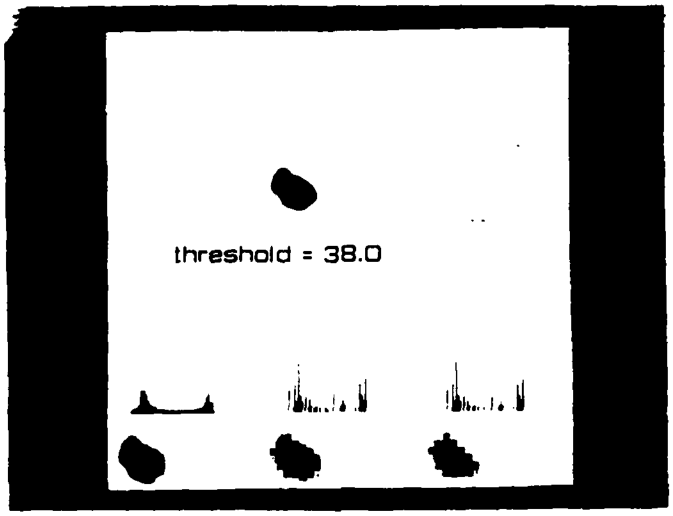


Figure 7. Same as Figure 5 for chromosome; standard deviation tolerance = 7.7.

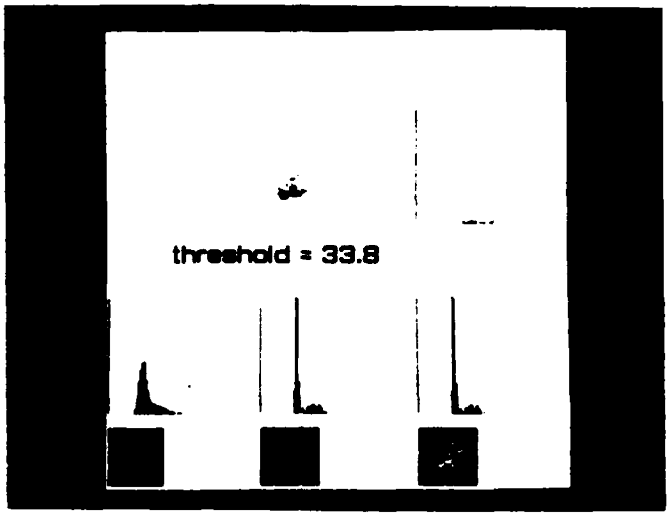


Figure 8. Same as Figure 5 except standard deviation tolerance = 3.6.

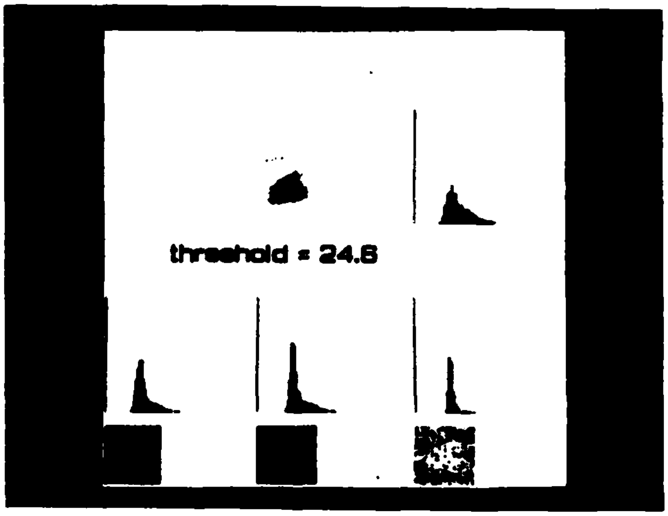


Figure 9. Same as Figure 5 except standard deviation tolerance = 1.6.

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The quadtree representation of binary arrays can be generalized to a quadtree approximation for images. A block is subdivided if its gray level standard deviation is greater than (e.g.) half of the global standard deviation. As a result, small blocks will tend to occur near region borders, and suppressing these blocks deepens the valleys on the image's histogram, thus making it easier to select a threshold for extracting objects from their background in the image.

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