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A parallel graytone thinning algorithm (PGTA)

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Abstract

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A parallel graytone thinning algorithm (PGTA) is proposed in this paper. This algorithm is a generalization of a well-known two-tone thinning algorithm of Zhang and Suen (1984) and is equally applicable for both graytone and two-tone images. The performance of PGTA is demonstrated on a variety of images, where it is seen that PGTA not only thins the object but also enhances the object-background contrast.

Keywords. Graytone thinning, parallel algorithm, contrast enhancement.

Introduction

The problem of skeletonization or thinning plays an important role in computer processing and analysis of images. This form of image representation captures the basic structural and shape features of an image with minimum requirement of data points. The literature on two-tone thinning algorithms is quite rich (Smith, 1987). To use a two-tone thinning algorithm to commonly available pictures such as printed and handwritten characters, remotely sensed imagery, micrograph pictures, fingerprints etc., it is necessary to segment the picture by a judicious choice of threshold. Once an image is thresholded, the information other than the object outline is lost forever and further processing in the graytone domain is not possible. All these shortcomings could be eliminated to a great extent if the thinning is accomplished in the graytone domain. An additional advantage of using a graytone thinning algorithm is that the resulting image is enhanced both in contrast of the object and smoothing in the background.

The graytone thinning methods available in the literature can be grouped into three major classes: (a) gray weighted distance (Levi and Montanari, 1970; Pal, 1989) based methods, (b) methods based on gradient distance (Kundu et al., 1986; Paler and Kittler, 1983; Wang et al., 1979), and (c) methods based on iterative dilation and erosion (Peleg and Rosenfeld, 1981). In the gray weighted distance class of algorithms, the gray weighted length of a path is proportional to the sum of the gray levels along the path. The gray weighted distance between two pels (pixels) is the lowest gray weighted length of any path between them. The skeleton corresponds to the set of pels which do not belong to any minimal gray weighted path from any other pel to the zero-valued background (Levi and Montanari, 1970).

In the gradient weighted distance class of algorithms, the gradient score at each pel p is computed. This score is based on the gradient magnitude of all pairs of pels that have p as their mid-point; thus those scores (Kundu et al., 1986; Wang et al., 1979) are high at points that lie midway between antiparallel edges.

MMMAT (Min-Max Medial Axis Transform) is an example of an iterative dilation and erosion type of algorithm (Peleg and Rosenfeld, 1981). Here, the gray image is eroded and dilated by local min and max operations. Let X be an input image. $X^{(-k)}$ denotes erosion of X k-times while $X^{(k)}$ denotes dilation of X k-times. Then, the k-th difference image is defined as

$$\Delta_k = X^{(-k+1)} - (X^{(-k)})^{(1)}.$$

It can be shown that Δ_k is positive for any pel p in the image. The skeleton at a pel p is $\max_k \Delta_k(p)$; $k = 1, 2, \ldots, n$ (say).

Although this method does not require any prior knowledge about the suitable threshold to obtain the correct segmented image, it does not also ensure the local gray level connectivity. In addition, the method of finding the parameter n is not well formulated.

In the present paper we propose a parallel graytone thinning algorithm (PGTA) belonging to class (c) stated above which takes care of the connectivity problem. Also, unlike MMMAT, it has a self-converging property. The algorithm is a generalization of the two-tone thinning algorithm due to Zhang and Suen (1948) (see also Lu and Wang, 1986) and hence it is applicable to two-tone images as well.

Parallel graytone thinning algorithm (PGTA)

Graytone thinning (GT) can be thought of as a generalization of the two-tone thinning algorithm. In the two-tone thinning algorithm, the object pels which are adjacent to the background are mapped to the background value. Similarly, in GT, pels which are very close to the background both in location and gray level, are mapped to the local maximum value (local background value). This similarity suggests that a two-tone thinning algorithm can be modified to suit the gray level environment.

The modified parallel thinning algorithm of Zhang and Suen (1984) is considered here for generalization to develop PGTA. The two-pass algorithm of Zhang is described below.

In the first pass, the contour point x_{mn} (candidate pel) is mapped to the local maximum value if the following four conditions are satisfied:

$$2 \leqslant B(p_1) \leqslant 6, \tag{1}$$

$$A(p) = 1, \tag{2}$$

$$p_1 * p_3 * p_5 = 0, \tag{3}$$

$$p_3 * p_5 * p_7 = 0. \tag{4}$$

Equation (1) was modified later on (Lu and Wang, 1986) as

$$3 \leqslant B(p_1) \leqslant 6. \tag{1a}$$

Here $A(p)$ is the number of '01' patterns in the ordered set $p_1, p_2, \ldots, p_8$ (see Figure 1), and $B(p)$ is the total number of nonzero neighbours of x_{mn}.

In the second pass, condition (1) and (2) remain the same but (3) and (4) are changed to (5) and (6) as follows:

$$p_1 * p_3 * p_7 = 0, \tag{5}$$

$$p_1 * p_5 * p_7 = 0. \tag{6}$$

To implement this algorithm for a gray level picture with similar checking of conditions, the neighborhood pels around the candidate pel are to be mapped temporarily to some compatible state

P_8 (m−n , n−1)	P_1 (m−1,n)	P_2 (m−1,n+1)
P_7 (m, n−1)	X_{mn} (m,n)	P_3 (m,n+1)
P_6 (m+1,n−1)	P_5 (m+1,n)	P_4 (m+1,n+1)

Figure 1. (3×3) neighborhood of the candidate pel (x_{mn}).

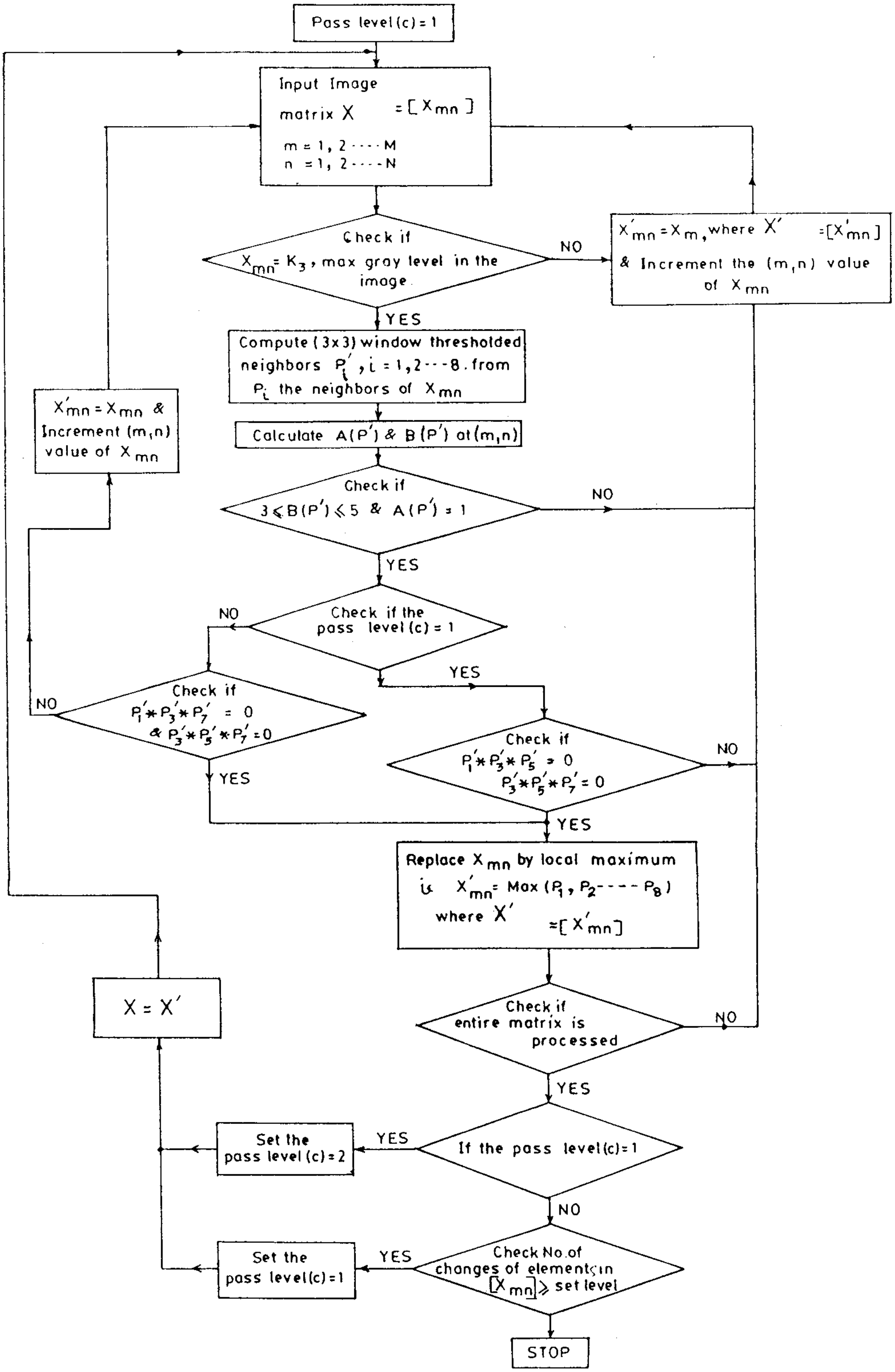

Figure 2. Flow chart of Parallel Graytone Thinning Algorithm (PGTA).

(two levels) depending on their spatial gray level distribution. In the present case, two-state mapping (thresholding) of neighborhood pels is done around a threshold value calculated locally.

The threshold value calculated over an $(N\times N)$ window is given by

$$K=\frac{1}{(N^2-1)}\sum_{i=1}^{N^2-1} p_i$$

where p_i is the gray value of the i-th neighborhood pel, while the candidate pel is not considered for computing K.

For a (3×3) window

$$K=\frac{1}{8}\sum_{i=1}^{8} p_i. \tag{7}$$

The mapped threshold value of the neighborhood pels is

$$p_i'=0 \quad \text{if } p_i\geqslant K,$$
$$=1 \quad \text{otherwise.}$$

The conditions (1a), (2), (3) and (4) are slightly modified to suit the gray level conditions as

$$3\leqslant B(p')\leqslant 5, \tag{8}$$

$$A(p')=1, \tag{9}$$

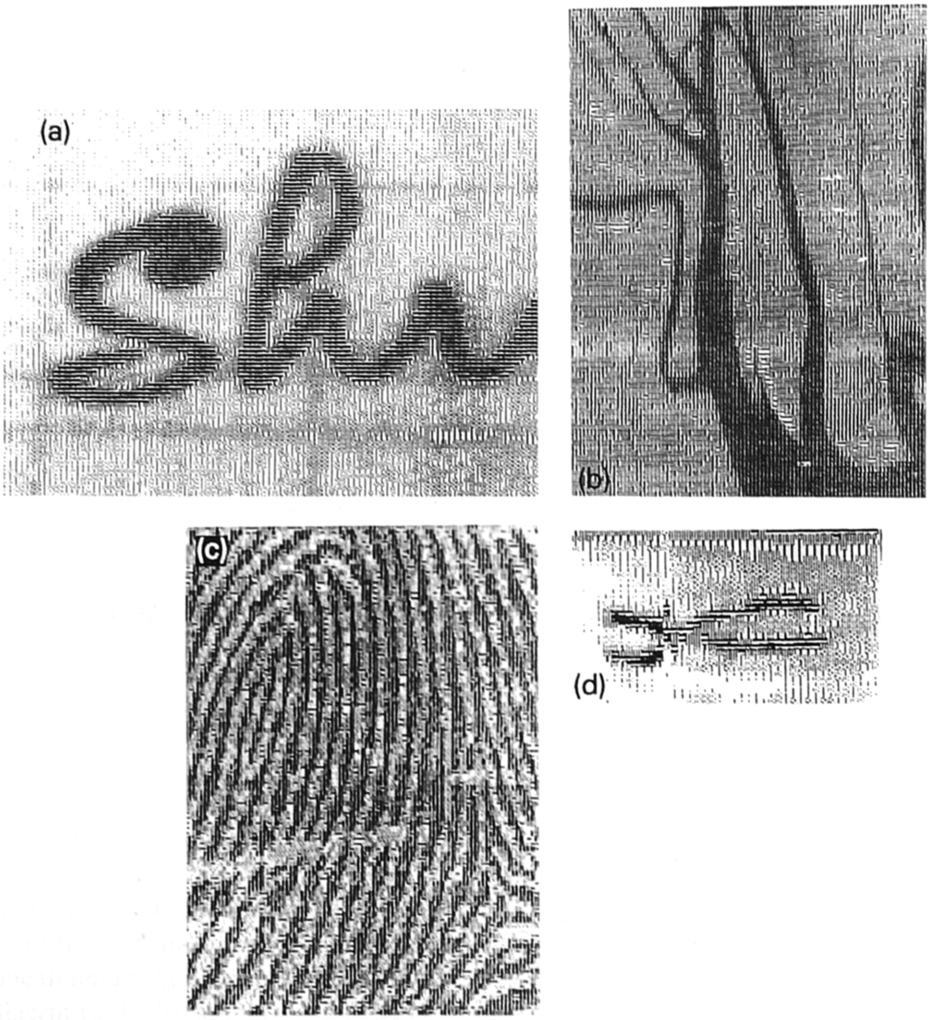

Figure 3. Input image data: (a) handwritten character *Shu* (96×96; 32 levels), (b) remote sensing image *IRS-1* (96×96; 32 levels), (c) fingerprint (96×96; 16 levels), (d) chromosome (64×64; 32 levels).

$$p'_1 * p'_3 * p'_5 = 0, \quad (10)$$

$$p'_3 * p'_5 * p'_7 = 0. \quad (11)$$

The four conditions are checked in the first pass (as in the two-tone algorithm) and if it is found to be true for all of them, then the candidate pel x_{mn} (Figure 1) is changed to the new value

$$x'_{mn} = \max(p_1, p_2, \ldots, p_8). \quad (12)$$

In the second pass, conditions (8), (9) and the following two other conditions are checked:

$$p'_1 * p'_3 * p'_7 = 0, \quad (13)$$

$$p'_1 * p'_5 * p'_7 = 0. \quad (14)$$

If all of the conditions are found to be true then x_{mn} is changed to the value expressed in equation (12).

In this method, the formula for K given by equation (7) gives better gray connectivity than other possibilities of K such as $K = x_{mn}$ or $K = (p_{\max} - p_{\min}) * F$ where F is a predetermined constant in the range $0 \leqslant F \leqslant 1$ while $p_{\max}$ and $p_{\min}$ denote the maximum and minimum gray levels in the window.

It is found that PGTA can extract the truely thinned version of the graytone object keeping the basic structure of the object intact.

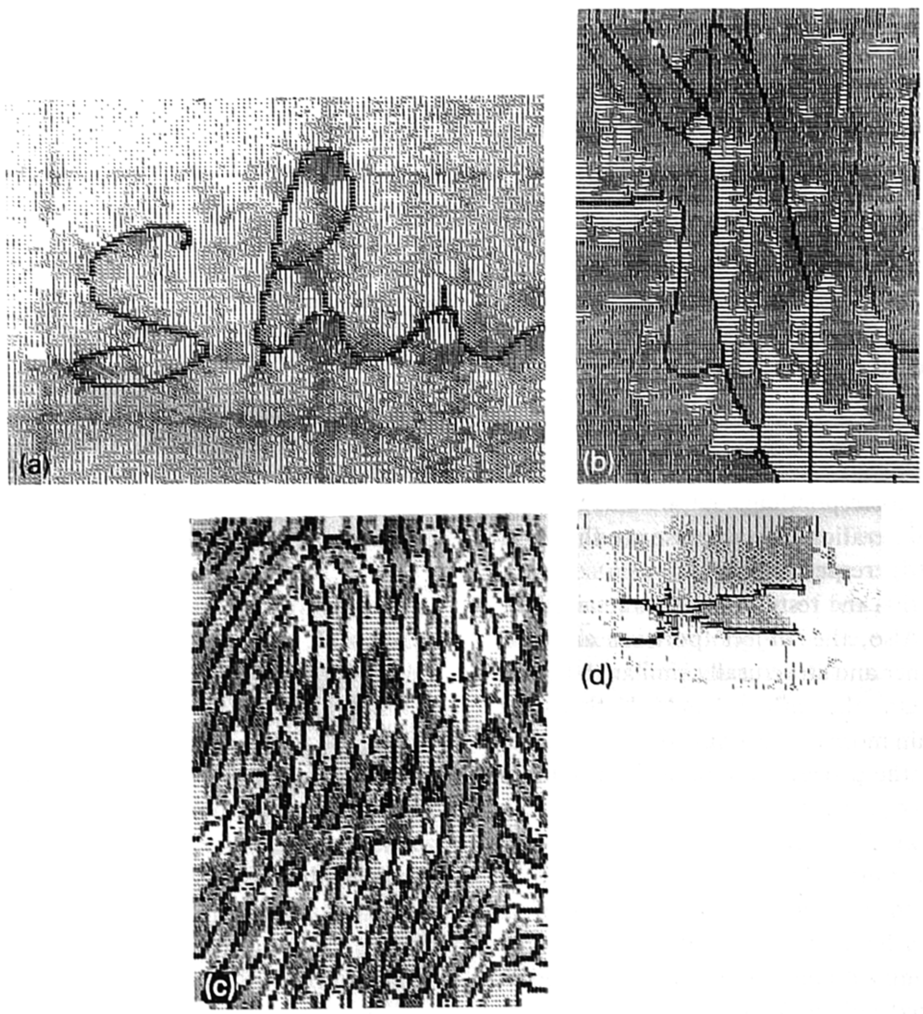

Figure 4. Results obtained after 10 iterations when PGTA is applied on Figures 3(a)–(d) respectively.

Results and discussion

PGTA was simulated on a PDP-11/24 computer. The flow chart of the algorithm is shown in Figure 2 which can be explained as follows.

Let $X=[x_{mn}]$ be the input gray level image matrix where x_{mn} is the gray level of the (m,n)th pel. In the first pass, the values of the pels are mapped to the local maximum value (equation (12)) for which the equations (8)-(11) are found to be valid. This forms a new image matrix X'. In the second pass again four new equations (8), (9), (13) and (14) are checked on each element of the X' matrix. Depending on the outcome (true/false) of the check, the pels are mapped to either the local maximum value (equation (12)) or kept unchanged. At the end of this pass, a new image matrix X is formed which is considered as the input image matrix for the next iteration. Let X_k denote the result of the k-th iteration. Let n_k denote the number of pels where the gray value has changed from the $(k-1)$-th to the k-th iteration. If n_k is less than a predefined number, the algorithm stops. The iteration continues until the number of changes (pel value change) falls below a predefined limit.

Four different types of images, namely, handwritten character *Shu* (96×96), remotely sensed data *IRS-1* (96×96), finger print (96×96) and chromosome (64×64) as shown in Figures 3(a)-(d), respectively, are considered here as input images. The corresponding output images obtained after 10 iterations in each case are shown in Figures 4(a)-(d), respectively.

It is found that the resulting images retain their gray nature. Also, the 'object' portions are considerably thinner and structurally similar to the input image. On the other hand, background portions remain more or less unaltered. It is also to be noted that the process automatically results in enhancement of contrast between object and background region with overall smoothing of the image.

PGTA is a fairly fast algorithm compared to the conventional graytone thinning algorithms. Moreover, as PGTA works on a gray level image, no a priori knowledge about an exact global threshold value (for correct segmentation) is necessary.

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