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(6) STRIP DETECTION USING RELAXATION

(10) Alan Danker
Azriel Rosenfeld
Computer Science Center
University of Maryland
College Park, MD 20742

ABSTRACT

This note describes some experiments in the detection of parallel sided strips using a relaxation-like process which iteratively reinforces collinear or anti-parallel edges. The process was tested on two types of data, tree trunks and runways.

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1. Introduction

Parallel-sided strips are important features in many types of imagery; examples include roads, runways, and treetrunks. They are characterized by the presence of "antiparallel" edges (i.e., as the strip is crossed, the gray level first increases and then decreases, or vice versa), and are usually detected by first detecting edges and then searching for such pairs; e.g., see [1].

This note reports on the use of relaxation methods [2] as an aid in detecting parallel strips. In this approach, after an initial step, collinear and antiparallel edges reinforce one another, so that the responses to long parallel strips are strengthened. For other recent applications of relaxation to pattern matching see [3].

The potential advantage of the relaxation approach is that it allows the edge detection decision to be deferred. Edge sensing is quantitative, and edges that belong to strips are then reinforced, so that the detection decision becomes (hopefully) trivial. It is not necessary to threshold the initial edge values as an initial step in searching for strips. This should be beneficial in cases where one edge of a strip is only weakly detectable, and where strong edges that do not belong to strips are present.

2. Edge sensing

Two edge-sensitive operators were used in the experiments reported in this note. The first was based on simple differences of averages of gray levels, e.g. (in the neighborhood $\begin{matrix} ab & cd \\ ef & gh \end{matrix}$)

$$\frac{1}{4}[a+b+e+f] - \frac{1}{4}[c+d+g+h]$$

responds to vertical edges. Note that its response is positive if the average gray level in the left half of the neighborhood is greater than that in the right half, and negative if the reverse is true. In order to smooth out small gaps in edges, the output of this operator was averaged in the vertical direction; e.g., if its output at (x,y) is $E(x,y)$, the averaged output is defined to be

$$\bar{E}(x,y) \equiv \frac{1}{5}[E(x,y-2)+E(x,y-1)+E(x,y)+E(x,y+1)+E(x,y+2)]$$

Finally, in order to obtain thinned edge responses, nonmaximum suppression in the horizontal direction was performed on the vertically averaged output values. Specifically, we define

$$E'(x,y) = \bar{E}(x,y) \text{ if } \bar{E}(x,y) \geq \max[\bar{E}(x-2,y),\bar{E}(x-1,y),\bar{E}(x+1,y),\bar{E}(x+2,y)]$$
$$= 0 \text{ otherwise.}$$

The second edge operator was a nonlinear operator which required that gray level differences of the same sign be present at several collinear points. Specifically, for the vertical direction, in the neighborhood

$$\begin{matrix} ab \\ cd \\ ef \\ gh \\ ij \\ kl \\ mn \end{matrix}$$

we require that at least four of the seven inequalities $a>b$, $c>d$, $e>f$, $g>h$, $i>j$, $k>\ell$, and $m>n$ hold, or that at least four of the reverse inequalities hold. When these conditions are satisfied, the output of the operator is defined to be $\frac{1}{7}[a+c+e+g+i+k+m] - \frac{1}{7}[b+d+f+h+j+\ell+n]$ (or its negative); otherwise, the response is zero. We shall denote this operator by E^*.

3. Relaxation

The relaxation process is a combination of two processes: reinforcement of collinear edge responses and competition of parallel edge responses (so that antiparallel edges reinforce). Both processes were weighted according to distance, but it turned out that the choice of weights made little or no difference in the results. We describe the processes in detail for the vertical edge case.

The input to relaxation is a set of normalized edge responses. These were taken to be the E' or E* values divided by the highest such (absolute) value in the scene. Thus the normalized values are in the range [-1,1], where negative values correspond to "left edges" (lower gray levels on the left than on the right) and positive values to "right edges". We will denote the initial response at (x,y) by $P^{(0)}(x,y)$.

Given the responses $P^{(i)}(x,y)$ at the ith iteration, those at the (i+1)st iteration were defined by an expression of the form

$$P^{(i+1)}(x,y) = \theta A^{(i)}(x,y)+(1-\theta)B^{(i)}(x,y)$$

where $0 \le \theta \le 1$. Here $A^{(i)}$ and $B^{(i)}$ are weighted averages of $P^{(i)}$ values in the vertical and horizontal directions, respectively. The weights in A are designed to reinforce collinear edges, while those in B are designed to allow parallel edges to compete and antiparallel edges to cooperate.

Specifically, the A average used a neighborhood consisting of the points (x,y), $(x,y\pm 1),\ldots,(x,y\pm k)$, where $k=2,3,4$, or 5. Two weighting schemes were used, where the weights w_j at $(x,y\pm j)$ were defined as follows:

a) Exponential weights:

j	w_j
0	1
1	1/2
2	1/4
3	1/8
4	1/16
5	1/32

b) Step weights:

j	w_j
0	1
1	1
2	1
3	1/2
4	1/2
5	1/2

Thus $A^{(i)}(x,y) = \sum_{j=0}^{k} w_j P^{(i)}(x,y\pm j)$; for purposes of normalization, this was divided by the number of neighbors that had nonzero edge responses. In the experiments described in the next section, only the exponential weights were used, but the step weights gave very similar results.

The B average used a neighborhood consisting of the points (x,y), $(x+1,y),\ldots,(x+4,y)$, for a left edge, and (x,y), $(x-1,y)$, $\ldots,(x-4,y)$, for a right edge. Here again, two weighting schemes were used:

a) Exponential weights:

j	w'_j
0	0
1	-1/2
2	-1/4
3	-1/8
4	-1/16

b) Step weights:

j	w'_j
0	0
1	-1/2
2	-1/2
3	-1/2
4	-1/2

Thus $B^{(i)}(x,y) = \sum_{j=0}^{k} w_j' P^{(i)}(x \pm j,y)$, divided by the number of nonzero edge responses in the neighborhood; here only the + signs are used for left edges and only the - signs for right edges.

In combining the A and B terms, it was found that $\theta=0.8$ produced good results; if θ was much lower than this, the enhanced edges were weakened, while θ close to 1 produced noisy results. Further improvement was obtained by truncating the B neigbhborhood if an edge opposite to that at (x,y) was found. In the results presented in the next two sections, $\theta=.8$ and truncation of the B neighborhood are used.

4. Examples

The process described in Section 3 was applied to the two images shown in Figure 1. The first of these is an infrared image that contains two tree trunks; the second is an aerial photograph of an airport.

Figures 2-6 show results for the tree trunk image using the following variations of the process:

Figure	Edge operator	A radius	B weights
2	E*	4	exponential
3	E'	4	exponential
4	E'	4	step
5	E'	3	exponential
6	E'	5	step

The A weights used were always exponential, and the B radius was always 5. Each figure shows the original confidences (as absolute values) and the results of five iterations of the process; all of these values have been scaled identically for display. It is seen that all the results are virtually identical, and that after a few iterations, very few lines survive, including the sides of the tree trunks.

Figures 7-8 show analogous results for the airport image, using both edge operators (E* in 7, E' in 8), with an A radius of 4 and exponential weights, and a B radius of 5 and step weights. Each figure shows the original confidences and six iterations of the process.

5. Discussion

The iterative scheme described in this paper appears to be a robust method of **enhancing** parallel-sided strips of a given size range in an image. It was implemented only in one orientation, but can easily be extended to a set of orientations (though this would, of course, increase the number of noise responses). It works quite well in spite of its simplicity (note that it is little more than an iterated convolution operation applied to the edge operator output), and is especially suitable for implementation by parallel image processing hardware. Perhaps its greatest advantage is that it avoids the need to make an initial edge detection decision. Thus it deserves consideration as an approach to strip detection in a variety of image domains.

References

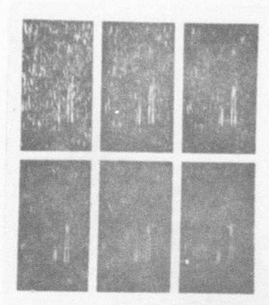
1. R. Nevatia and K. R. Babu, Linear feature extraction, Proc. Image Understanding Workshop, Nov. 1978, 73-78.

2. A. Rosenfeld, Iterative methods in image analysis, Pattern Recognition 10, 1978, 181-187.

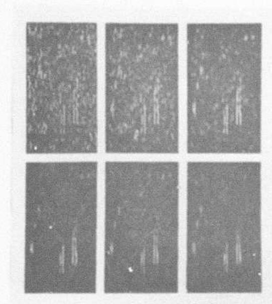
3. A. Rosenfeld, Some experiments in matching using relaxation, Proc. Image Understanding Workshop, Nov. 1978, 110-114.

a b

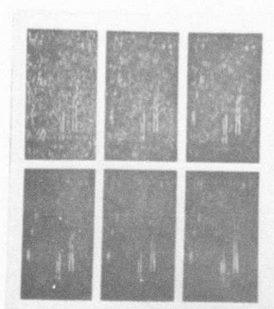
Figure 1. Input pictures



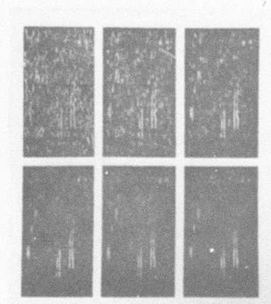
2



3



4



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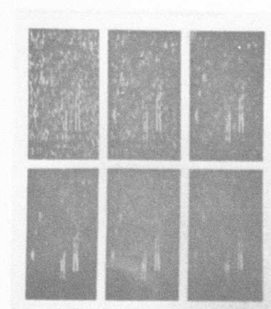

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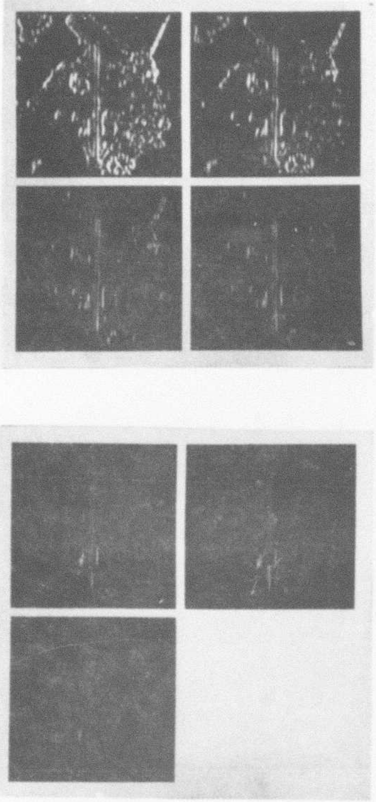
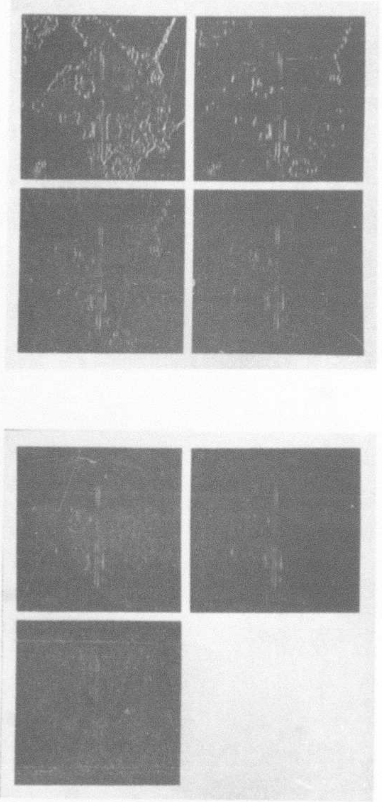
Figures 2-6. Results for Figure 1a.



7



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Figures 7-8. Results for Figure lb.

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