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AN ALGORITHM FOR THINNING NOISY IMAGES

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ABSTRACT

In this paper we present an algorithm for thinning noisy images using morphological operations. The proposed algorithm removes noisy spurs and extracts a meaningful skeletal set from noisy images. This approach is useful in model-based vision applications where the features of the image are required for object recognition. We demonstrate the use of this algorithm in sensor array imaging situations.

I. INTRODUCTION

The process of reducing an image to unit thickness is called skeletonization. Thinning involves successive removal of outer layers of an image, until a skeleton of the image remains. The purpose of thinning is to delete redundant information and at the same time retain the characteristic features of the image. Thinning is used as a preprocessing step in many pattern recognition and machine vision applications.

Standard thinning algorithms are useful when the image to be preprocessed is noise free. But in practical situations, such as in sensor array imaging, the reconstructed images are noisy. In such situations, conventional thinning algorithms produce skeletons which do not reflect the features of the original images. Our objective is to develop an algorithm which deletes noisy spurs and produce useful skeletons.

We present a two step algorithm for thinning noisy images. The first step consists of removing noisy spurs from an image using a combination of morphological operations In the second step, thinning is performed using the standard Morphological Skeleton Transform(MST)[1,2].

This paper is organized as follows: In Section II we introduce the partial data problem in a sensor imaging setup and explain the need for thinning noisy images. Section III discusses thinning based on Morphological Skeleton Transform and shows the inadequacy of direct application of MST for thinning noisy images. We describe our two step thinning algorithm and demonstrate the application of this algorithm in sensor array imaging in Section IV.

II. SENSOR ARRAY IMAGING SETUP

In many practical situations, it is required to recover an image from the complex field data measured by an array of sensors. The data received in a sensor array imaging setup is sparse and noisy. The data is usually a transformation of the field distribution on the object to be imaged. An image is reconstructed by computing the inverse transform on the received data after incorporating the phase factor due to propagation. Fig. 1 shows the images reconstructed from sparse data collected using a simulated sensor array imaging setup[3,4]. These images are noisy and have poor resolution. Hence it is necessary to process them for object recognition.

In model based vision systems for object recognition, low level features are extracted from an image and higher-level description of the image is developed from the extracted features. The resulting representation of the image data is compared with the models of the objects to hypothesize the object in the image. A thinned image shown in Fig. 2b is generally required for the representation of the object shape. Since most of the images reconstructed in a sensor array imaging setup are noisy, standard thinning algorithms produce skeletons which may not be useful for extracting the shape information. It is necessary to process the image not only to remove noise from the image but also to fill the small holes in the image so that skeletonization yields an image similar to Fig.2b.

III. MORPHOLOGICAL SKELETON TRANSFORM(MST) APPROACH TO THINNING

A thinning algorithm executes iteratively several passes over an image and deletes a few points in each pass. A point is deleted[5] if 1) it is an edge point(it lies along the contour of the image), or if 2) it is not an end point(it is not a point which lies on the extremities of a stroke), or if 3) it is not a break point(it is not a point whose deletion would break the connectedness in the image). Care is taken to see that excessive erosion does not take place during the process of deletion.

There are many approaches to thinning. In **global approach**, a distance transform of the image is computed, where the pixels are labelled according to the distance from an edge. The skeleton of a image always lies along the medial axes of the limbs of the image. Therefore a set

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of pixels lying symmetrically with respect to distinct contour parts of the image forms the skeleton and it is obtained by thresholding the gradient of the distance transform. However, to ensure connectedness of the resulting skeleton and to preserve the topological properties of the image, suitable additional pixels may also be assigned to the skeletal set.

In **local approach** to thinning, some formal tests are performed on the 8-neighbours of every pixel to decide whether it can be deleted without loss of connectedness and topology. These algorithms prevent excessive erosion by postponing the deletion of a pixel in some *ad hoc* manner.

Another promising approach to thinning is the use of **Morphological Skeleton Transform**. Morphology refers to analysis of geometric structure or texture within an image. The objective is to understand the textural or geometric properties of an image by probing the image with various forms of microstructure. These probes are known as structuring elements.

In mathematical morphology[1], the skeleton of a set $\mathbb{S}$ in the Euclidean plane is defined in the following manner: For each x in $\mathbb{S}$, let $\mathbb{D}(x)$ denote the largest Euclidean disk centered at x such that $\mathbb{D}(x)$ is a subset of $\mathbb{S}$. Then x is in the skeleton of $\mathbb{S}$ if there does not exist a disk $\mathbb{D}_1$, not necessarily centered at x, such that $\mathbb{D}_1$ properly contains $\mathbb{D}(x)$ and such that $\mathbb{D}_1$ is contained in $\mathbb{S}$.

An exact analog to Euclidean disk is not available in digital morphology. Hence a square disk as shown in Fig.3 may be used as the structuring element for the MST.

The definition of the digital skeleton can be stated analogous to the Euclidean skeleton, and can be represented as a subset of a two dimensional discrete space $\mathbb{Z}^2$. Before proceeding to the description of MST, the necessary morphological operations required for MST definition are introduced. The four basic morphological operations are dilation, erosion, opening and closing[1].

Let the set X represents an image, B represents the structuring element and $B^s(-b: b \in B)$ represents the symmetric set of B, B_z represents the translate of B by a vector z, X_{-b} represents translate of X by vector $-b$ and $\emptyset$ represents the null set. Then dilation of X by B is defined as a set of all points z such that B_z is contained in the original image X. Erosion of X by B is defined as a set of all points z such that the translate B_z is contained in X. Opening of X by B is the set resulting from erosion of the symmetric set of B followed by dilation with B. Closing of X by B is the set resulting from dilation of B^s followed by erosion of B. These operations can be represented as follows:

Dilation:
$$X \oplus B^s = \{ z: B_z \cap X \neq \emptyset \} = \bigcup_{b \in B} X_{-b} \qquad (1)$$

Erosion:
$$X \ominus B^s = \{ z: B_z \subseteq X \} = \bigcap_{b \in B} X_{-b}. \qquad (2)$$

Opening(X_B):
$$X_B = (X \ominus B^s) \oplus B. \qquad (3)$$

Closing(X^B):
$$X^B = (X \oplus B^s) \ominus B. \qquad (4)$$

In Morphological Skeleton Transform the skeleton SKEL(X) of an image X can be computed using repeatedly the operations erosion and opening as shown below:

$$\left.\begin{aligned} &SKEL(X) = \bigcup_{n=0}^{N} S_n(X), \\ &S_n(X) = [X \ominus nB] - [X \ominus nB \bigcirc B], \\ &N = \max \{n: X \ominus nB \neq \emptyset \}, \end{aligned}\right\} \qquad (5)$$

where $\ominus$, $-$ and $\bigcirc$ represent the erosion, difference and closing operations,respectively. nB is obtained by use of repeated dilation by B n-times. $S_n(X)$ is the skeleton subset.

For a noise-free image as in Fig.2a, MST produces a skeleton shown Fig.2b, which reflects the shape of the original object. But when it is applied on noisy images shown in Fig.1, it produces skeletons as shown in Fig.4, which do not reflect the shape of the original image(Fig.2b). A method is necessary to distinguish between the noisy spurs and the image, and to extract a meaningful skeleton from the noisy image. This is difficult because the width of the noisy spurs may not be available beforehand and may not be same all over the image.

In this paper we propose a method by which noisy spurs are deleted from an image before standard thinning algorithms are applied. We use a combination of opening and closing operations to clean the noise and then use MST to perform the thinning.

IV. ALGORITHM FOR THINNING NOISY IMAGES

Morphological operations can be used as filters because the geometrical features of an image can be modified by convolving the image with a structuring element. Morphological operations are preferred to other digital filters as they have several attractive features[6] like:(1) simplicity, (2) systematic detection and quantification of the shape and size of geometric features in images and (3) duality(i.e., for each morphological operation operating on an image there is another operation operating on the background of the image). Moreover they can be used to find neighbours of a given pixel.

Fig.5,6,7 and 8 illustrate the results of the operations dilation, erosion, opening and closing, respectively, performed on the images in Fig.1 using the structuring element shown in Fig.3. Dilation expands the image(Fig.5), whereas erosion shrinks it(Fig.6). Opening(Fig.7) suppresses the spikes, whereas closing fills in small holes in the images(Fig.8). It is seen from the figures that any of these operations alone cannot be used to clean noise. For example, the dilation operation expands the noisy spurs. Erosion operation removes noisy spurs but erodes the image also by expanding the noisy holes. Opening operation removes noisy spurs but noisy holes are not filled. Closing operation fills noisy holes and also removes noisy spurs, but the noisy spurs along edges are not removed. Hence a combination of these operations is required as a preprocessing step for thinning noisy images.

Two such combinations of morphological operations namely, open-closing and clos-opening are defined in [6]. In open-closing, opening operation is followed by a closing operation performed with the same structuring element. Likewise, in clos-opening, closing operation is followed by an opening operation with the same structuring element. Fig.9 shows the results of the open-closing operation using a 2x2 structuring element. It is seen from the figure that even after the combination of operations, some noise spurs still remain whereas some useful parts of the image have been lost. This is due to the fact that the same structuring element is used for both opening and closing. If during opening operation, a noisy spur expands to the size of the structuring element, then this spur is not removed in the following closing operation since it uses the same structuring element. Also some valid parts of an image may be lost when a single structuring element with all pixels activated is used. This happens, for example, in a noisy image if a valid image pixel has less than three neighbours while using a 2x2 structuring element.

To overcome these problems, we suggest two modifications. One is the use of different structuring elements for opening and closing. We use a 2x2 structuring element for opening and a 3x3 for closing. During opening noise spurs may expand to the size 2x2, but these will be deleted during the closing operation since it uses a 3x3 structuring element.

The second modification is that the opening operation is performed on the same image with different structuring elements shown in Fig.10. and the resultant images are combined by OR operation. This opening operation is similar to the neighbourhood operation, where a pixel is tested for its neighbour. This ensures that pixels that have only one neighbour are not deleted. It also ensures that opening is done uniformly in all directions, i.e., it is isotropic.

The result of this operation is shown in Fig.11. These operations have removed the distortions introduced by the noisy spurs and they have filled the noisy holes. If a standard thinning operation is performed on these images(Fig.11), skeletons as shown in Fig.12 are obtained. The following algorithm is used for thinning a noisy image :

Algorithm for thinning noisy images	
Step 1.	Let X be the image
Step 2.	Perform opening operation on X using all the six 2x2 structuring elements
Step 3.	Combine the resultant images using an OR operation
Step 4.	Perform closing operation using by 3x3 structuring element
Step 5.	Use morphological Skeleton Transform algorithm on resultant image

These operations have resulted in a skeleton which preserves many important features of the skeleton of the original noise-free image, as can be seen by comparing Figs.11a and 11b with Fig.2b.

V. CONCLUSIONS

In this paper we have addressed the problem ofthinning noisy images. We have shown that meaningful skeletons can be brought out from images by first using a combination of morphological operations and then applying a standard thinning algorithm. We have demonstrated the use of this technique for thinning poorly resolved, noisy images obtained in a simulated sensor array imaging setup.

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REFERENCES

[1] J. Serra, *Image analysis and Mathematical Morphology,* New York: Academic Press, 1982.
[2] Edward R. Dougherty and Charles R. Giardina, *Matrix Structured Image Processing,* pp. 98-130, New Jersey, Prentice-Hall,1987.
[3] B.Yegnanarayana, C.Mariadossou and Pramod Saini, *Signal reconstruction from partial data for sensor array imaging applications,* Signal Processing, to appear in February 1990.
[4] B.Yegnanarayana, R.Ramaseshan and A.Ravichandran, *Image reconstruction from multiple frames of sensor array data,* Indo-US workshop on Spectrum Analysis in One and Two Dimensions, 27-29 Nov.1989, New Delhi.
[5] N.J.Naccache and R.Shinghal, *An investigation into the skeletonization approach of Hilditch,* Pattern Recognition, vol.17, no.3, pp. 279-284, 1984.
[6] P.Maragos and R.W.Schafer, *Morphological Filters: Part-I: Their Set-theoretic Analysis and Relations to Linear Shift-Invariant Filters,* IEEE Trans. on ASSP, Vol.35, No.8, August 1987.

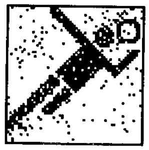
(a)  (b) 

Fig.1. 128x128 point images reconstructed from a sensor array imaging setup
(a) using 16x16 array
(b) using 32x32 array.

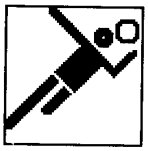
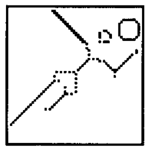
(a)  (b) 

Fig.2. (a) Original image and
(b) its skeleton.

o o o
o o o
o o o

Fig.3. A 3x3 structuring element.

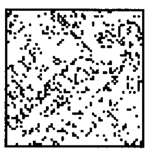
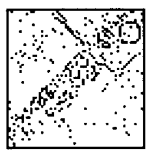
(a)  (b) 

Fig.4. Skeletons of noisy images of Fig.1 thinned by Morphological Skeleton Transform

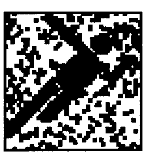
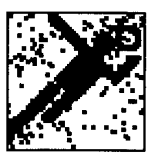
(a)  (b) 

Fig.5. Noisy images of Fig.1 after dilation operation.

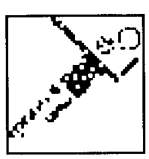
(a)  (b) 

Fig.6. Noisy images of Fig.1 after erosion operation.

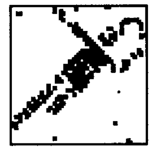
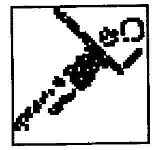
(a)  (b) 

Fig.7. Noisy images of Fig.1 after opening operation.

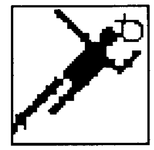
(a)  (b) 

Fig.8. Noisy images of Fig.1 after closing operation.

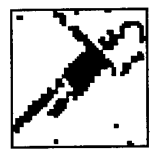
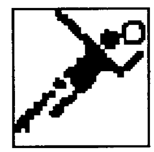
(a)  (b) 

Fig.9. Noisy images of Fig.1 after open-closing operation.

o *	o o	* o	* *	o *	* o
o *	* *	* o	o o	* o	o *

o - element belonging to image * - don't care

Fig.10. Different 2x2 structuring elements.

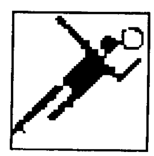
(a)  (b) 

Fig.11. Noisy images processed using different sizes of structuring elements for open and close operations.

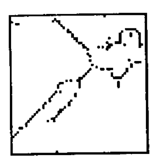
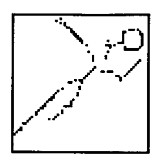
(a)  (b) 

Fig.12. Skeleton of image in Fig.11 thinned by Morphological Skeleton Transform.