AN ALGORITHM FOR THE DETECTION OF SMALL ROUNDED PNEUMOCONIOSIS OPACITIES IN CHEST X-RAYS AND ITS APPLICATION TO AUTOMATIC DIAGNOSIS

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INTRODUCTION

Computer diagnosis of pneumoconiosis has been studied by several groups since 1970's. Fundamental approaches for classification of profusion of pneumoconiosis opacities can be divided into two categories. One is based on texture analysis of density pattern of lung area, which has been adopted by a large majority of research groups.[1-8] The other is an approach trying to detect directly small opacities of pneumoconiosis. It may be superior to texture analytic approach because it is robust against fluctuations of film quality and individual differences of normal structural patterns in lung area. And, perhaps the latter approach can meet the requirement better according to the ILO classification system whose categorization is based on the density of pneumoconiosis opacities. Typical methods of detecting small rounded opacities have been developed.[9,10] However, category classification based on them has not been performed. Recently, two opacity detection methods have been proposed.[11,12] One is based on a contour line processing and the other adopts a matched filtering technique. Experiments of four major category classifications have been performed by those two methods, whose results show the usefulness of the opacity detection method. This paper presents a new method to identify small rounded opacities of pneumoconiosis and to classify the grade of their density.

DETECTION OF SMALL ROUNDED OPACITIES

The new method for detecting small rounded pneumoconiosis opacities in chest X-rays is based on the processing of local density pattern. The gray value in an opacity area is of the distribution like a local convex surface. Detection of such convex surfaces is performed by two processing steps. The first step is to locate local peaks, and the second one is to identify the shape and the size of them, which is the segmentation of the local convex surfaces from their neighboring area.

The First Step

Candidates of pneumoconiosis opacities are detected by this processing. Figure 1 shows a filter to detect convex surface. Detectors are arranged on three concentric circles. Each detector covers, in general, rectangular region, and its output is the mean pixel value in that region. The output of the filter, X, is given as follows.

$$X = \begin{cases} 3, & A > MAX3, \\ 2, & A > MAX2 \text{ and } A < MAX3, \\ 1, & A > MAX1 \text{ and } A < MAX2 \text{ and } A < MAX3, \\ 0, & \text{others} \end{cases}$$

where, MAXi (i=1,2,3) is the maximum of B_i, C_i, D_i, ...,I_i which are output values of detectors on the same circumference. Diameters of three concentric circles are 1.5, 2.0, and 3.0 mm. They are determined considering the sizes of pneumoconiosis opacities p, q and r. Filter outputs 1, 2, and 3 mean that local convex surfaces can be candidates of pneumoconiosis opacities whose sizes are p, q and r, respectively. Many false pneumoconiosis opacities are detected by the proposed filter. They are called noise opacities in the following and the following screening algorithm to exclude those noises is adopted. First, expansion and contraction processing is applied to merge candidates which are closely adjacent to each other. The next step is the noise reduction in which characteristics of each candidate are evaluated and those which satisfy the following conditions are excluded.

1. Area is less than a threshold h_s.
2. Film density is less than a threshold h_p.
3. The shape is long and slender.

The third condition is investigated as follows. Let us denote the area of a candidate, its widths in the directions of abscissa and the ordinate by s, l_x and l_y, respectively. If the shape of the candidate is a circle, its diameter 1 is given as:

$$1 = 2\sqrt{s/\pi},$$

which is equal to l_x and l_y. Considering this relationship, long and slender candidates can be detected as those which satisfy the following condition:

$$(l_x + l_y)/2 > 3l.$$

The Second Step

The second processing step includes precise measurement of opacity area and a supplementary noise reduction.

Identification of the boundary of pneumoconiosis opacity is performed as follows. It is assumed that the gradient vector at any pixel which belongs to a pneumoconiosis opacity is directed to the top of its convex surface. And the pneumo-
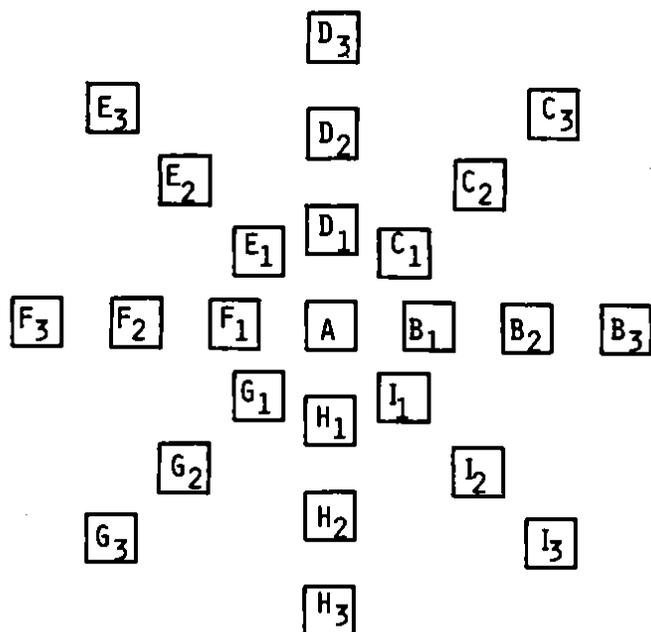
Figure 1. Pneumoconiosis opacity candidate detection filter.

coniosis opacity area defined in this paper is the union of the opacity candidate area and its neighborhood in which gradient vectors are directed to the opacity candidate area.

The second noise reduction algorithm is applied at this stage and the final result is obtained. Opacities which meet the following conditions are excluded.

1. The absolute value of a gradient vector in the opacity area is larger than a threshold h_d.

2. Those opacities which have large discrepancy between the output of the pneumoconiosis opacity candidate detection filter and the area measured in the second step.

EXPERIMENTS

Experimental Conditions

The films used in this study were 11 ILO 1980 standard films whose opacity shapes are rounded. Their classification is given in Table I. Each film was digitized by a drum scanner at a resolution of 5 pixels/mm with 12 bits accuracy and 3 partial zones with 350*200 pixels were extracted from each

of the right and the left lung area. They correspond to the upper, the middle, and the lower lung zones. That is, 6 partial zones were extracted from one standard film. It is known that no pneumoconiosis opacities can be recognized in the lower lung area for two ILO standard films 1/1 q/q and 1/1 r/r, and four zonal images extracted from those areas were excluded from the experimental materials. Therefore, the number of zonal images used for automatic diagnosis was 62. Parameter values adopted in the following experiments were as follows.

h_s = 5 pixels,

h_p = 3200,

h_d = 500.

Verification of Opacity Detection Algorithm

Pneumoconiosis opacities identified by an expert reader and those detected by the proposed method were compared to each other. The test material was the upper half of the left lung area of the film 3/3 r/r. The number of pneumoconiosis opacities identified by an expert reader[*]) and that detected by the proposed method were 120 and 109, respectively. Among them, 66 opacities coincide with each other.

Classification Experiments

A. Features

In spite of the application of noise reduction in twice, noise opacities cannot be excluded completely. Therefore, it is necessary to extract information on the opacity density as much as possible, and the following 14 kinds of features were used for classification.

1. The numbers of opacities x_1, x_2, x_3 for which the convex surface detection filter outputs are 1, 2, and 3, respectively.

2. The numbers of opacities purged from x_1, x_2, and x_3 by the first noise reduction x_4, x_5 and x_6.

3. The sums of area for each opacity size x_7, x_8, x_9.

4. The number of opacities x_{10} and the total sum opacity area x_{11}.

5. The numbers of opacities for each size x_{12}, x_{13}, x_{14}.

The feature parameters $x_{10},..., x_{14}$ can be derived from the other parameters. However, the use of these dependent features were useful for classification.

Table I

Experimental Materials

major category	ILO 1980 standard film
0	0/0 X 2
1	1/1 p/p, 1/1 q/q, 1/1 r/r
2	2/2 p/p, 2/2 q/q, 2/2 r/r
3	3/3 p/p, 3/3 q/q, 3/3 r/r

B. Classification Method

Defining fourteen-dimensional feature vector $x^t = (x_1, x_2, ..., x_{14})$, distance of an input image from a category k is defined as follows:

$$d(k) = \| x - r_k \|$$

where, r_k is the reference pattern vector of category k. It is defined as the mean of feature vectors of the category k. The computer diagnostic testing procedure was one-at-a-time removal test procedure. That is, it consisted of removing one sample from 62 partial zones, training on the remaining 61 samples, and resubmitting the withdrawn sample for reclassification.

C. Classification Results

Results for four major category classifications are given in Table II. Zonal correct classification rate is 69.4 percent. If we adopt a majority rule for overall film classification, it is perfect. Classification rates reported hitherto range between 50 and 80 percent, which have been attained all by texture analysis approaches.

Table II

Confusion Matrix for 4 Major Category Classifications

| | | assigned category | | | |
		0	1	2	3
input	0	6	1	3	2
category	1	1	12	1	0
	2	0	2	14	2
	3	5	1	1	11

The second experiment is the classification of ILO substandard films. Seven substandard films were used, which consist of two normal, two 2/2 and three 3/2 films. Zonal images with the same size were used for classification. Reference patterns were defined by using all zonal images of ILO standard films. Normal/abnormal classification results is shown in Table III. Correct classification rate was 83 percent, which shows the effectiveness of the proposed method.

CONCLUSION

Identification method of pneumoconiosis opacities and classification based on it have been given. The proposed method is not sensitive to the changes of film quality, which is superior to texture analytic approaches. And the correct classification rate by the proposed method has been shown to be comparable to them. However, many false opacities are detected as pneumoconiosis opacities, and the further improvement of the method is necessary.

Table III

Confusion Matrix for Normal/Abnormal Classification

| | | assigned category | |
		N	A
input	N	6	6
category	A	1	29

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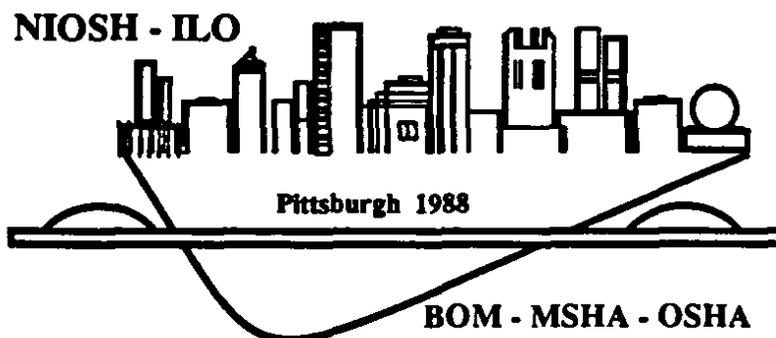
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