MEASUREMENT OF ROUNDED OPACITIES IN THE LUNG OF X-RAY IMAGES TOWARDS QUANTITATIVE DIAGNOSIS OF PNEUMOCONIOSIS

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INTRODUCTION

From a clinical and occupational health viewpoint, the classification of pneumoconiosis films is of primary importance. The category of profusion used for recording the severity of the pneumoconiosis is based on assessment of the concentration of opacities by comparison with standard pneumoconiosis films whose profusions are given by a four-point scale: categories 0, 1, 2 and 3.[1] However, in practical radiographical diagnosis, objective reading is very difficult even to the experienced readers. It is a fact that there is considerable variation in reading the same film, not only by different readers, but also by the same reader at different times. Therefore, it has been strongly desired to develop an automated measurement method for quantitative diagnosis of pneumoconiosis X-ray films.

In most of previous studies on automated classification of pneumoconiosis films, the approach is to examine some kinds of texture features measured from X-ray images by regarding the opacity distribution as a texture pattern.[2-6] In such approach, however, it is difficult to avoid the influence of rib images and vessel shadows in chest X-ray images, and impossible to introduce necessary diagnosing experiences of medical experts into computer diagnosis process.

Since the advent of the more sophisticated digitization system in recent years which can provide high-resolution digital images, it has been possible to directly detect some kinds of very detailed objects in a chest X-ray film by computer, such as blood vessels, cancer lesions and pneumoconiosis small opacities. In this paper a new method for automated classification of pneumoconiosis chest X-ray films is presented, in which individual small rounded opacities are recognized, and the measured density of them is used as a classification feature. In experiments using ILO standard pneumoconiosis films, it is shown that density values of the small rounded opacities detected by this method are approximately proportional to the categories of profusion of pneumoconiosis. Moreover, the individual opacities detected by our system are compared with those by experienced radiologists to evaluate accuracy in opacity recognition. From the result, we see that not only the density values will be available as one of the effective features for computer diagnosis of pneumoconiosis, but also the detected small rounded opacities may be provided to the readers as reference data, and they are useful in training readers of pneumoconiosis films.

OUTLINE OF THE PROCEDURE

The processing procedure consists of the following three steps. First, the small rounded opacities in an input image are enhanced by a linear filter with a weight function designed based on a model of the small rounded opacity, then candidates of the opacities are obtained as a connected component pattern by thresholding the filtered image. Second, components due to shadows of ribs and vessels are removed by using a shape feature of a connected component to detect only objects suspected to be caused by the small rounded opacities. Third, the film is categorized according to the opacity density which is given by the ratio of the area or the number of the extracted opacities to the area of the lung region.

DETAILS OF THE PROCEDURE

Extraction of Opacity Candidates

Uniform weighted smoothing is used to suppress the random noise which is introduced in the processes of image generation and image digitization. Namely, it gives each point the average gray level of its neighboring points and the point itself.

The small rounded opacities are appearing or even overlapping with many kinds of other shadows such as ribs and blood vessels in a chest X-ray image. A linear differentiation filter is employed to enhance the opacities, in which a weight function is designed based on the local distribution of gray levels of the opacities. We see that the gray levels at a small rounded opacity in an input image are lower than those of the surrounding background. Each of the opacities is observed as a spot-like object with a circular border, whose gray level distribution inside the border is like a bowl shown in Figure 1(a), although its shape is likely to be more complicated. Therefore, a basic model of the weight function designed here is as shown in Figure 1(b), in which, every point on the circle with the radius Rl has the value 1, points in the central area with the radius R2 have negative values distributing as a bowl, and others are zero. The operation with this mask is a type of the 2nd order differentiation, and can enhance the bodies of the opacities against the background whose brightness may be variant according to the zone of the lung. Figure 1(c) shows a weight function practically used in the experiments.

The candidate regions of the small rounded opacities are ob-

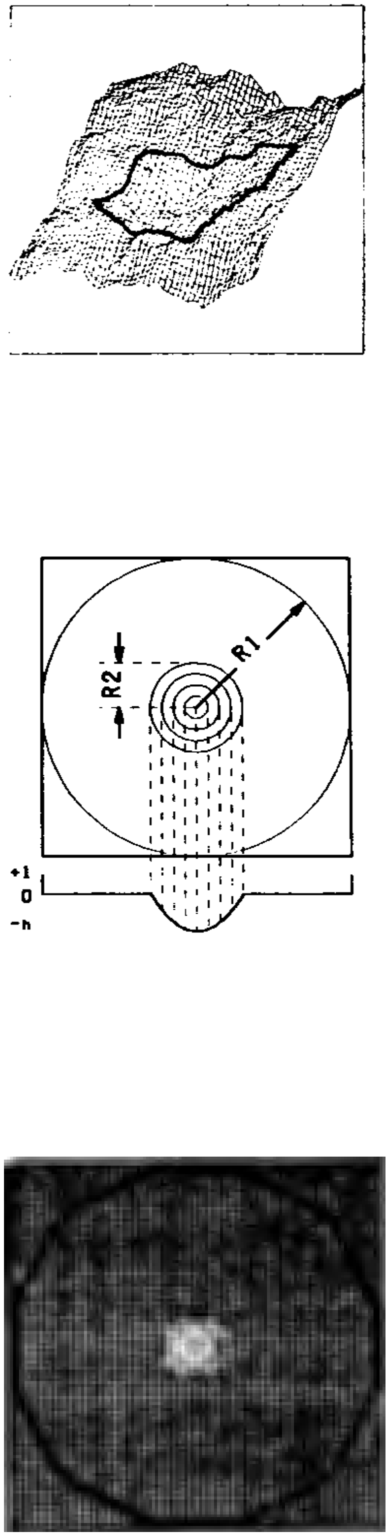

Figure 1. Small rounded opacity and weight function. (a) Local level distribution of an opacity and its neighborhood. (b) Weight function model. (c) Weight function used in the experiments.

tained by clipping the enhanced image with a pre-specified threshold. That is, values of pixels in the filtered image are changed into 0 if they are less than the threshold, then the remaining connected components are regarded as the candidate regions.

Recognition of Opacities

The candidate regions obtained above usually include many components caused by rib images and vessel shadows. Considering that the small rounded opacities should assumedly be isolated and be circular, and that the elongated regions may be generated by rib borders, the opacities can be extracted from the candidate regions by removing those components whose horizontal lengths are longer than a given value.

Furthermore, local maximum points of the enhanced image are detected in each of remaining regions to find the number and the location of the small rounded opacities. The operation is shown by the following equation:

where $\{f_{ij}\}$ and $\{g_{ij}\}$ are the input image (clipped enhanced image) and the output image (maximum point pattern), respectively, and N_{ij} is a local neighborhood region of the point (i,j). When the above operation is done at a considerably smooth area in the enhanced image, the extracted maximum points may construct a connected component by themselves. Every such component is shrunk into a single point.

Density Calculation and Categorization

The 1980 ILO Classification states that classification of a radiograph for profusion of small opacities requires a mental process of integrating profusion over the affected zones.[1] However, in order to classify the pneumoconiosis films automatically, it is necessary to set up some objective measurements for evaluating the profusion of pneumoconiosis films. Here, a density of opacities is used as the measurement, which is defined as the ratio of the area or the number of the extracted opacities to the entire observed area in the lung region. The area of opacities is calculated by the total number of pixels of the opacities recognized from the candidate regions, while the number of opacities is specified as the number of the maximum points. The observed area is the area of processed lung region after removing the area of the components caused by rib borders. Finally, the chest X-rays are categorized according to the density values.

EXPERIMENTAL RESULTS AND DISCUSSION

Eleven chest X-ray images selected from a set of international standard pneumoconiosis radiographs which was accompanied with the 1980 ILO Classification were used in the experiments. They include nine pneumoconiosis films containing three categories (1, 2 and 3) of each of three sizes (p, q, and r) and two films with category 0. Each film was digitized into 3300×3400 pixels with 12 bits of gray level. Some of them are shown in Figure 2.

Since profusion relates better than size to indices of exposure within any one occupational group,[1] a family of the linear filters matched to the size of small rounded opacities were employed in the enhancement step. The value of the parameters (R1, R2) in the enhancement filter are (2, 10), (3, 20) and (4, 25) for the size p, q, and r, respectively. An example of candidate regions extracted from a film (category 3, size r) is shown in Figure 3. The opacities recognized from it are shown in Figure 4, while the maximum points detected from its enhanced image are shown in Figure 5, where gray values of the enhanced image are drawn in terms of contour lines and the location of each maximum point is represented by a circle with the radius proportional to the corresponding maximum value of the enhanced image. Figure 6 shows those maximum points superimposed by the circles on the corresponding original image. The opacity densities (vertical axis) calculated from each category of films (horizontal axis) are shown in Figure 7. From the results, it is known that the difference of the density between the category 3 and the category 2, or between the category 2 and the category 1 is relatively large, while it is difficult to distinguish the category 1 and category 0 decisively. A reason of this difficulty is that as the size (or the number) of the opacities become smaller, the extraction results will be more likely to be influenced by the blood vessel shadows.

In order to evaluate the accuracy of small rounded opacities detected by computer, they were compared with the opacities traced by experienced radiologists. The following procedure was employed in this tracing experiment. First an image to be

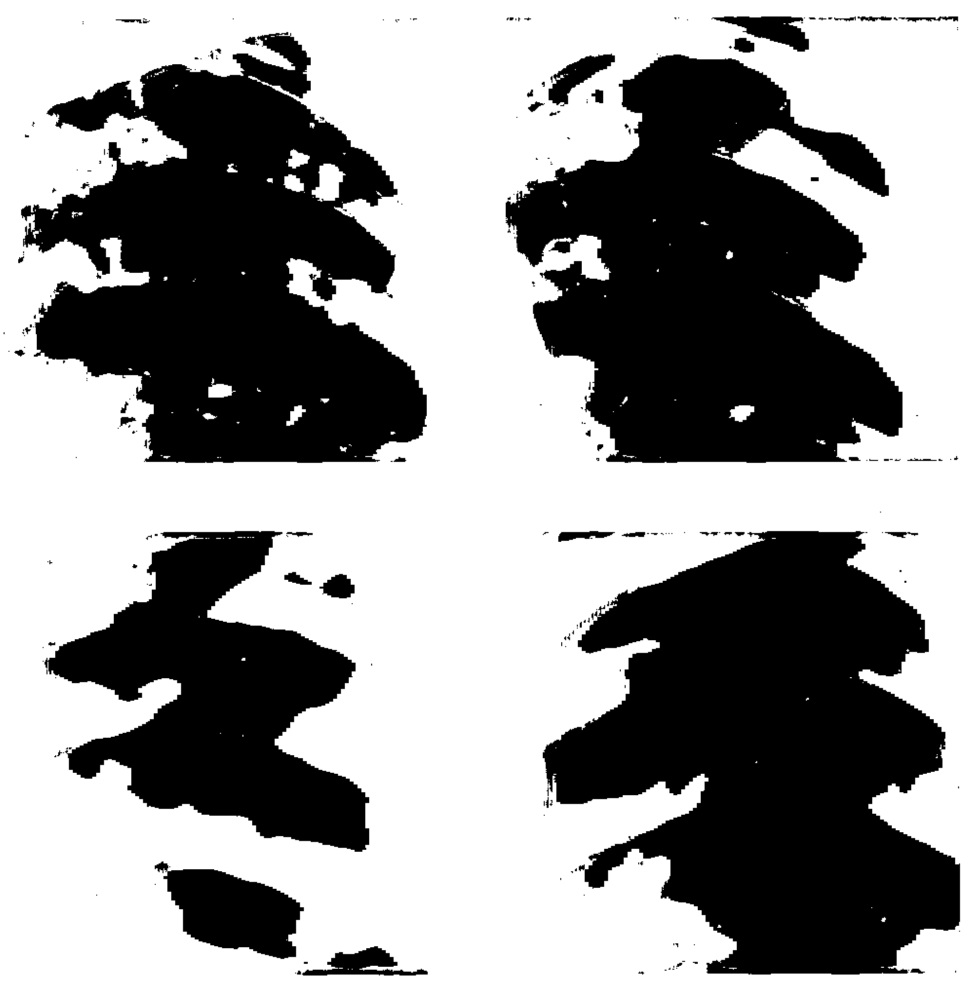

Figure 2. Examples of images used in the experiments cut from a set of international standard films by ILO. (a) (3/3,r/r). (b) (2/2,r/r). (c) (1/1,r/r). (d) normal.

traced is displayed on a high-resolution screen. Then, radiologists trace the small rounded opacities within the area specified by the same radiologists by using an interactive input device. On the screen, the traced opacities and the observed area are displayed by spots at the central position of them and a closed curve, respectively. Meanwhile, the location information of them is stored in the memory and used in the comparison. In Figure 8, each opacity traced by a radiologist is represented by a spot, and that extracted by computer is shown by a circle on the original image. Both results were compared only in the inter-rib regions of the image. Summary of the result is given in Figure 9.

Figure 3. An example of extracted candidate regions of the small rounded pneumoconiosis opacities. (category 3, size r)

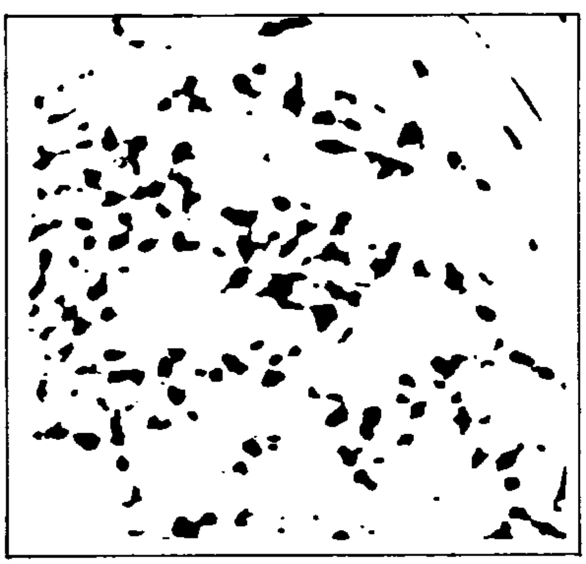

Figure 4. Extracted small rounded pneumoconiosis opacities.

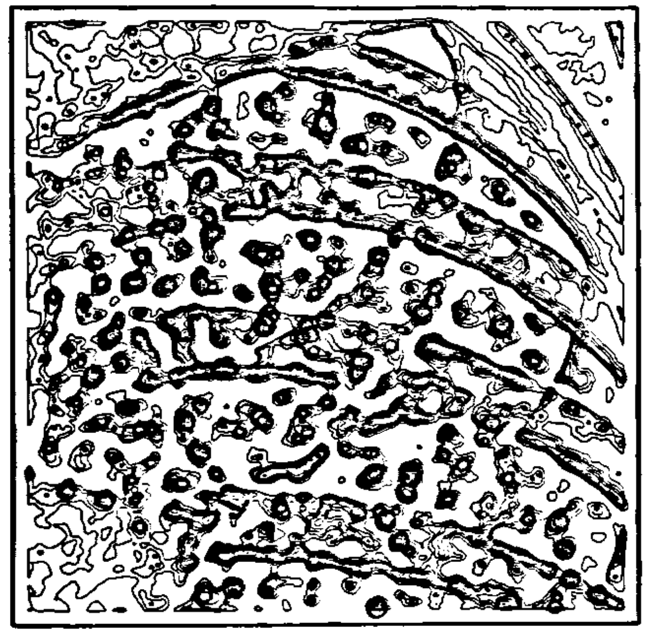

Figure 5. Maximum points of the enhanced image extracted from each of small rounded opacities.

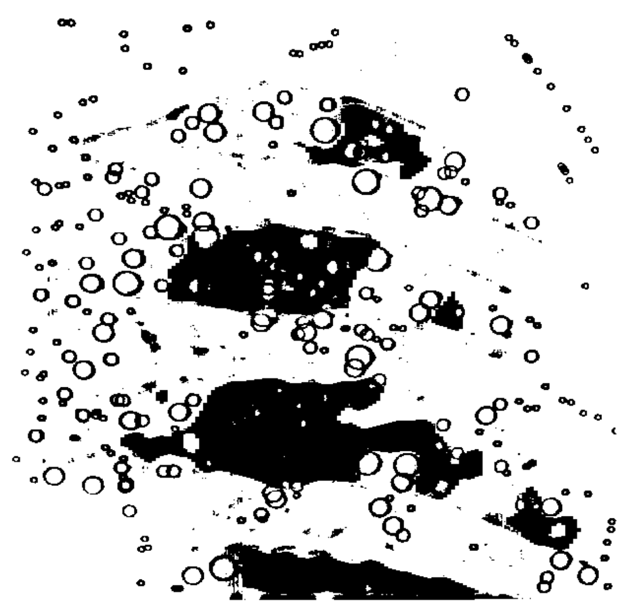

Figure 6. Extracted maximum points superimposed on original image.

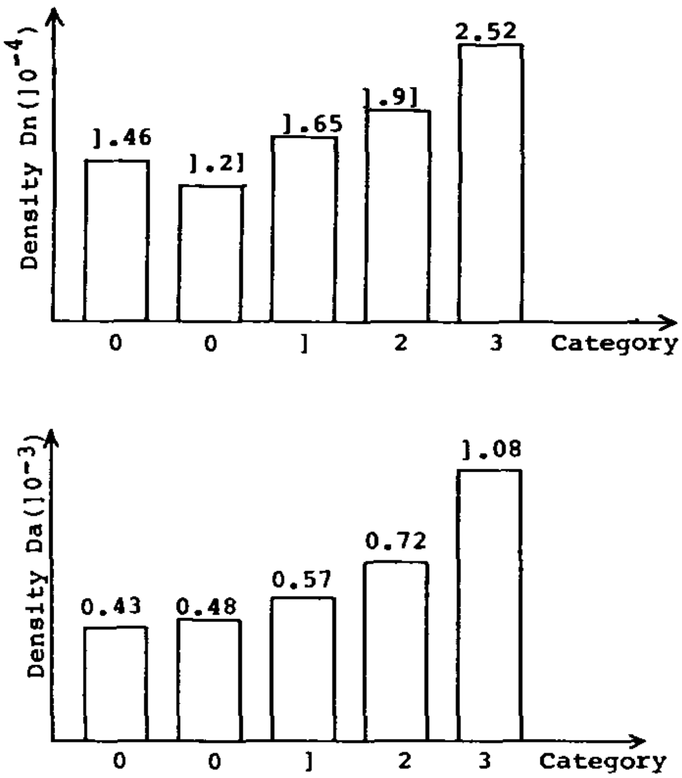

Figure 7. Density of opacities calculated from ILO standard films. (a) Area density. (b) Number density. (size r)

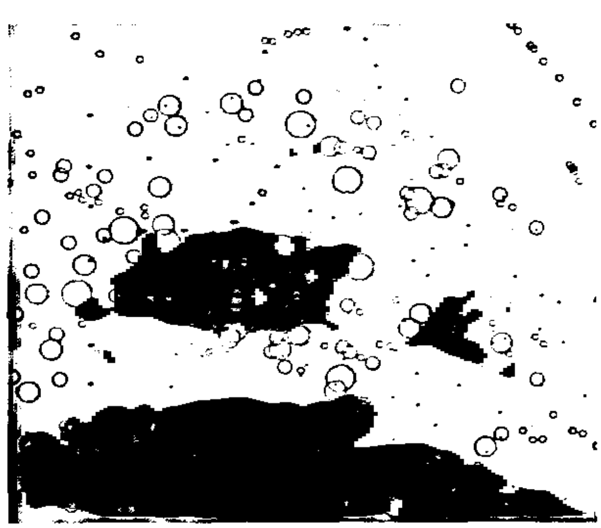

Figure 8. An example of small rounded opacities extracted by an experienced radiologist, and those by computer in the same original image. (category r, size r)

The extraction procedure of small rounded opacities described in this paper was also applied to the pneumoconiosis images obtained by the Fuji computed radiography system. Figure 10 shows both results by computer and radiologists on the original image, and the notation is the same as that used in Figure 8. The results showed that the procedure was also effective to computed radiography image.

CONCLUSION

A method to detect pneumoconiosis small rounded opacities and to evaluate their densities was proposed for automatic categorization of the profusion. It was shown by experiments using ILO standard pneumoconiosis films and the computed

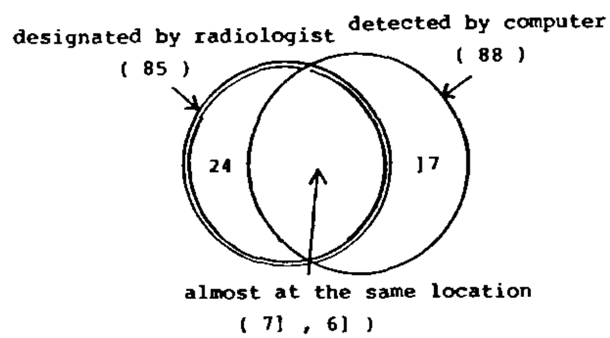

Figure 9. Result of comparison between the opacities extracted by experienced radiologist, and those by computer (Figure 8).

Figure 10. An example of small rounded opacities extracted by experienced radiologists, and those by computer on a film obtained by the Fuji computed radiography system. (category 3, size q)

radiography images that the opacity density measured by the proposed procedure was approximately proportional to the categories of profusion of pneumoconiosis. To improve the system performance, it is necessary to develop a procedure to recognize blood vessel shadows more correctly.

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