New Image Processing Models for Opacity Image Analysis in Chest Radiographs

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Abstract

The aim of this research is to develop new image processing models that can be used to characterize single opacities and opacity density within pre-selected regions of interest (ROI). We derive our new image processing models based on the International Labor Organization (ILO) standard for assessing opacity shape and profusion. Pattern Spectrum analysis is used for opacity shape and profusion measurements. Opacity enhancement is done using a novel AM-FM model. We use radial pattern spectra to detect the presence of opacities within the ROIs, and measure opacity density. The opacity shape and profusion measurement results compare favorably with the ILO standards. The AM-FM model appears to be well-suited for single opacity enhancement.

1. Introduction

Opacity detection refers to the presence of foreign particles in the lung that can cause serious health hazards to the miners. Accumulation of these lead to a condition called Pneumoconiosis, a lung disease caused by the inhalation of dust particles. The International Labor Organization has established a protocol to score the degree of profusion (opacity distribution), size and shape of opacities observed in chest radiographs associated with medical conditions like Pneumoconiosis [1,2].

The profusion is classified into 4 categories ranging from '0' to '3' with '0' being the normal and '3' being the most abnormal case. There are two types of shapes recognized as 'regular' and 'irregular' opacities. The regular or rounded opacities have their sizes classified into three types: 'p', 'q' and 'r'. The irregular opacities are divided into types: 's','t' and 'u'.

In the following discussion, a study of the opacity distribution is made on 2 cases, namely 'q' and 'u'. The regular opacities 'q' are measured using a circular structuring element and the irregular cases 'u' with directional line elements. The difference in the profusion and lung congestion can be clearly seen in the figures 1(a), 1(b), and 1(c), going from a normal to an abnormal condition, respectively.

Manual measurement of individual opacities is extremely time consuming. Hence it is important to develop accurate models that can provide reliable measurements of opacity shape, size, and density. The primary focus of our study is to develop an image representation for detecting, enhancing, and segmenting individual opacities, but also to help assess opacity density over regions of interest.

To characterize opacity density, we use a radial pattern spectrum distribution based on a structural element that is representative of the opacity [5]. For circularly symmetric opacities such as for types p, q, and r, we use a structural element that is also circularly symmetric. For irregular opacities such as for types s, t, and u, lines, orientated at different angles are used. The directional elements can be used to measure directional variations associated with the irregular opacities.

An AM-FM model is used for modeling single opacities and for image enhancement and detection.

2. Dataset

The radiographs were obtained from the coal or silica dust exposed miners. The X-rays were digitized at a resolution of 12 bits. Two B-certified radiologists classified the opacities. A total of 236 regions of interest (ROIs) (166, 49, and 21 with profusions of category (shape and size) 0, 1(q), and 1(r), respectively) were identified from 74 digitized chest radiographs.

3. Opacity properties

The x-ray database that was used pertained mainly to an interstitial medical condition called

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Pneumoconiosis. It is usually caused by environmental or occupational factors, such as the inhalation of coal dust particles, silica or asbestos dusts and even organic dust particles. Pneumoconiosis that results from irritant dusts may cause increasing breathlessness, coughing, and spitting of blood.

The accumulation of these irritants in the lung, appear in the form of abnormal areas of increased density, called opacity. They are of different types: interstitial and air-space to name a few, that cloud the lung region making it difficult to breathe. The degree of damage and lung congestion determines the opacity characteristics and its profusion, which in turn talks about the density of the distribution.

3.1 ILO specification

The shape and size of opacities is an important factor in opacity classification. The two kinds of shapes identifiable are: rounded and irregular. In both cases three sizes are differentiated.

Rounded opacities are classified into three categories:
p = diameter up to about 1.5 mm
q = diameter exceeding 1.5 mm and up to about 3 mm.
r = diameter exceeding about 3 mm and up to 10 mm.

Irregular opacities are classified into three categories:
s = width up to about 1.5 mm.
t = width exceeding 1.5 mm and up to about 3 mm.
u = width exceeding 3 mm and up to 10 mm.

Large opacities are of size greater than 10 mm in diameter. They vary anywhere between 10 mm to an area occupying the entire upper zone of a lung.

3.2 Profusion

In order to classify profusions into certain categories the radiograph is compared with the standards. According to the ILO Standards Guide the categories are:
Category 0 - Small opacities absent or less profuse that the lower limit of category 1.
Categories 1,2 and 3 - Represent increasing profusion of small opacities as defined by the corresponding standard radiographs.

Out of the four major categories of 0,1,2,3 it is sub-classified to 0/-, 0/0,0/1; 1/0,1/1,1/2; 2/1,2/2,2/3; 3/2,3/3,3/+. Here 0/0 is a category where the radiograph showed no opacitites.0/1 is profusion of category 0 but category 1 was seriously considered. If the absence of opacities is particularly obvious the profusion should be recorded as 0/-. Other categories are also graded the same way. For example 2/1 is profusion of major category 2, but with category 1 having been seriously considered as an alternative. Profusion, which is without serious doubt category 2, that is, near the middle of the major category is classified 2/2.

4. Methods

The two basic issues addressed in this section are Opacity Detection and ROI analysis. The Pattern Spectrum is used for analyzing the properties of the ROIs and the AM-FM model is used to detect and enhance single opacities.

4.1 ROI Analysis

The Pattern Spectrum of an image is obtained from what is known as the grayscale discrete size transform (DST) [5,7]. For a grayscale image its discrete size transform is defined

$$f \Downarrow (\ldots, d_{4k}(f;B), \ldots d_{41}(f;B), d_0(f;B), \ldots. \; d_1(f;B), \ldots, d_k(f;B), \ldots)$$

where,

$$d_k(f;B) \mid \begin{cases} fokB \; 4 \; fo(k \; 2 \; 1)B, k \varnothing 0 \\ f \notin |k| B \; 4 \; f \notin (|k| \; 4 \; 1)B, k \; \Omega 0 \end{cases}$$

The grayscale DST is a multi-resolution image decomposition scheme, which decomposes an image f into residual images f O kB – f O $(k+1)B$ and $f \not\in |k| B$ - $f \not\in |k \; 2 \; 1| B$ obtained by successive approximations of f by means of structural openings and closings. The pattern spectrum of a grayscale image f, in terms of a structuring element B, is given by:

$$P_{f;B}(k) \mid \|d_k(f;B)\| \mid \begin{cases} \|fokB \; 4 \; fo(k \; 2 \; 1)B\|, k \varnothing 0 \\ \|f \notin |k| B \; 4 \; f \notin (|k| \; 4 \; 1)B\|, k \; \Omega 0 \end{cases}$$

where,

$$\|f\| \mid \sum_{x,y} |f(x,y)|; k \varnothing 0 (only)$$

The pattern spectrum is the 'magnitude' of the DST. Only the non-negative values are considered.

Circular structuring elements were used to obtain the pattern spectrum of regular opacities. For irregular opacities, we used lines as the structuring elements. The graded opacities were measured with the resolution of 6 pixels for 0.5 mm. On this basis, the structuring elements had a constant length of 6 and the radial pattern spectrum was calculated for every 5∀, ranging from 0∀to 180∀.

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4.2 Single Opacity Detection

A new model for single opacity characterization is demonstrated in Figures 4 and 5. The new AM-FM model is used for modeling image intensity over background regions as given by [3,4]: $I(x,y) = a(x,y)\cos\lambda(x,y)$. The amplitude function $a(x,y)$ is used for representing the strong brightness over the opacity region, while it drops to small values over the background (Figures 4(a), 5(a)). The phase signal $\lambda(x,y)$ is used for representing the strong intensity variation in the background, and the reduced variation over the opacity region (Figures 4(b), (c), and 5(b)). Methods for estimating the AM-FM parameters can be found in [4] and have been omitted in this paper.

5. Results

The pattern spectra results are shown in Figures 2 and 3, while the AM-FM results on single opacity enhancement are given in Figure 5. Figure 2 shows the results of computing the pattern spectrum with a '+' structural element, while Figure 3 shows radial pattern spectra results using a linear element that is 6 pixels long, and rotated every 5°, ranging from 0° to 180°.

The pattern spectra results agree with the ILO specification. For the q-2 opacities in the ROI in Figure 2(a), the pattern spectrum is shown in 2(c) for the image region that does not contain any rib structures; as shown in Figure 2(b). A sharp peak in pattern spectrum is characteristic of the density associated with type 2 profusion. For irregular opacities, there are clearly defined preferred directions in Figures 2(b), and 2(c) as compared to the normal radial pattern spectrum of Figure 2(a). The concentrated peaks in 2(b) correspond to u-1 opacities, and clearly become more pointed in the more advanced opacities demonstrated in Fifure 2(c). The measured opacity density agrees with the classification by the B readers.

For the AM-FM model, the results are summarized in the Figure captions of Figures 4 and 5. Overall, the estimated AM-FM parameters show good agreement with the ideal model. The estimated instantaneous frequency magnitude is low over the opacity region while it maintains high values over the background pixels. Similarly, the instantaneous frequency magnitude is relatively low over the rib edges that resemble opacities (Figure 5(c)).

6. Conclusions and Future work

The AM-FM model has shown great promise for characterizing individual opacities. The regular Pattern Spectrum and the radial pattern spectrum provide an automatic method for measuring opacity density, and the results indicate good agreement with the ILO standards. The next step towards opacity detection would be the use of a Bayesian system for analysis from the pattern spectrum of an image. Better enhancement could be obtained by combing the pattern spectrum and AM-FM approaches, feeding the output from the AM-FM model to a pattern spectrum analysis model.

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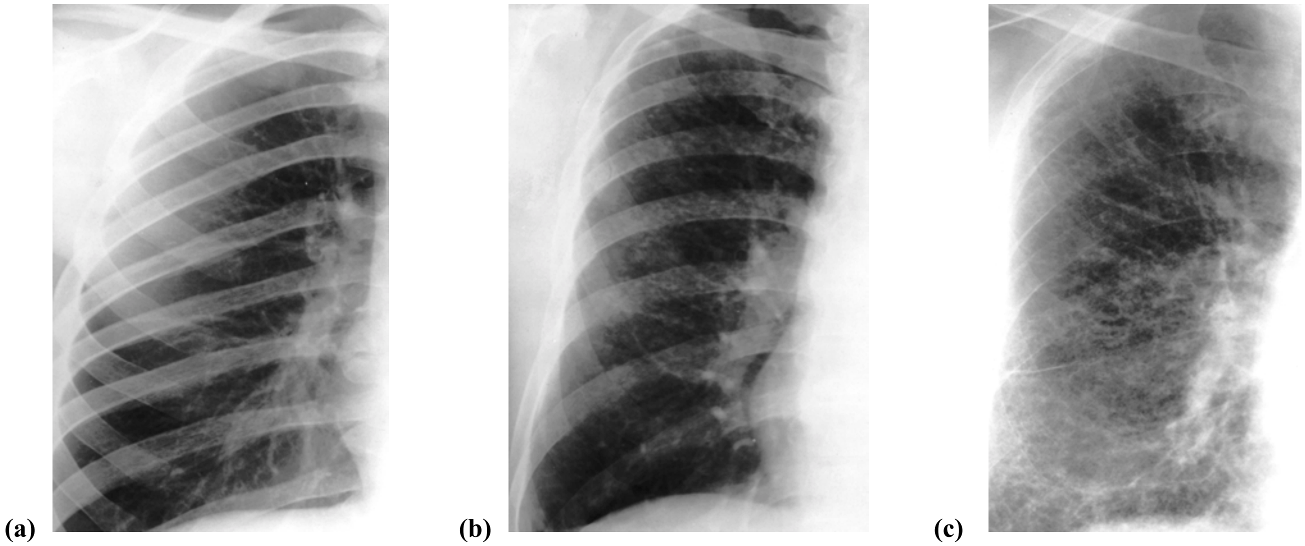

Figure 1. The figures show a small portion of the right lung for each case. 1(a) is a normal lung with no opacities, 1(b) is an example of a 'u' which has a 'an opacity distribution of u/u and a profusion of type 1/1' which is close to being normal but with the presence of irregular opacities sporadically scattered in the lung. 1(c) is also of the category 'u/u', but with a greater profusion level of '2/2'. As it is clear from the picture, the opacities are clustered and the degree of the spread is much higher in this case.

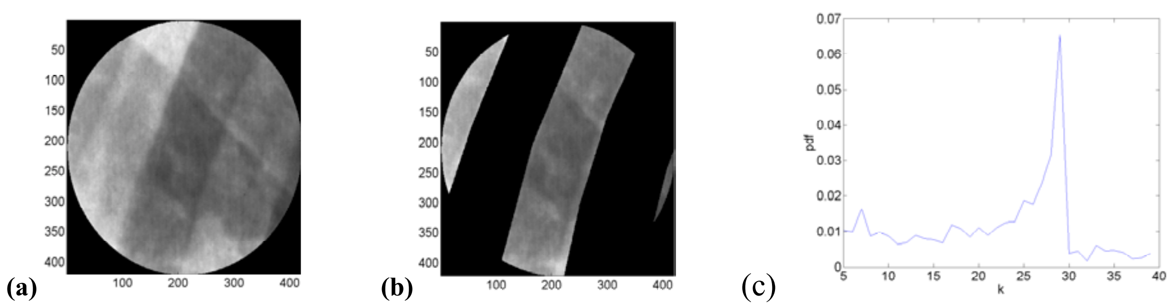

Figure 2. Morphology results. Two regions of interest are shown in 2(a) and 2(d). For the probability density functions, the parenchyma regions shown in 2(b) and 2(e) were used. Since both were classified as type q-2, the ILO standard specifies high perfusion opacities of diameter between 1.5 and 3.0mm. High perfusion is clearly detected in the peaks in Figures 2(c) and 2(f). Furthermore, given that the images were scanned at 300dpi, the opacity size is correctly detected to be between 18 and 36 pixels (for 1.5 and 3.0mm).

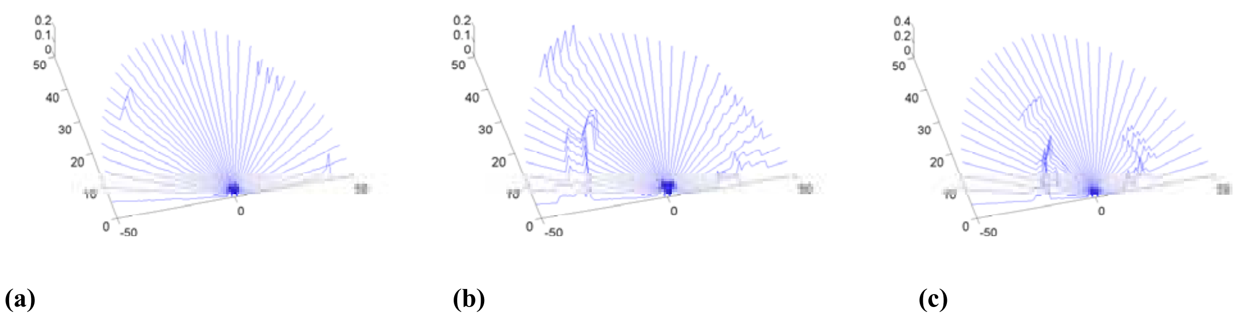

Figure 3. Shows the radial pattern spectra for a normal, u-1, and u-2 ROIs. The structural element used is a linear element of 6 pixels long (0.5 mm).

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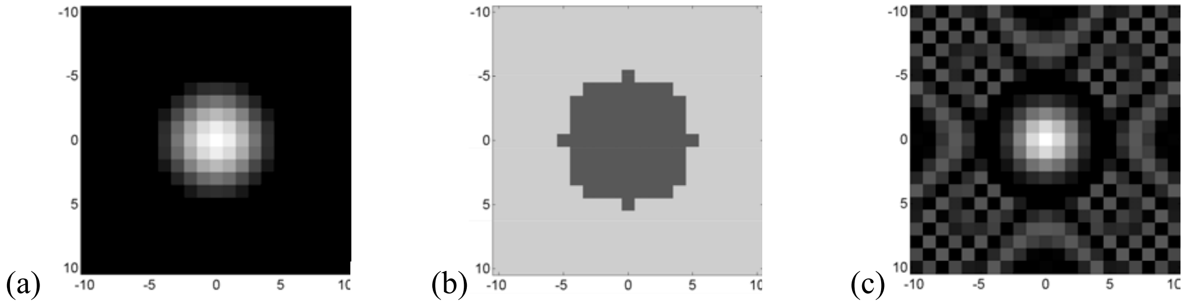

Figure 4. AM-FM image model for circularly symmetric opacities. In all cases, all AM-FM parameters are a function of radial distance from the center of the image. In 4(a), we have the amplitude model, and in 4(b), we have the instantaneous frequency magnitude. The corresponding AM-FM model is shown in 4(c).

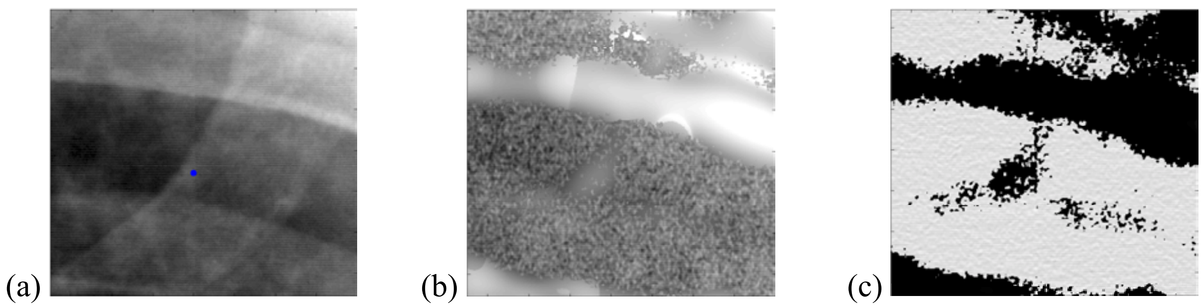

Figure 5. AM-FM results. Original image region with identified opacity in the central part of the image only (indicated by dot in the center). Estimated image amplitude in 5(b) and estimated instantaneous frequency magnitude shown in 5(c). In 5(b) and 5(c), the log of the AM-FM is used for display purposes. Note the strong agreement with the model in Figures 1 and 2.

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