IMAGE QUALITY EVALUATION FOR RADIATION DOSE OPTIMIZATION IN CR BY SHAPE AND WAVELET ANALYSES

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ABSTRACT

It is one of the primary responsibilities of any department of diagnostic radiology to minimize the amount of unnecessary radiation administered to patients during diagnostic procedure. In this paper, we present three effective ways of quantifying the information content of computed radiography (CR) images for radiation dose optimization through shape and wavelet analyses. The experimental results demonstrate that the shape and wavelet analyses can be efficiently used to determine an optimum radiation dosage in computed radiography.

1 INTRODUCTION

Computed Radiography (CR) may replace screen-film radiography (SFR) because of its ability to limit radiation exposure [8]. In fact, CR has demonstrated its advantages over conventional radiography including greater dynamic range, wider exposure latitude digital image enhancement, improved accessibility of images to clinicians, and more reliable image retrieval. However, it is necessary to demonstrate that CR is at least as effective as SFR in clinical applications using optimized radiation dosage. In this study, we develop an image quality evaluation method for dose reduction by image analysis techniques, specifically by shape and wavelet analyses.

Although there exist many methods of evaluating image quality, ROC analysis is the most credible and acceptable way to measure the image quality by the radiology. Statistical analysis is another promising evaluation method that performs clinical simulations and direct analysis on diagnosis accuracy [3]. However, these two methods are very expensive to perform. A binary detection based task-oriented assessment of image quality is advocated by H. Barrett [1], which is attractive for its simplicity and the fact that it also takes the purpose of the image into full consideration. We believe that this task-oriented approach is an important starting point to develop meaningful methods for image quality evaluation. After we classified important tasks involved in medical diagnosis and identified segmentation as the most common task performed in medical practice, in [9], we proposed to use segmentation as a tool to evaluate the quality of compressed images.

In this particular dose reduction study, a set of hand-wrist images embedded with some small invading objects are acquired by varying radiation doses. The basic tasks are defined as to detect the invading objects and to extract the anatomical structures for further surgical operations. After identified the basic tasks involved, we propose three effective ways of quantifying the information content of computed radiography images for radiation dose optimization through shape and wavelet analyses.

The paper is organized as follows. Section 2 describes the image analysis methods – shape and wavelet analyses. In section 3, we present image quality evaluation methods to quantify the information differences among images acquired with various radiation dosages. Section 4 gives the experimental results, and section 5 presents the conclusions.

2 SHAPE AND WAVELET ANALYSES

To accomplish the basic tasks of detection of the invading objects and the extraction of the anatomical structures, we first use morphological filters to detect the invading objects, and then use active contour models (snakes) to modify the contours of the invading objects. Then, a sophisticated segmentation method, based on integration of region growing and edge detection, is applied to extract the anatomical structures of bones. Furthermore, to locate the major effect of reduction in radiation dosage, we use wavelet filters to decompose the images into a set of multiscale channels to assess the major information lost by comparison. Next, we describe each method.

2.1 Shape analysis

Morphological filters are used to detect the invading objects, which allow us to suppress the background while retaining size and location information [2], [5]. Features brighter than the background, but smaller than the structuring element, can be removed from an image with the opening operation. Thus, if the features of interest are brighter than the background, opening the image by a structuring element bigger than the largest feature will remove the features from the image leaving behind an estimate of the background. Subtracting the estimate of the background from the original image extracts the features of interest. The background reduction is performed as follows:

$$\text{Background reduction} = \mathbf{A} - (\mathbf{A} \circ \mathbf{B}), \tag{1}$$

where $\mathbf{A}$ is the original image, $\mathbf{B}$ is the structuring element whose size is larger than any of the brighter features of interest, and "$\circ$" is the gray-scale opening operation. The location of the extracted features will be exactly the same as those in the original image. In gray-scale morphology, the structuring element can be any three-dimensional structure such as cylinder and hemisphere. A binary opening operation is then applied to specifically extract the invading objects.

Next, the deformable contour models, snakes, are used to modify the contours of the invading objects [6]. In this approach, by modeling the initial contour extracted by morphological filters as a physical object called an active contour, and the data as an external force to which the object is attracted, an iterative procedure is initiated to cause the active contour to move toward the data and ultimately conform to it. A fast algorithm for active contours can be found in [11].

2.2 Segmentation

In order to extract the anatomical structures of the hand-wrist images accurately, we apply a segmentation method that integrates region growing and edge detection for a meaningful segmentation result [10]. Starting with a simple region growing method, we use a highly reliable merge score in terms of region similarity, size constraint and connectivity measure. The edge information is then integrated to verify and, where necessary, to correct region boundaries, which yields more reliable and meaningful segmentation results. In particular, we use edge information to serve two purposes: (1) to eliminate false boundaries and (2) to modify the contours (see [10] for details).

2.3 Wavelet Analysis

To locate the major effect of reduction in radiation dosage, the images are decomposed into a set of multiscale channels. Because of their good space/frequency localization property, wavelet filters are employed for this task [4], [7]. The wavelet transform decomposes a signal into a set of orthogonal components describing the signal's variations across scales. Specifically, the discrete wavelet transform pair can be written in the following matrix form:

$$\mathbf{f} = \mathbf{W}^T\mathbf{d}, \tag{2}$$

$$\mathbf{d} = \mathbf{W}\mathbf{f}, \tag{3}$$

where $\mathbf{f}$ is the image vector, $\mathbf{W}$ is the orthogonal wavelet transformation matrix, and $\mathbf{d}$ is the wavelet coefficient vector.

Rather than defining the transform matrix $\mathbf{W}$ explicitly, it is much easier to describe the underlying decomposition algorithm, which uses two complementary filters h and g. The low-pass filter satisfies the so-called quadrature mirror filter (QMF) conditions:

$$|H(\omega)|^2 + |H(\omega+\pi)|^2 = 1, \tag{4}$$

$$H(0) = 1 \Leftrightarrow H(\pi) = 0, \tag{5}$$

where $H(\omega)$ is the Fourier transform of h. The high-pass filter g is the modulated version of h given by

$$g(k) = (-1)^k h(1-k). \tag{6}$$

The wavelet decomposition is implemented iteratively by successive filtering and decimation using the QMF filterbank described above [7].

3 IMAGE QUALITY EVALUATION FOR DOSE OPTIMIZATION

In this section, we concentrate on how to use the results obtained by image analysis methods to evaluate the image quality. The low-level measures, mean-square error (MSE) and signal-to-noise ratio (SNR), are two reasonable indicators of relative visual distortion for most types of images, but they can not take into account the purpose and context of images. The task-oriented evaluation approach takes the purposes of images into full consideration. After defining the basic tasks as detecting the invading objects and extracting the anatomical structures of the hand-wrist radiographic images, we propose to use shape and wavelet analyses to evaluate the quality of images acquired by varying radiation dosages.

For the task of detecting the invading objects, we first focus on the detectability of various materials, sizes, and shapes. Then we further compare the shape information of the detected invading objects by the misclassification measure, which is defined as

$$\text{Percentage of misclassifications} = \frac{\text{number of misclassified pixels}}{\text{total number of pixels}}. \tag{7}$$

The percentage of misclassifications is also used to quantify the segmented anatomical structures of the bones for its simplicity. To locate the effect of dose reduction, we examine the wavelet multiscale/multichannel representations. The MSE of each channel compared to the best image (the maximum available dose image) can be used to indicate the loss of information caused by dose reduction.

4 EXPERIMENTAL RESULTS

In this dose reduction study, we have acquired three sets of images of phantoms and cadaver hand specimens embedded with some small invading objects by varying radiation dosages. The invading objects consist of different sizes, shapes, and materials (like plastic, glass, graphite and wood). The radiographic technique of images obtained within each data set varied over range of 45-50kVP and 1-3mAs. Computed images are digitally acquired with a size of 1.7k × 2.0k × 10 bits.

The shape and wavelet analysis methods are applied to the sets of images of various dosages. The invading objects are detected by morphological filters and their shapes are modified by active contour models. The experimental results are shown in Fig. 1. By comparing the detectability of the invading objects in all sets of images, we found that the detectability is independent of size and shape, but heavily dependent of the type of material. The greatest difference is between the plastic and wooden objects. For example, the detectability of plastic objects is about 80% at 45kVP and 1mA, and 85% at 45kVP and 3mA, while the detectability of wooden objects is about 30% at 45kVP and 1mA, and 40% at 45kVP and 3mA. Further, the percentage of misclassifications is calculated for each image with different dosage, which is shown in Fig. 2. As we can see in Fig. 2, most of the misclassifications are due to plastic and wooden objects. The segmentation results are shown in Fig. 3, where the extracted anatomical structures of bones are illustrated for different dose images. Fig. 3 also shows the percentage of misclassifications for the bones of different dosages. As shown in Fig. 2 and Fig. 3, the effect of dose reduction on the bones is less than that on the invading objects.

Finally, we consider the effect of dose reduction on image quality by wavelet analysis. Fig. 4 shows the result of wavelet decomposition into 16 channels. We compute the MSE of the signal in each channel with a reference of the best image that is acquired at 45kVP and 3mA. The MSE comparison is also depicted in Fig 4. It can be easily seen in Fig. 4 that dose reduction affects the high frequency channel significantly and the information in low-pass channel is well preserved.

5 CONCLUSIONS

We have presented a task-oriented image quality evaluation method by shape and wavelet analyses, and applied the method to the radiation dose optimization problem. Shape analysis and segmentation methods can provide us with a good quantitative evaluation means which takes into account the specific diagnostic purposes, while wavelet analysis locates the major information lost by dose reduction effectively. The experimental results show that the shape and wavelet analyses can be efficiently used to determine an optimum radiation dosage in CR. In conclusion, shape and wavelet analyses can provide us efficient quality evaluation methods with reliable performance, and hence can be used to optimize the radiation dosage in computed radiography.

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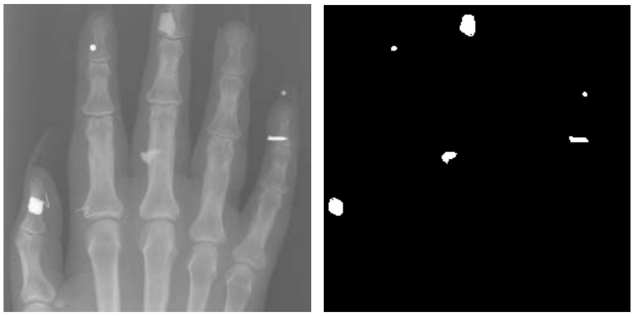

Figure 1: (left) The hand-wrist CR image, (right) detected invading objects.

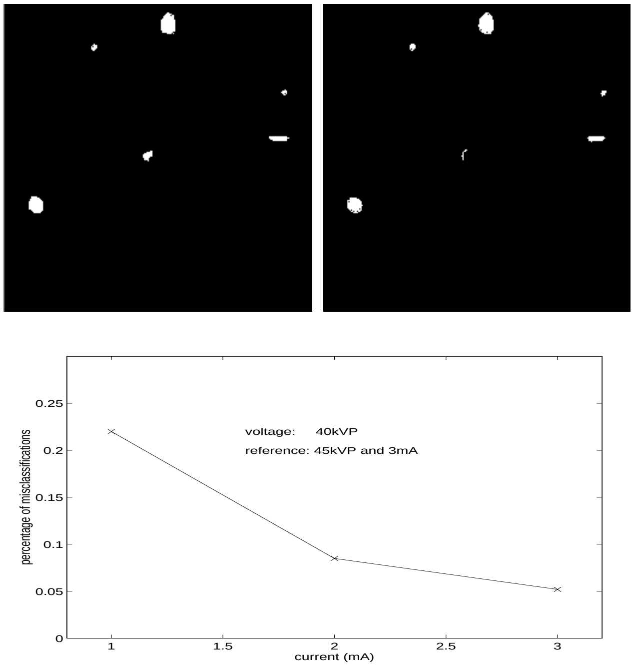

Figure 2: (up left) Detected invading objects at 40kVP and 3mA, (up right) detected invading objects at 40kVP and 1mA, (bottom) percentage of misclassifications of the invading objects.

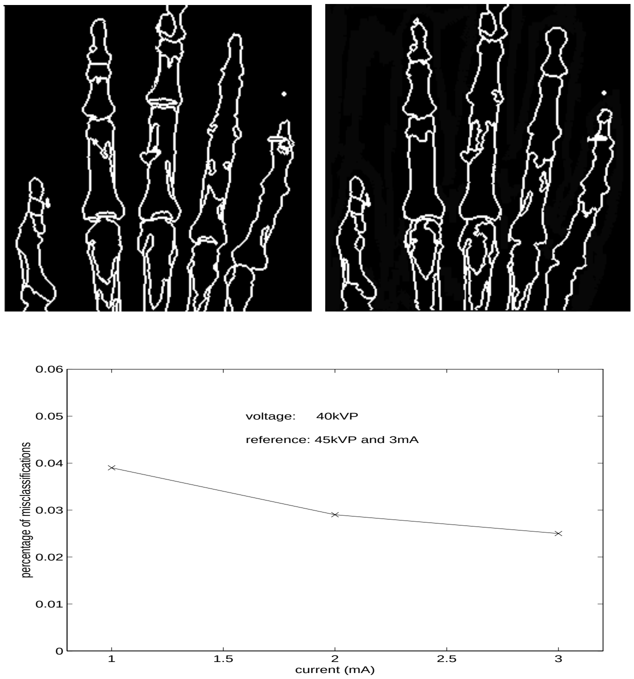

Figure 3: (up left) Segmented bones at 45kVP and 3mA, (up right) segmented bones at 40kVP and 3mA, (bottom) percentage of misclassifications of the bones.

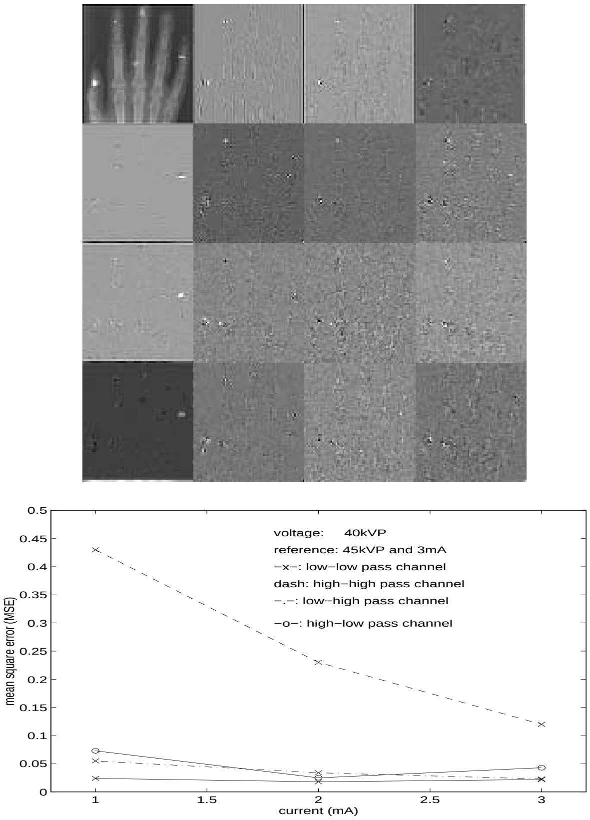

Figure 4: (up) Wavelet transform of the image at 45kVP and 3mA, (bottom) MSE.