Histogram Processing-based Image Enhancement of Digital Radiography for Detection of Cardiac Calcification

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Abstract—**We are investigating histogram processing based image enhancement techniques to improve the ability of digital radiography (DR) for the detection of cardiac calcification. Computed tomography (CT) is an established tool for the diagnosis of coronary artery calcification. Digital radiography could be a cost-effective alternative. In this study, we assume that the DR image intensity values of calcified tissue have a Gaussian distribution. We use multiple Gaussian functions to fit the intensity histogram curve of DR images. Based on the mean and standard deviation parameters, we incorporated the histogram equalization enhancement method for each histogram portion of cardiac calcification. Thus, the calcification image was enhanced exclusively. We used three-dimensional (3D) CT images as the "gold standard" to evaluate the enhanced DR images for calcification detection. We acquired both CT and DR images from patients with coronary artery diseases. Experimental results show that the image enhancement method improved the ability of digital radiography for the detection of cardiac calcification.**

Keywords—**digital radiography, intensity histogram, coronary artery calcification.**

I. Introduction

Cardiovascular disease is the leading cause of death in the United States, responsible for approximately 500,000 deaths per year [1]. More than one millions Americans have heart attacks or angina every year. The increasing incidence of cardiovascular diseases requires a cost-effective, accurate, and noninvasive screening technique for large-scale populations.

The relationship between coronary artery calcification and atherosclerotic heart disease has been well documented [2]. Early detection of cardiac calcification is directly helpful for diagnosing heart diseases. A large body of literature about the detection of cardiac calcification with standard film-screen technology and fluoroscopic techniques exists. Although those techniques have high positive predictive values for the detection of calcium, they have limited sensitivity for the detection of coronary artery disease [3][4][5][6][7]. The enhanced capabilities of electron beam computed tomography (EBCT) and multi-detector computed tomography (MDCT) to detect coronary calcium have established these techniques as potential screening tools for coronary artery disease [8]. Although Computed tomography (CT) is an established tool for detecting cardiac calcification, whether screening the general population with these advanced techniques will be cost-effective is still unclear.

Recently, with advancements in digital radiography and flat-panel technology, digital radiography (DR) has markedly improved imaging of cardiothoracic disease [9]. Dual-energy digital radiography (DEDR) is being evaluated as a potential cost-effective screening tool for the detection of cardiac calcification [10][11][12][13]. Dual-energy subtraction technique can produce a standard image (high kVp image), a subtracted soft-tissues image that removes bone contrast from the underlying soft tissue contrast, and a bone image that displays bone and calcified thoracic structure [14]. The detection of calcified cardiothoracic structures is improved on bone images [15]. In addition to being helpful in the detection of valvular and myocardial calcification, the subtracted bone image is particularly useful in the detection of coronary artery calcification. Encouraged by this progress, we try to use image enhancement technology to extract cardiac calcification information directly from conventional single energy DR image. We believe it will reduce the screening cost and the radiation dose further.

Generally, the image enhancement approaches fall into two broad categories: spatial domain methods and frequency domain methods [16]. For example, windows technology has been developed for clinical image analysis. That adjustable window's level and window's width are working together to provide a special widow function to enhance the details of the image. Unfortunately, such technology is difficult to show calcification on a conventional DR image not only because cardiac calcification is overlapped with bone, lung and mediastinum but also because the calcium's volume is far less than 1% of the heart [12].

In order to develop the image enhancement approach, we propose a histogram processing-based scheme for DR images. We assume that the DR image intensity values of calcified tissue have a Gaussian distribution. We then use multiple Gaussian functions to fit the DR intensity histogram. Based on the mean and standard deviation parameters, we incorporate histogram equalization enhancement for cardiac calcification. The goal is to extract calcified tissue pixels only and then to extend the calcification intensity histogram to a full display gray scale. Thus the equalized calcification image is used to aid in the interpretation of the DR images for the localization and detection of calcium. We used three-dimensional (3D) MDCT images as the "gold standard" to evaluate the ability of DR for the detection of cardiac calcification.

In this paper, we apply histogram processing-based image enhancement methods to detect coronary artery disease. In this study, we reported an automatic image enhancement scheme for this important application of cardiac diseases. Both CT and X-ray images were acquired from patients with cardiovascular disease. Experimental results, discussions, and conclusions are also reported.

II. Materials and Methods

A. Image Acquisitions

We originally identified a group of 13 patients with findings of cardiac calcification on the MDCT. All patients have also undergone evaluation of the chest within 6 months of chest DR.

All CT scans were non-ECG gated studies using 4- or 16-slice MDCT. The CT examinations were obtained for a variety of clinical indications using imaging protocols that varied considerably in slice thickness, radiographic technique, and presence or absence of intravenous (IV) contrast material. The CT studies were analyzed for the presence of blood vessels, valvular, or coronary artery calcification. Totally 113 calcification lesions were confirmed by experienced radiologist for 13 patients, 38 lesions existed in blood vessels, 32 lesions presented at valvular and 43 lesions distributed into the coronary artery.

Patients were imaged using a digital radiography unit (Revolution XR/d, GE Healthcare). A 60-kVp image (low-energy image) was acquired first. After less than 200-msec delay, a second conventional 120-kVp image (high-energy image) was acquired. After post processing of the two images, a standard 120-kVp image, a subtracted soft-tissue image, and a subtracted bone image were presented.

B. DR Image Enhancement

Figure 1 shows the flowchart of the enhancement algorithm. The proposed image enhancement approach is composed by two parts: The DR histogram curve fitting and the histogram equalization.

Histogram curve fitting includes computation of DR intensity histogram, histogram profiles and parameters extraction. Multiple Gaussian functions are used to fit the histogram curve of the DR images. We assume that DR intensity values of calcified tissue have a Gaussian distribution and that DR intensity values of all tissue can be modeled as one or more Gaussian distributions.

$$X=\sum_{1}^{n} N(\mu_n, \sigma_n^2) \tag{1}$$

In addition, the summation of various Gaussian functions is also Gaussian distributed as described below:

$$U = X + Y \sim N(\mu X + \mu Y,\ \sigma_X^2 + \sigma_Y^2) \tag{2}$$

Actually, Gaussian distribution as a model of quantitative phenomena in the natural and behavioral sciences is due to the central limit theorem. Many measurements and physical phenomena such as photon counts and noise can be well approximated by a Gaussian distribution [17]. Although the mechanisms underlying these phenomena are often unknown, the use of a Gaussian distribution model can be theoretically justified by assuming that many small, independent effects are additively contributing to each observation. As we reported, Gaussian distribution has been applied to describe the CT intensity histogram of cardiac calcification tissues [12]. We believe that the DR intensity values within a calcification region can be described as a series of variables with an approximate Gaussian distribution. The image intensities within this region are described as $I \sim N(\mu, \sigma^2)$. Based on the mean and standard deviation parameters, we can incorporate histogram equalization to enhance cardiac calcification.

Histogram equalization includes the weighted vector generation and weighted image generation. In our histogram equalization method, we use a Gaussian function that is the same as the calcification distribution to enhance the DR image, thus enhancing the pixels within the calcification distribution and limiting other pixels outside of the distribution. Thereby, we can highlight the calcification from the heart or chest. The weighted vector is a Gaussian function as follows:

$$\text{Weight}(I) = e^{-\frac{1}{2}\left(\frac{1-\mu}{\sigma}\right)^2} \tag{3}$$

The mean and standard deviation parameters were the results of the histogram curve fitting part. To selectively display a calcification region, we use the Gaussian function as the weighting vector during the histogram equalization processing. The weighted image as the enhancement result depends on the mean μ and the standard deviation σ. The histogram equalization is to extract calcification tissue pixels only and to extend the calcification intensity histogram to full display gray scale. The equalized calcification image is used to aid the interpretation of the DR images for the localization and detection of calcium.

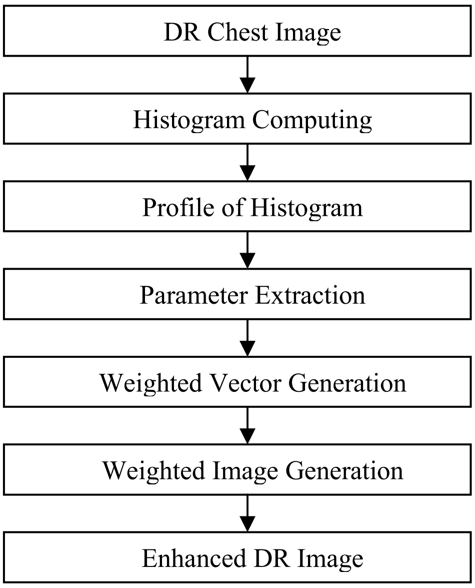


Figure.1 Flowchart of the proposed algorithm

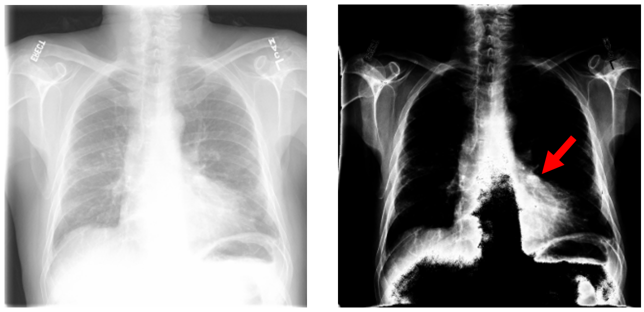
III. Experiments and Results

A. Visually Evaluations

We visually evaluated the enhanced DR images that were processed with our enhancement algorithm. Before enhancement, DR images were adjusted by window and level to find the suspicious calcification. The DR images would not change anymore after enhancement. The contrast images between before and after enhancement were used to compare the ability for calcification detection.

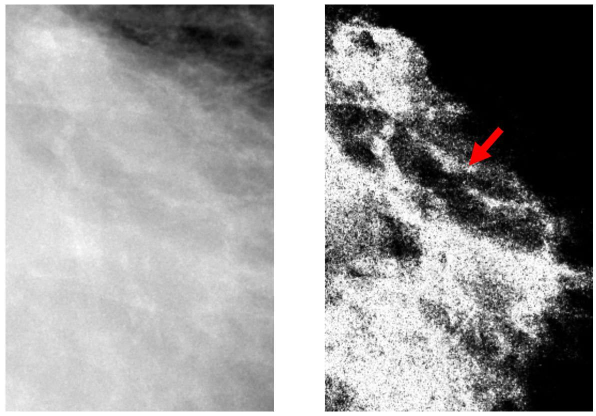
Figure 2 shows the comparison of a DR image before and after enhancement. Figure 2(a) shows the conventional DR image before enhancement. It is difficult to identify the cardiac calcification lesions. Figure 2(b) shows the enhanced image of (a) and the calcium is shown by the arrow on the image.

We also evaluated the enhancement algorithm at a local region of conventional DR images. A small window (251 x 381 pixels) of the heart image was extracted from the conventional DR image. Figure 3 shows the comparison of the DR image before and after enhancement. With the enhancement, coronary artery calcification is visible on the processed image.



(a) A Conventional Chest DR image (b) Enhanced image of (a)

Figure 2. Comparison of a chest DR image before (a) and after (b) enhancement. The arrow indicates the coronary artery calcification.



(a) Heart region of a conventional chest DR image (b) Enhanced image of (a)

Figure 3. Comparison of a regional heart DR image before (a) and after (b) enhancement. The arrow indicates the coronary artery calcification.

B. Parameters Distribution Evaluations

We obtained the mean μ and standard deviation σ distributions that resulted from curve fitting. An experienced radiologist inspected all CT data, enhanced DR and DEDR images to determine which parameters can show cardiac calcification. We first evaluated four serial DR images of the same patient and then evaluated all 13 patients' DR images. Figure 4 and Figure 5 show those distributions respectively. The Red, green and blue data points represent the parameters from the conventional DR images, subtracted soft images, and subtracted bone images respectively. All points were directly from the curve fitting results. The solid points can show cardiac calcification clearly. As shown on those two figures, most parameters from the fitting results can show cardiac calcification clearly.

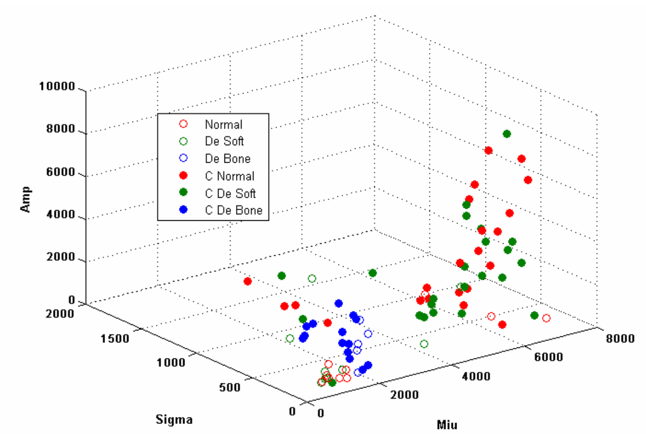


Figure 4. Gaussian parameter distribution for a patient with four serial DR images.

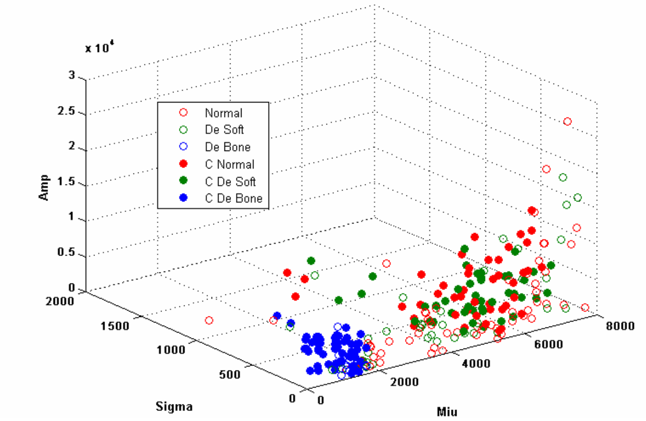


Figure 5. Gaussian parameter distribution for all 13 patients' DR images.

IV. CONCLUSIONS

We developed an automatic image enhancement method including histogram curve fitting and histogram equalization for conventional DR images. This enhancement algorithm has shown potential values for improving the image quality. The enhanced DR images could be used for clinical application in detecting cardiac calcification.

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