Mammography Images Restoration by Quantum Noise Reduction and Inverse MTF Filtering

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Abstract—**This work proposes a new restoration method to improve mammographic images by using Anscombe Transform and Wiener Filter to quantum noise reduction. Besides, it is performed an image enhancement by using a restoration inverse filter, calculated based on the image system modulation transfer function (MTF). This pre-processing technique were used for a set of mammographic phantom images in order measure the number of microcalcifications correctly detected by a computer-aided detection (CAD) algorithm. Results showed that the proposed method improved breast images quality by overcome the acquisition process constrains and reducing noise. The performance of the breast microcalcification CAD was improved when using the restored images set in comparison to the original one.**

Keywords-**image restoration, mammography, Anscombe transform, quantum noise**

I. Introduction

Breast cancer represents a significant percentage of cancer death among women all over the world [1,2]. Studies showed that breast cancer possibility of cure can increase by up to 40 percent if it is detected still in its early stage [3]. X-ray mammography is considered the most useful technique for breast cancer early detection and it is still used all over the world [1].

One mammographic image finding that can indicate the existence of breast cancer is the microcalcification. It consists on a very small deposit of calcium with 0.2 mm to 0.5 mm of diameter. Mammographic image has to be acquired in a short exposure time for patient safety and so it shows high quantum noise level. Consequently, microcalcification image shows low local contrast due to quantum noise and its small sizes and its detection is a difficult task for the radiologists. False negative rates for radiologist mammography interpretation range from 10 to 30 percent [5].

Microcalcification detection on mammographic regular examinations requires image with high spatial resolution and low noise level, besides radiologist great skills [4-6]. Recently, many researchers around the world have been developing image-processing systems, known as computer-aided detection (CAD) to aid radiologists to detect microcalcifications in mammographic images [7-8]. However, it is necessary to acquire good quality images in order to assure great performance of these computer procedures [9]. For that reason, many techniques have been developed in order to enhance mammographic images. Pre-processing techniques for noise reduction and image enhancement is widely used to improve CAD detection and also to improve cancer diagnosis [10-14].

Several works have been carried out by using Anscombe transform and the Wiener filter to reduce quantum noise in medical imaging, and good results have been obtained [15,16]. However, its use for mammography was never been carried out yet and should be investigated. Thus, this work presents an algorithm for mammographic images quantum noise filtering by using Anscombe transform (AT) and Wiener filter, followed by an enhancement algorithm that uses a restoration inverse filter based on the image system modulation transfer function (MTF). Thus, this pre-processing scheme can help to produce images with better quality in order to improve visual detection of microcalcifications by radiologists and also to increase the performance of computational schemes to aid diagnosis of breast cancer.

II. Mammographic image formation model

On mammographic the formation process, a blurring is introduced by a modulation transfer function (MTF), which degrades the acquired image spatial resolution.

Quantum noise is the predominant noise in mammographic images and cannot be ignored [9]. It comes from acquisition system low-counts X-ray photons. It is signal-dependent and can be described by a Poisson distribution [4]. The electronic noise from digital mammography systems or from a digitized screen-film mammography can be modeled by a Gaussian noise, signal-independent [17] and can be incorporated into the digital mammographic image g as an additive term, according to equation (1):

$$g = u + n \tag{1}$$

where u is the mammographic image blurred by the acquisition system modulation transfer function and corrupted by quantum noise, and n is the additive Gaussian noise incorporated to the digitized mammographic image g.

III. Proposed Method

The proposed method for mammographic images restoration consists on the use of a noise reduction algorithm followed by an inverse filter. Since quantum noise can be described by a Poisson distribution, we propose the use of the AT [15] to transform quantum noise to an additive noise. This procedure enables the use of any classical noise reduction technique, as Wiener filter, to reduce mammography image noise. The inverse filter was calculated based on the image system MTF, and was used after noise reduction procedure.

A. Anscombe Transform

Using the AT, it is possible to have a good estimation of blurred image u, as this transformation converts the signal-dependent Poisson noise into a approximately signal-independent Gaussian additive noise, whose mean is equal to zero and its variance is equal to one [18,19]. The AT of a random variable $\widetilde{U}_i$ is given by equation (2):

$$\widetilde{Z}_i = 2 \cdot \sqrt{\widetilde{U}_i + \frac{3}{8}} \tag{2}$$

where can also be represented by an additive model as equation (3):

$$\widetilde{Z}_i = 2 \cdot \sqrt{\widetilde{U}_i + \frac{1}{8}} + \widetilde{N}_i = \widetilde{S}_i + \widetilde{N}_i \tag{3}$$

where $\widetilde{N}_i$ represents the Gaussian additive noise. Thus, after this nonlinear transformation, it is possible to use any well-known techniques to additive noise filtering by using the new image in the Anscombe domain [15]. Finally, we used the inverse Anscombe transform to obtain the noise-reduced image. In this work, we use the Wiener Filter [20] in the Anscombe domain to reduce the quantum noise in our mammography images.

B. MTF compensation filter

After the Poisson noise filtering, mammographic images were enhanced by using a MTF compensation filter, based on the inverse of image system limitations. We used an inverse filter [20] calculated by from image system MTF, obtained computationally by an algorithm developed in a previous work [12]. In these calculations, we considered the mammographic equipment and the film digitizer's MTF. The inverse filter can be calculated using the equation (4).

$$IF(u, v) = \frac{1}{MTF(u, v)} \tag{4}$$

This enhancement must be done in the frequency domain by applying the 2D fast fourier transform (FFT). Thus, the restored image is obtained by the product between the original image and the proposed filter on the frequency domain, followed by the inverse Fourier transform.

IV. Results

In this work, we use two mammographic images of a breast phantom CIRS, model 011-A (CIRS, EUA) acquired with two different doses levels by a Lorad M-III mammographic unit. One image was acquired using 4.75 mGy and the other with 8.25 mGy. Images with high dose level present low quantum noise. This phantom contains several regions of interest (ROI) with fibers, masses and microcalcifications of different sizes, as shown in Figure 1.
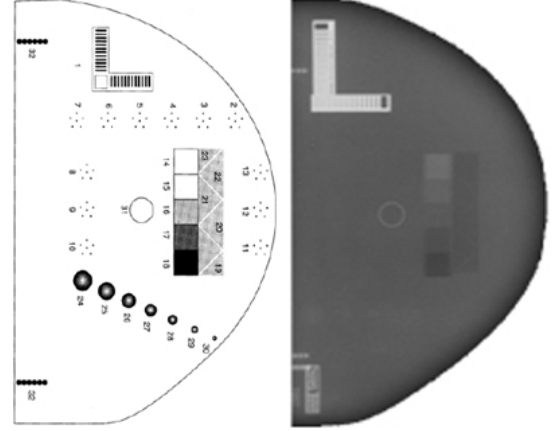

Figure 1. Certification Phantom CIRS, model 011-A used for experimental tests. (a) Answer sheet provided by the manufacturer showing the phantom structures and its regions of interest. Structures from 2 to 13 correspond to groups of six microcalcifications each, with known sizes: (2) 0.13mm, (3) 0.16mm, (4) 0.19mm, (5) 0.23mm, (6) 0.27mm, (7) 0.40mm, (8) 0.23mm, (9) 0.19mm, (10) 0.16mm, (11) 0.23mm, (12) 0.19mm e (13) 0.16mm. (b) Mammographic image of the phantom, acquired by a Lorad M-III equipment.

These images were digitized by a Epson film scanner model Perfection V750 Pro, with contrast resolution of 3800 gray levels (12 bit). We evaluated the reduction of quantum noise, the improvement in spatial resolution and the effect of the restored images on a mammography CAD performance for automatic microcalcification detection. Each image, acquired by two different dose levels, was digitized using two different spatial resolutions: 300 and 600 dpi. Thus, we had a set of four digitized mammography images. All image processing algorithms was developed in Java, using a NetBeans 6.0 compiler.

A. Evaluation on noise reduction

In order to evaluate the proposed method for quantum noise reduction, uniform regions of 80 x 80 pixels was extracted from each one of the four phantom images. Three cases were considered for the analysis of quantum noise reduction: original images with no pre-processing technique to reduce the quantum noise, original images processed by the median filter (MF) and the original images processed by AT described in section III. After this step, the MTF compensation filter was applied for all three cases.

Considering the restored image as the signal and the difference between its image and the original noisy image, we can define the signal-to-noise ratio (SNR) by using equation (5) [21]:

$$SNR = \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} \hat{f}(x,y)^2}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [f(x,y) - \hat{f}(x,y)]^2} \quad (5)$$

where $f(x,y)$ is the original image and $\hat{f}(x,y)$ is the restored image [21]. Images with low noise level present high SNR.

It was measured the SNR of all three cases, in order to compare the performance of these noise reduction methods. Table 1 shows the results. It can be noticed that the images which were applied the Anscombe transform showed better results.

Table I
SNR MEASUREMENTS FOR RESTORED IMAGES USING DIFFERENT NOISE REDUCTION TECHNIQUES

Image Set	Spatial Resolution (dpi)	Radiation Dose(mGy)	SNR(db)
Restored without noise reduction	300	4.75	73.1
	300	8.25	74.3
	600	4.75	75.0
	600	8.25	75.4
Restored after using MF for noise reduction	300	4.75	66.6
	300	8.25	73.6
	600	4.75	67.1
	600	8.25	72.4
Restored after using AT for noise reduction	300	4.75	83.4
	300	8.25	89.5
	600	4.75	85.2
	600	8.25	91.0

B. Evaluation on spatial resolution

In order to evaluate the improvement on image spatial resolution achieved by using the proposed method, a region with a line pair test (Figure 1) was extracted from each one of the four phantom images. It contains line pairs for spatial resolution evaluation ranging from 5 to 20 lp/mm (line pairs per mm). Spatial resolution evaluation can be performed by identifying the smallest correctly achieved line pair in the original images, comparing to the restored ones.

Due to the subjectivity of visual observation for line pair test evaluation, it was calculated a line profile, considering a perpendicular line to the line pair test region. Thus, it is possible to determine the maximum spatial resolution achieved for each image [22,23].

Figure 2 illustrates the result for a mammographic phantom original image acquired with 8.25mGy and 600dpi, with no restoration. Figure 2 (a) shows the line pair test extracted from the image and Figure 2 (b) shows the line profile

measured in terms of grayscale levels. The same image was restored by using the AT and MTF compensation, as proposed in this work. After being restored, the line profile was also calculated (Figure 3). In this case, spatial resolution was increased (14 to 19 lp/mm) after image restoration.
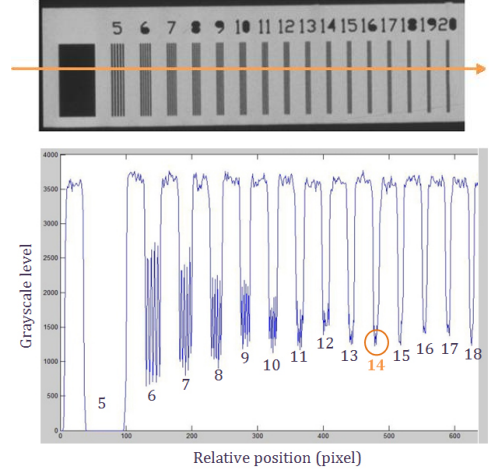

Figure 2. Spatial resolution evaluation for a mammographic phantom image. (a) image of the line pair test; (b) line profile showing that the smallest correctly achieved line pair for this case was 14 lp/mm.
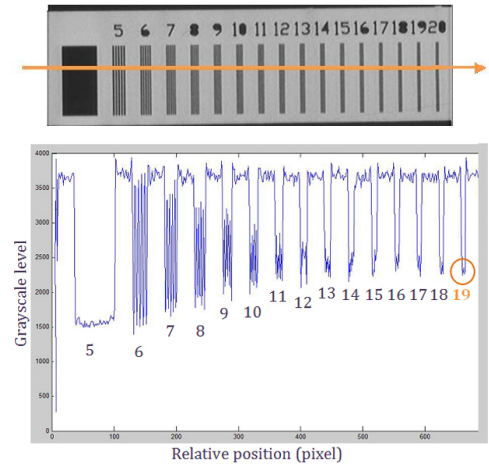

Figure 3. Spatial resolution evaluation for a restored image. (a) image of the line pair test; (b) line profile showing that the smallest correctly achieved line pair increased to 19 lp/mm.

V. EVALUATION OF RESTORATION ON A MAMMOGRAPHY CAD SYSTEM PERFORMANCE

It was evaluated the performance of a computer-aided detection (CAD) system for automatic microcalcifications detection in mammographic images. We compared the performance of a CAD system using both original and restored images, in order to evaluate the advantage of restoration method proposed in this work on the enhancement of structures of interest in mammographic images.

It were selected 12 ROIs (region of interest) in each one of the four digitized phantom images: six ROIs with a cluster of six microcalcifications each (regions 2 to 7 in Figure 1) and six ROIs with no microcalcifications or any mammography findings. The images with microcalcifications were used for CAD detection rate analysis (true positive) and the images which no mammography findings were used for CAD error rate analysis (false positive). All ROIs were restored by the proposed method, i.e., we built a group of 96 ROIs: 48 originals images and 48 restored images.

All these images were used to evaluate the performance of a computer-aided detection scheme for automatic detection of microcalcification, developed in a previous work [24]. The main objective was to compare the CAD performance when using the restored images instead of the original ones.

Figure 4 illustrates some results obtained by using the CAD for automatic microcalcification detection on our phantom images. In Figure 4, the first and the second ROIs (a and b) show the detected microcalcifications when using the original ROIs images acquired with 4.75mGy and digitized with 300dpi. The third and fourth images (c and d) show microcalcifications detected by the CAD when using restored images, considering the same ROIs. It can be noticed that more microcalcifications were detected in images that had been restored by the algorithm proposed in this work.

Figure 4. Results obtained with the algorithm for automatic microcalcification detection. (a) and (b): original images; (c) and (d): restored images.

ROIs a and b have six microcalcifications each. CAD detection for both images produced six false-negatives, since only six signals from twelve were detected. By using the same ROIs, but now enhanced by the restoration method (c and d images), the number of detected signals was increased (nine microcalcifications were detected), reducing to three cases of false-negatives. Moreover, structures enhanced in image c and d corresponds to very small microcalcifications: 0.13 mm and 0.16 mm, respectively, which shows an important contribution of the proposed algorithm to enhance such structures which is so difficult to be detected due to their small sizes.

For a better investigation, all results achieved for microcalcifications detection were grouped according to its size. It was considered three groups containing 12 microcalcifications each: 0.13 to 0.16 mm, 0.19 to 0.23 mm and 0.27 to 0.40 mm. The graphics on Figure 5 shows the results obtained for automatic microcalcifications detection (true positive) by the CAD system when used the original

and the restored ROIs. The tables in Figure 5 show the number of microcalcifications correctly detected for each group of microcalcifications sizes (the maximum number of microcalcifications per group is 12).
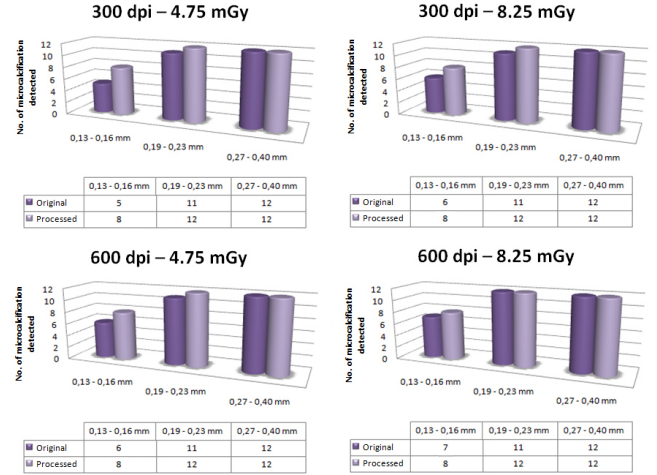

Figure 5. True-positive rates. Number of microcalcifications correctly detected by the mammography CAD system. (a) results obtained with images acquired with 4.75mGy and digitized with 300dpi; (b) images acquired with 8.25mGy and digitized with 300dpi; (c) images acquired with 4.75mGy and digitized with 600dpi and (d) images acquired with 8.25mGy and digitized with 600dpi.

The error rate (false-positive) can be measured by considering the number of signals incorrectly detected by the CAD on images with no microcalcifications. Figure 6 shows the results obtained for false positive rates achieved by the CAD system. It was considering the ROIs extracted from phantom images without any structure of interest, acquired with different doses and spatial resolution.

VI. Discussion

In this paper we investigate the use of Anscombe transform for mammography quantum noise reduction and the MTF inverse filter for image restoration. This method requires only the knowledge of the image acquisition system MTF, as it did not require any information about the noise produced during image acquisition. Results showed that the restored images presents less noise (high SNR) and better spatial resolution (smaller line pair per millimeter could be visible in the image). Besides, images restored by the proposed method improved the performance of a mammography CAD system for automatic microcalcification detection in digitized breast images.

Restoration improvement considering noise reduction by AT was evaluated by measuring the image SNR, as shown in Table 1. We compared SNR measured by using restored images with no noise reduction and by using restored images with two different noise reduction methods: MF and AT. Results showed that images restored after AT presents better

300 dpi − 4.75 mGy

	False positive
▪ Original	4
▪ Processed	2

300 dpi − 8.25 mGy

	False positive
▪ Original	6
▪ Processed	2

600 dpi − 4.75 mGy

	False positive
▪ Original	8
▪ Processed	4

600 dpi − 8.25 mGy

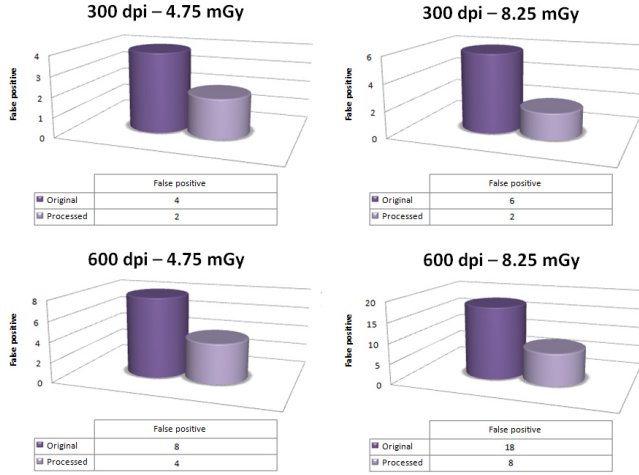|	False positive
▪ Original	18
▪ Processed	8

Figure 6. False-positive rates. Number of microcalcifications incorrectly detected by the mammography CAD system. (a) results obtained with images acquired with 4.75mGy and digitized with 300dpi; (b) images acquired with 8.25mGy and digitized with 300dpi; (c) images acquired with 4.75mGy and digitized with 600dpi and (d) images acquired with 8.25mGy and digitized with 600dpi.

SNR. Restoration improvement achieved for the images spatial resolution was evaluated by using the line pair test pattern, as shown in Figure 2 and 3. Analysis about the results presented in Table 2 shows that for all images, the restoration method improved image resolution. It can be noticed that ROIs acquired with high dose level (better SNR) presented better improvement in spatial resolution than the ROIs with low-count X-ray photons.

One of the most relevant result found in this study was the increase on CAD detection rate (true positive) followed by a decrease in CAD error rate (false positive). These results show that the proposed method can reduce image noise and preserve high-frequency signals in the image. The graphics on Figure 5 showed that CAD system detected all microcalcifications with large sizes (0.27 to 0.40 mm) using either original or restored images. These microcalcifications probably would be detected by the radiologists in a mammography examination. However, considering the smallest microcalcification group (0.13 to 0.16 mm) much better detection rate was obtained when using the restored images. These microcalcifications are considered very small sizes microcalcifications and its detection by a radiologist without computer-aid is a difficult task. This shows an important contribution of this work, as one missed microcalcification could mean a cancer not being early detected. Analyzing the same group of microcalcifications acquired with other spatial resolutions and radiation doses, it can be noticed that the CAD detection rate depends on image resolution and noise. Images acquired with lower spatial resolution (300 dpi) and higher noise (4.75 mGy) led to the worst CAD performance. However, after image restoration, CAD performance was the same for all images.

Considering the error rate, Figure 6 showed the number of false positive per image achieved by the CAD. In Figure 6(a) the error rate decreased about 50 percent, in 6(b) about 66.6 percent, in 6(c) about 50 percent and in 6(d) about 55.5 percent, which shows the significant decrease in error rate when the ROIs are pre-processed by the proposed method. In practice, a false negative could mean a case of breast cancer that was not detected and a false positive may refer to a patient doing unnecessary additional examination, such as a breast biopsy. CAD schemes expected to eliminate false negatives cases and also reduce false positives cases.

Visible improvements in mammographic images were also achieved, providing greater detectability for structures associated to breast cancer, as reported in a similar work [10]. The proposed pre-processing algorithm presented relevant results if compared with other works in literature [11,12], where the reported increase on CAD performance was 3 and 12 percent, respectively, when using enhanced images, but with higher rate of false-positives cases. In another work [13], where some enhancement algorithms were tested, the reported increase on CAD performance was 5 and 9 percent when median filter and Gabor filter, respectively, was used. No significant increase was observed when using Wiener filter.

VII. Conclusion

We presented a restoration method by using Anscombe transform and MTF compensation for mammographic image quality improvement. Results showed that restored mammographic images presented low noise level and better spatial resolution. Besides, considering a CAD performance, pre-processed image set achieved better performance for an automatic microcalcification detection scheme. For better results, new tests should be performed, considering a larger number of images and new lesions associated to breast cancer.

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