A SYSTEMATIC EVALUATION OF A NEW WAVELET-BASED IMAGE ENHANCEMENT ALGORITHM FOR DIGITAL MAMMOGRAPHY

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The purpose of the present study was to investigate the effectiveness of a new wavelet–based breast image enhancement filter and to conduct a comparative evaluation with the Hyperbolic Logarithmic histogram equalization filter. Mammographic images were processed using the new image-processing algorithm, developed in C++. The detail coefficients of the DWT up to scale 5 were processed, by first defining upper and lower threshold values and then raising to a power of 2 the DWT-coefficient values found within the pre-selected threshold range. Additionally, the DWT-coefficient values lying outside the thresholding range were multiplied by a fixed factor. The Hyperbolic Logarithmic histogram equalization filter was used to process the image by modifying the graylevel probability density function. These two filters were applied to 157 digitized mammograms and the processed mammograms were blind-reviewed by an experienced radiologist. Eleven mammographic image parameters were evaluated and filter performances were assessed by statistical analysis of the physician's evaluation. With respect to the 11 visually evaluated image parameters, the scale-5 wavelet-based filter showed statistically significant improvement in all of the cases, while the hyperbolic logarithmic filter enhanced the image in 6 cases. Overall processing time was less than 3s.

Introduction

Mammography is the most efficient technique that is used to detect cancer and other deseases related to breast. A range of digital filters was applied to the mammograms in order to improve the diagnostic potential of the phycisians. Wavelet-based filters, over the past few years, were developed and accomplished the object of image enhancement.

In the present study, a new wavelet-based enhancement filter and a histogram equalization filter, developed in C++, were applied and evaluated with regard to the enhancement of X-Ray digitized mammograms. An experienced radiologist assessed the processed mammograms according to eleven image parameters.

Material and Methods

The hyperbolic logarithmic histogram equalization [1-3] is based on modifying the input probability density function into a desired output graylevel histogram. Equations 1 and 2 illustrate the output probability density model and the corresponding mapping function that was developed in the present study:

$$P_g(g) = \frac{1}{g\left[\ln(g_{\max}) - \ln(g_{\min})\right]} \quad (1)$$

$$g = g_{\min}\left[\frac{g_{\max}}{g_{\min}}\right]^{CDF} \quad (2)$$

where, g_{min} and g_{max} are the minimum and maximum gray-levels of the image, *CDF* is the Cumulative Distribution Function of the normalized histogram and g is the calculated gray-tone of the processed image.

Wavelet-based enhancement involves three steps. First, the Discrete Wavelet Transform [4] in five scales is applied to the mammograms. Second, the wavelet coefficients (details) are redistributed according to figure 1 and equation 3. In the present study the coefficient values between the predetermined threshold (T) are used as exponents of power of 2 [5-7].

$$W_{out} = W_{in} + (T - T^2), \text{ if } W_{in} > T$$
$$W_{out} = W_{in} - (T - T^2), \text{ if } W_{in} < -T$$
$$W_{out} = W_{in}^2 \quad , \text{ otherwise} \quad (3)$$

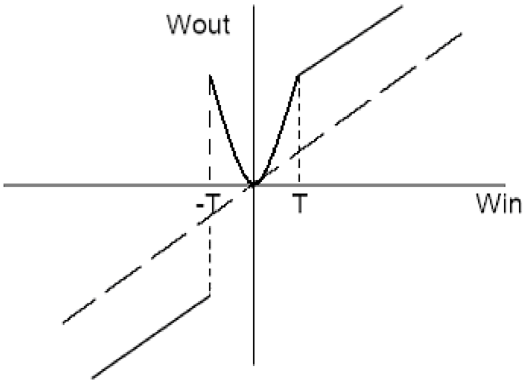

Figure 1. Wavelet-based enhancement filter

Win and Wout are considered to be the input and the output wavelet coefficient respectively and T is a threshold value. Finally, the Inverse DWT [4] is applied in order to reconstruct the processed mammograms.

One hundred and fifty-seven mammograms were created using a General Electric DMR Plus mammographic unit with molybdenum/molybdenum (Mo/Mo) anode/filter combination and 650mm focus to film distance (FFD). Film images were digitized on a Microtec Scanmaker II SP (1200x1200 dpi, 8-bit graylevel). These mammograms were analyzed with specialized software developed in C++. A number of mammographic image quality parameters were investigated. Specifically, each filter was evaluated in relation to the choice of positive or negative effects on:

1. The contrast between dark and light areas.
2. The improvement of normal fatty breasts.
3. The improvement of dense fibro-grandular breasts.
4. The display quality and delineation of calcifications.
5. The good visualization of vessels, veins, ducts.
6. The good visualization of pathological findings.
7. Image detail related to the characterization of a lesion as benign or malignant.
8. The accentuation of tumour inhomogeneity.
9. The delineation of tumour borders.
10. The good visualization of breast skin and soft tissues.
11. The good visualization of the thoracic muscle.

Results and discusion

Due to low contrast resolution, the discrimination of structures within the breast is problematic. The wavelet-based filter improved image contrast significantly and enhanced the appearance of image features (parameter 1 in Table 1) in a percentage of 95%, while hyperbolic logarithmic in a percentage of 91% of the cases. Analytical results of the scores achieved by both filters are illustrated in Table 1.

In the case of normal fatty, as well as dense fibro-grandular breasts, wavelet-based filter enhanced mammograms in 95% of the cases (parameters 2 and 3 in Table 1), while hyperbolic logarithmic in 88% and 90% of the cases respectively (parameters 2 and 3 in Table 1).

Parameters	Wavelet Filter (%)	Hyperbolic Logarithmic (%)
1.	95	91
2.	95	88
3.	95	90
4.	80	24
5.	95	8
6.	85	39
7.	90	40
8.	91	35
9.	96	47
10.	82	0
11.	86	1

Table 1: The score % achieved by each filter

The visualisation of the micro-calcifications is a significant factor of assessing the risk of breast cancer. Enhancement was accomplished in 80% of the cases by the wavelet-based algorithm, while histogram equalization filter scored 24% of the cases (parameter 4 in Table 1).

It is significant for the physicians to identify soft breast tissues, such us vessels, veins, and ducts, in order to separate a tumour from surrounding tissues (parameter 5 in Table 1). Significant improvement was achieved by the wavelet-based filter in 95% of the cases, while histogram equalisation filter failed to enhance images, scoring only 8%.

In order to assess the physical characteristics of the tumours, it is important for the physicians to identify the tumour’s boundaries, as well as its textural structure (parameters 6, 7, 8, 9 in Table 1). Significant enhancement was accomplished by the wavelet-based filter in 85%, 90%, 91% and 96% of the cases respectively, while histogram equalisation filter managed to enhance images in 39%, 40%, 35% and 47% of the cases respectively for each feature (parameters 6, 7, 8, 9 in Table 1).

In many cases, it is important for the radiologists to distinguish the breast skin, in order to identify lesions related to infections, hematomas or dermal nevi. Hyperbolic logarithmic algorithm failed to enhance mammograms. However, wavelet-based filter enhanced images in 82% of the cases (parameter 10 in Table 1).

In the two rare pathological cases of lesions in the retro mammary space or in axillary lymphadenopathy, it is important for the physicians to identify the major thoracic muscle. Significant enhancement was accomplished by the wavelet-based filter in 86% of the cases, while the histogram equalization filter failed to improve mammograms (parameter 11 in Table 1).

Figures 2-4 and 5-7 illustrate two examples of Region of Interest (ROI) from mammograms with a tumour and micro-calcifications respectively.

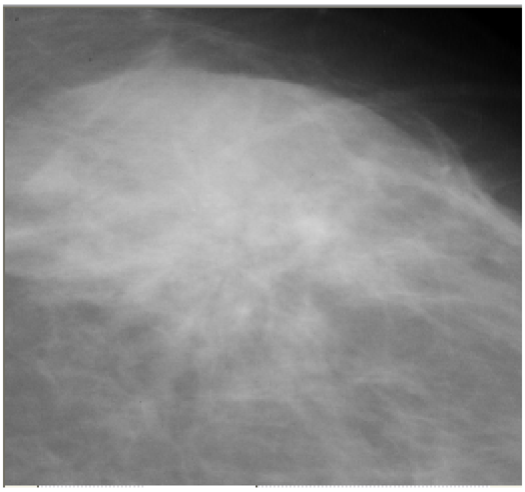

Figure 2. Original ROI of mammogram

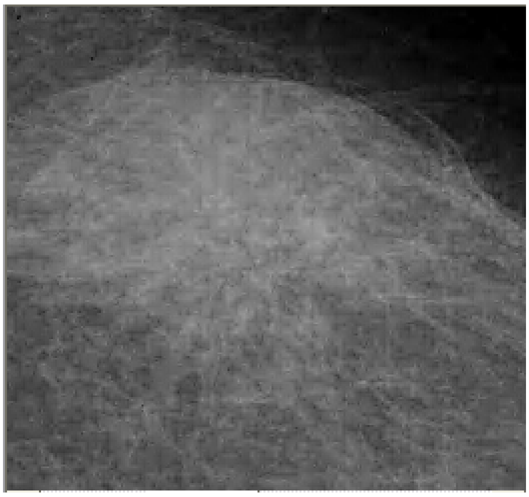

Figure 3. Wavelet-based processed mammogram

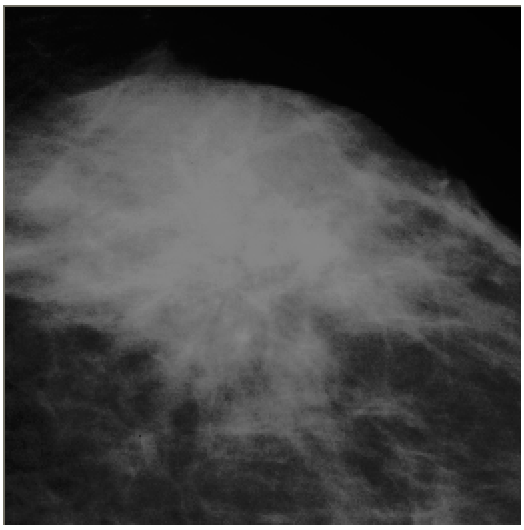

Figure 4. Histogram equalization hyperbolic-logarithmic processed mammogram

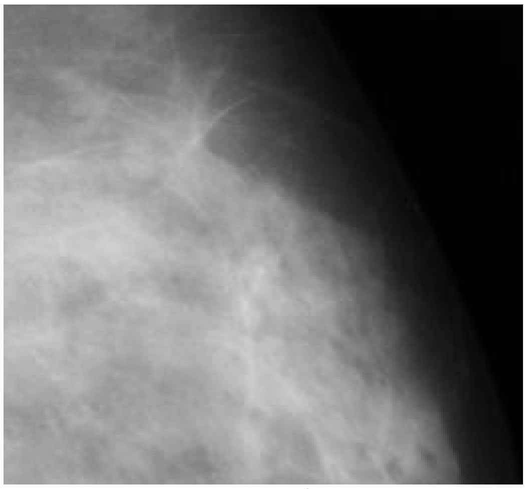

Figure 5. Original ROI of mammogram

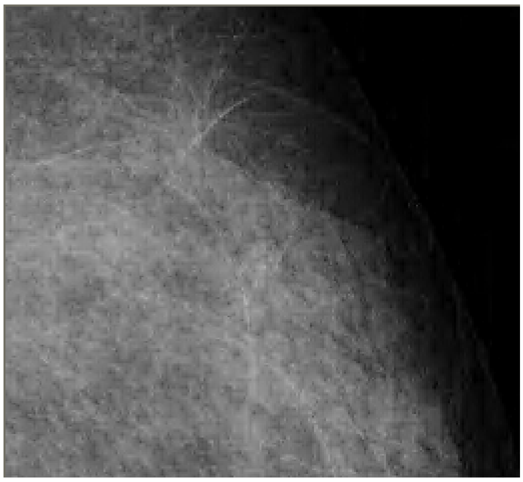

Figure 6. Wavelet-based processed mammogram

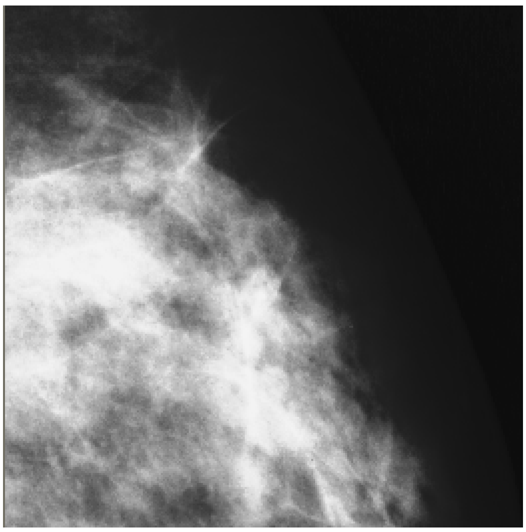

Figure 7. Histogram equalization hyperbolic-logarithmic processed mammogram

Conclusion

Wavelet-based algorithm was found to effectively enhance the mammograms in all of the image quality parameters, improving the diagnostic potential for radiologists. The performance of histogram equalization hyperbolic logarithmic algorithm was also satisfactory, yet not equally effective in all cases. For both algorithms, the processing time was less than 3 seconds, rendering the application available in clinical route.

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