FAST ENHANCEMENT OF MAMMOGRAPHIC IMAGES USING WAVELETS AND CLAHE ON A DISTRIBUTED PROCESSING SYSTEM.

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Abstract: Purpose: In this study, the wavelet-based parabolic non linear enhancement filter (WPNLEF) and the contrast limited adaptive histogram equalization (CLAHE) technique were employed for contrast enhancement of mammograms on a distributed processing system. Methods and Materials: Sixty patients (30/60 with suspicious findings and 30/60 normal cases) underwent mammographic examination at the EUROMEDICA medical center, Athens, Greece, by means of a General Electric DMR Plus mammographic unit. Mammograms were digitized on a Microtec Scanmaker II SP (1200x1200 dpi). Computation of both algorithms (WPNLEF and CLAHE) was parallelized to meet real time computing requirements, on a distributed processing system. An experienced radiologist evaluated the processed images with a number of quality parameters (such as masses, parenchyma, microcalcifications, contrast improvement and breast periphery). These quality parameters were selected for the estimation of the effectiveness of the two filters on the processed mammograms. Results and Conclusions: WPNLEF enhanced the visualization of breast skin and soft tissue. CLAHE improved significantly the detection of microcalcifications and masses in dense breast parenchyma. According to the evaluation of the radiologist, the combination of the two filters gave more diagnostic information than using only the WPNLEF or the CLAHE technique. Time processing load decreased significantly (threefold) rendering the algorithms plausible for clinical application.

Introduction

Diagnostic mammography is currently the most reliable method for the early detection of breast cancer [1]. The goal of mammography is to detect the location and exact size of suspected breast abnormalities, which are in most cases masses or microcalcifications. However, microcalcifications especially, are extremely difficult to view in early stages due to their small size and high attenuation properties, resulting in low contrast visualization of these small tiny specks of calcium in mammograms [2]. Digital image processing techniques have been shown to improve the visualization of microcalcifications and have become necessary tools in the hands of expert physicians for more accurate and successful detection of microcalcifications related abnormalities in early stages [3].

Histogram equalization techniques and wavelet analysis have been proved to be effective in enhancing the visualization of malignant mammographic features [3-8]. These techniques have been shown to provide impressive results; however, their significant drawback still remains high computational times to meet fast time processing in clinical routine.

In this study, we investigated whether the combination of WPNLEF and CLAHE may potentially give more diagnostic information to the physician than using only the WPNLEF or CLAHE, in enhancing the visualization of mammograms. Additionally, computation of both algorithms was parallelized to meet fast computing time requirements, on a distributed processing system.

Materials and Methods

Sixty patients (30/60 with suspicious findings and 30/60 normal cases) underwent mammographic examination at the EUROMEDICA medical center, Athens, Greece. Mammograms were acquired on a General Electric DMR Plus mammographic unit with Molybdenum/Molybdenum (Mo/Mo) anode/filter combination and 650mm Focus to Film Distance (FFD). Among the 60 patients included in the study, 30 had suspicious findings and 30 were normal cases. Mammograms were digitized on a Microtec Scanmaker II SP (1200x1200 dpi, 8-bit graylevel).

All images were processed with the CLAHE algorithm and a wavelet-based parabolic non linear enhancement filter, which were implemented in custom made MATLAB source code. Additionally, computing steps for both algorithms were parallelized, in order to function on a distributed processing system.

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Wavelet-based enhancement

Wavelet-based enhancement was accomplished be using Daubecies-4 (DAUB4) Discrete Wavelet Transform [9]. Images were decomposed into five scales. The Horizontal, Diagonal, and Vertical details were redistributed using a parabolic non linear enhancement mapping function (see figure 1) according to equation 1 [8]. The values of threshold *T* and *a* (see equation 1) were chosen by an experienced radiologist (N.D.) for optimum visualization results.

$$\begin{aligned} W_{out} &= W_{in} + aT(T-1), if \quad W_{in} > T \\ W_{out} &= W_{in} - aT(T-1), if \quad W_{in} < -T \qquad (1) \\ W_{out} &= W_{in}^{2}, otherwise \end{aligned}$$

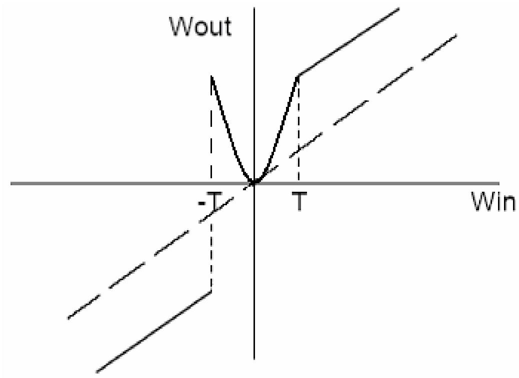

Figure 1: Parabolic non linear mapping function

Win and *Wout* are the input and the output wavelet coefficients respectively. Finally, the Inverse DWT was applied in order to reconstruct the processed mammograms.

Contrast Limited Adaptive Histogram Equalization

The CLAHE filter is quite effective in low contrast images, such as mammograms. CLAHE functions adaptively and the basic steps for its implementation are: a) division of the image into a number of non-overlapping contextual regions of equal sizes, b) computation of the histogram of each contextual region, c) enhancement of the contrast of each contextual region, by clipping its respective histogram under a certain threshold *T*, d) redistribution of the histogram in such a way that its height did not exceed the clip limit, e) bilinear interpolation of the neighboring contextual regions and modification of the image graylevels according to the Cumulative Distribution Function (CDF) of each contextual region.

Evaluation

The image-enhancing effectiveness of the 2 filters was assessed by an experienced radiologist (N.D.) that evaluated the following image quality parameters:

1. Contrast between dark and light areas
2. Improvement of dense fibro-grandular breasts
3. Visualization of calcifications
4. Good visualization of pathological findings
5. Discrimination of a lesion as benign or malignant
6. Delineation of tumour borders
7. Good visualization of breast skin and soft tissues

Parallelization steps for CLAHE and WPNLEF

The locally interconnected array computer architecture comprised a server (PIV, 2.8 GHz) and 10 workstations (3 PIII, 800Mhz) interconnected via a Cisco Catalyst 2950 Switch. Pixel processing algorithms were built up in MATLAB source code using the MATLAB distributed computing engine [10]. CLAHE parallelization was performed using 8 workstations (WS), whereas the remaining 2 were used for the WPNLEF.

CLAHE parallelization: The server divided the image (1024x1024) into 8 equal sized (128x1024) sub-image regions, which were distributed to 8 different WS. Each WS performed the following operations: a) divided the sub-image region into 64x64 contextual regions, b) calculated the CDF of each contextual region, c) clipped the histogram under a certain threshold *T*, and d) redistributed the histogram so that its height did not exceed the clip limit *T*. These steps were performed in order to compute the CDF of each contextual region. The CDF results were returned to the server. The bilinear interpolation was performed to the 8 WS of the grid and their results were sent to the server, which displayed the processed image.

WPNLEF parallelization: Initially the direct discrete wavelet transform was performed on the server. The horizontal and vertical details were sent to 2 separate WS. The WSs performed the redistribution of the wavelet coefficients using the parabolic non linear enhancement mapping function of equation 1. The same process was performed on the server for the diagonal details. Results were returned to the server, which reconstructed the image using the inverse discrete wavelet transform. The same process was applied for the remaining 4 scales, using only the approximation coefficients. The reconstructed image was displayed on the server.

Results and Discussion

The application of the CLAHE and the WPNLEF in two different mammograms is demonstrated in figures 2.1-2.3 and figures 3.1-3.3. CLAHE improved significant the visualization of pathological findings, whereas the WPNLEF enhanced the appearance of dense breast tissues. The combination of both filters gave significantly more diagnostic information according to the radiologist's evaluation (see table 1), succeeding the highest scores for all the parameters, than using CLAHE or the WPNLEF alone. The results of the radiologist's evaluation are summarized in table 1.

Time processing load decreased significantly (threefold) rendering the algorithms plausible for clinical application (see figure 4).

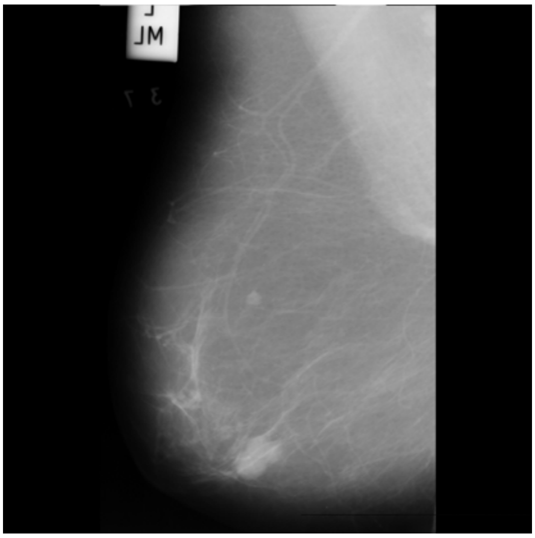

Figure 2.1: Original image

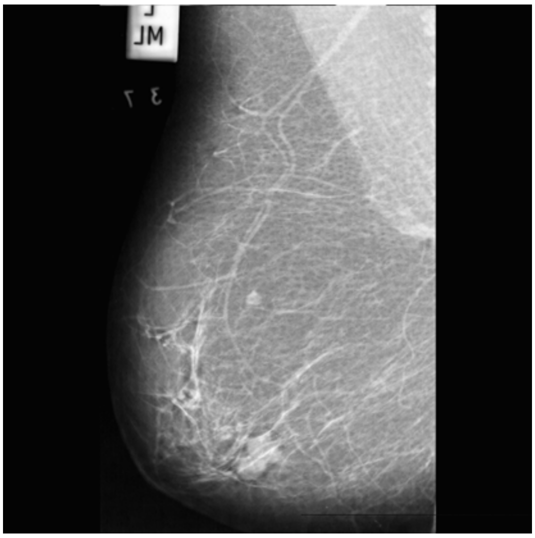

Figure 2.2: CLAHE (window 64x64 clip limit 0.01)

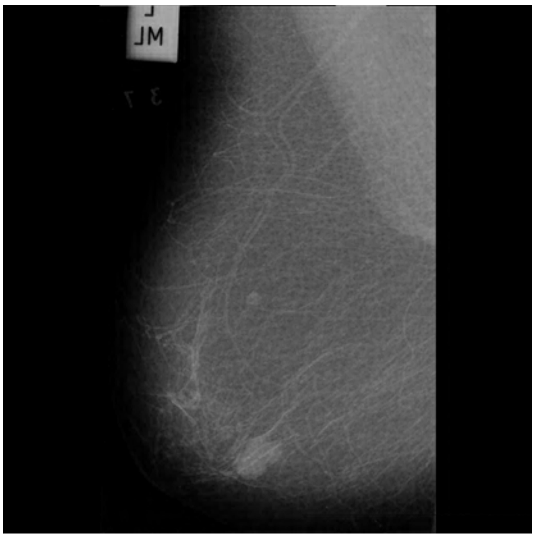

Figure 2.3: WPNLEF

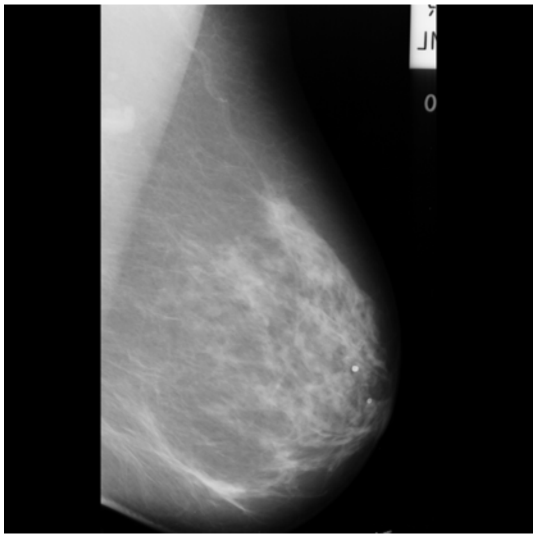

Figure 3.1: Original image

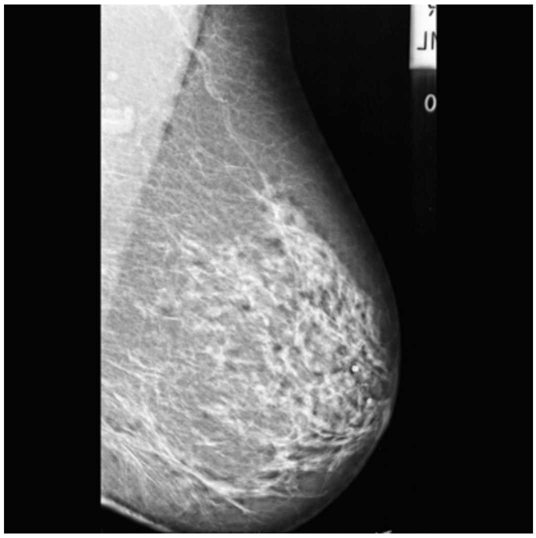

Figure 3.2: CLAHE (window 64x64 clip limit 0.01)

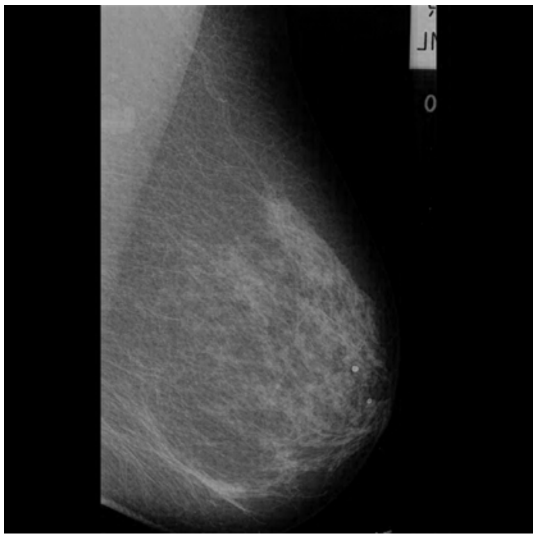

Figure 3.3: WPNLEF

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Table 1: Image enhancement effectiveness in a number of qualitative parameters assessed by the experienced radiologist (N.D.)

Parameters	Filter I. CLAHE (%)	Filter II. WPNLEF (%)	Combination of CLAHE and the WPNLEF (%)
Contrast between dark and light areas	85	90	90
Improvement of dense fibro-granular breasts	85	90	90
Visualization of microcalcifications	80	75	80
Good visualization of pathological findings	95	80	95
Discrimination of a lesion as benign or malignant	95	90	95
Delineation of tumour borders	95	91	95
Good visualization of breast skin and soft tissues	95	95	95

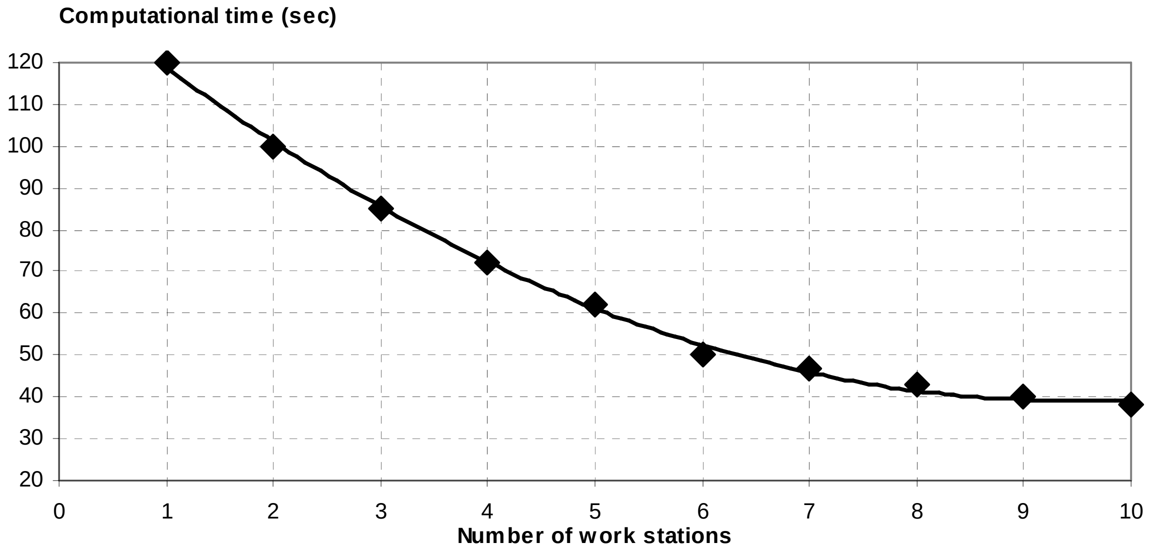

Figure 4: Computational requirements of both filters (CLAHE and WPNLEF) on the distributed processing system

CLAHE and WPNLEF achieved a high score on improving contrast between dark and light areas 85% and 90 % respectively (parameter 1 in *Table 1*). The improvement of dense fibro-granular breasts was 85% for CLAHE and 90% for WPNLEF (parameter 2 in *Table 1*). Enhancement of microcalcifications was accomplished by both filters, with 80% and 75% for CLAHE and WPNLEF respectively (parameter 3 in *Table 1*). In many cases it is very important the visualization of pathological findings. CLAHE worked sufficiently in 95% of the cases, whereas WPNLEF accomplished 80% (parameter 4 in *Table 1*). The importance of the discrimination of a lesion as benign or malignant is of great significance. Both filters succeeded a high score, 95% and 90% respectively (parameter 5 in *Table 1*). The poorest delineation of tumor borders was demonstrated by the WPNLEF, which achieved 91% percentage (parameter 6 in *Table 1*). In many cases, it is important to distinguish the breast skin, in order to identify lesions related to infections, hematomas or dermal nevi. CLAHE and WPNLEF attained the same score, 95% (parameter 7 in *Table 1*) in this task.

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