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MAMMOGRAPHIC IMAGE ENHANCEMENT USING WAVELET-BASED PROCESSING AND HISTOGRAM EQUALIZATION

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Abstract. *The purpose of this study was to investigate the effectiveness of a wavelet–based breast-image enhancement filter and to conduct comparative evaluation with five Histogram Equalization Mapping Functions (HEMF). An image processing application was developed in C++ for the enhancement of mammographic images. Wavelet-based image enhancement was implemented by processing the DWT detail coefficients with a sigmoid function. HEMF enhancement was based on modifying image display by adjusting the gray-level probability density function (uniform, exponential, rayleight and two hyperbolic). These filters were applied to 130 digitized mammograms. The processed mammograms were blind-reviewed by an expert radiologist. A number of mammographic image parameters, such as definition of masses, vessels, microcalcifications, etc. were evaluated. Filter performances were assessed by statistical analysis of the physician's evaluation. Of the 12 visually evaluated image parameters, the scale-2 wavelet-based filter showed significant improvement in 6 parameters, the two hyperbolics in 6 parameters, and the exponential in 5 parameters, while the rest showed no significant image enhancement. Significant results were the improved visualization of micro-calcifications and of mammograms with fatty and fatty-grandular content. Processing time was less than 3s for the wavelet-based and hyperbolic filters in a typical desktop PC.*

1 INTRODUCTION

Over the past few years, wavelet-based techniques have been developed and applied in many areas of image processing. Image enhancement is an area that wavelet-based techniques have proven to perform successfully. In this study, a systematic evaluation of a wavelet-based enhancement filter and five histogram equalization filters were performed to X-ray mammographic images. An experienced radiologist assessed 11 mammographic image quality parameters for all the processed mammograms, in order to investigate the accuracy of the 6 filters.

2 MATERIALS AND METHODS

2.1 Wavelet-based filter

The wavelet-based sigmoid non-linear enhancement function involves three steeps [5, 6, 7]. First, the DAUB4 DWT (Discrete Wavelet Transform) [4] was applied in two scales for each mammogram. Second, the detail coefficients were processed in both scales, using a sigmoid function (A) as described in Eq.1.

$$W_{out} = a[sigm(c(W_{in} - b)) - sigm(-c(W_{in} + b))]$$
$$a = \frac{1}{sigm(c(1-b)) - sigm(-c(1+b))} \quad \textbf{(Eq.1)}$$
$$sigm(y) = \frac{1}{1+e^{-y}}$$

The W_{out} denotes the output coefficients, W_{in} are the input coefficients and parameters a and b control the threshold and the gain respectively. Figure 1 illustrates the process schematically.

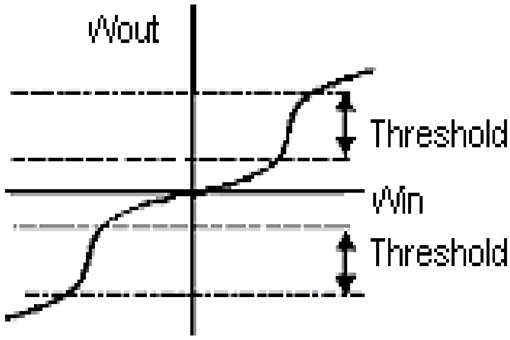

Figure 1. Function (A): Sigmoid non-linear enhancement

Finally, the processed mammograms were reconstructed using the Inverse DWT (IDWT) [4]. Schematically, the overall process is described in Figure 2.

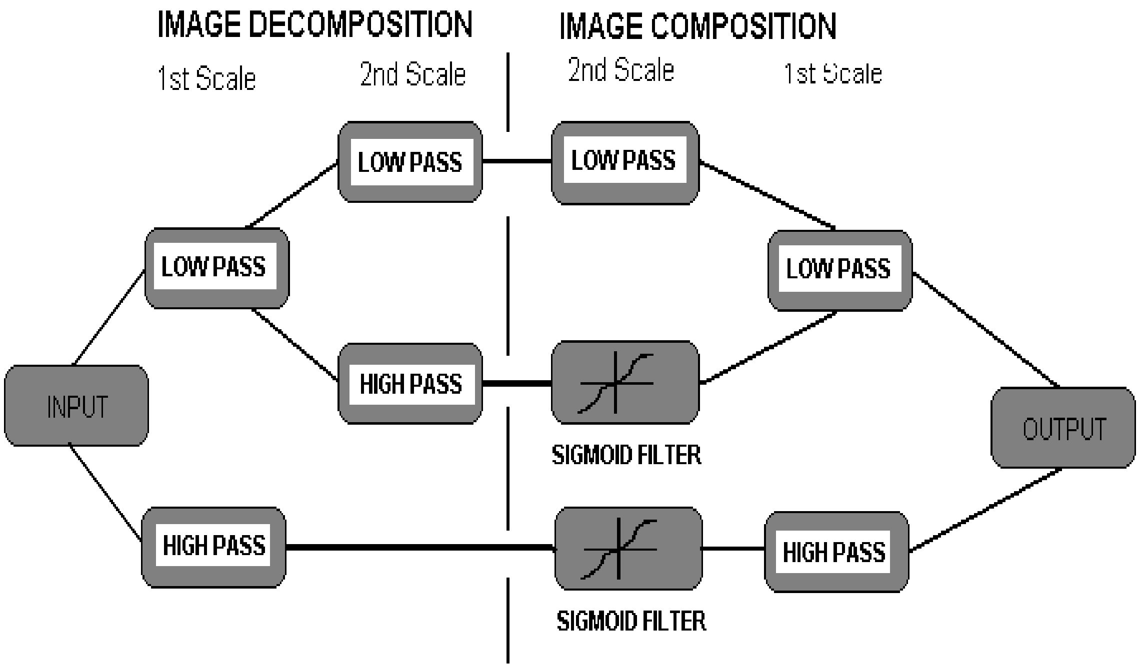

Figure 2. 2-scale analysis with non linear contrast enhancement function

2.2 Histogram equalization filters

Five Histogram Equalization Mapping Functions (HEMF) were developed and applied to mammograms [1, 2, 3]. The HEMF functions are based on corresponding probability density models for the desired output graylevel histogram. Table 1 illustrates the equations that were used in this study.

OUTPUT PROBABILITY DENSITY MODEL		MAPPING FUNCTION
Function (B): **Uniform**	$P_g(g)=\frac{1}{g_{\max}-g_{\min}}$	$g=(g_{\max}-g_{\min})CDF+g_{\min}$
Function (C): **Exponential**	$P_g(g)=c\cdot\exp[-c(g-g_{\min})]$	$g=g_{\min}-\frac{1}{c}\ln(1-CDF)$
Function (D): **Rayleight**	$P_g(g)=\frac{g-g_{\min}}{c^2}\exp\left[-\frac{(g-g_{\min})^2}{2c^2}\right]$	$g=g_{\min}+\left[2c^2\ln\left(\frac{1}{1-CDF}\right)\right]^{1/2}$
Function (E): **Hyperbolic_1** (Cube Root)	$P_g(g)=\frac{1}{3}\frac{g^{-2/3}}{g_{\max}^{1/3}-g_{\min}^{1/3}}$	$g=\left[\left(g_{\max}^{1/3}-g_{\min}^{1/3}\right)CDF+g_{\min}^{1/3}\right]^3$
Function (F): **Hyperbolic_2** (Logarithmic)	$P_g(g)=\frac{1}{g[\ln(g_{\max})-\ln(g_{\min})]}$	$g=g_{\min}\left[\frac{g_{\max}}{g_{\min}}\right]^{CDF}$

Table 1: The output probability density models and the respective mapping functions

The g_{min} and g_{max} are the minimum and maximum graylevels in the image, *CDF* is the Cumulative Distribution Function of the histogram, *g* is the calculated gray-tone of the processed image, and *c* is a weight factor.

2.3 Set up of the study

One hundred and thirty 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 130 mammograms were analyzed with a special-purpose application developed in C++. A number of mammogram image quality parameters were evaluated. Specifically, each filter was evaluated based on the choice of positive or negative effects related to:

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.

3 RESULTS AND DISCUSSION

Analytical studies have shown that hyperbolic-2 (Function F) histogram equalization filter enhanced the image quality 91% on average over all the test images (see: feature 1, table 2), while the wavelet based sigmoid filter (Function A) rates were 69% and hyperbolic-1 (Function E) rates were 68%. Thus, contrast in dense and fibro-grandular breasts was increased considerably in relation to the original images. Table 2 illustrates in detail the evaluated parameters and the percentage scores achieved by each filter.

In mammograms of senior women, full of fatty tissue, hyperbolic-2 filter (Function F) enhanced image quality 88%, hyperbolic-1 (Function E) 67% and sigmoid (Function A) 52% on average (see: feature 3, table 2). Nevertheless, in mammograms of young women, dense and full of fibro-grandular tissue, hyperbolic-2 filter (Function F) enhanced image quality in 90%, hyperbolic-1 (Function E) in 67% and exponential (Function C) in 36% cases (see: features 2 and 3, table 2).

The visual quality improvement of the micro-calcifications (see: feature 4, table 2) is important for the patient management and to assess the risk of breast cancer. Enhancement of the mammograms was achieved only by the two hyperbolic filters (Function E, Function F) at rates up to 24%, while the rest of the filters failed to improve the image quality. However, soft tissues such as veins, vessels and ducts (see: feature 5, table 2) were enhanced by the wavelet-based filter (Function A) at rates up to 36%.

In many cases, the characterization of a tumour as benign or malignant depends greatly on the morphology of the tumour [.], thus it is important for radiologists to discern the outline of a tumour, as well as to evaluate its texture structure (see: features 6,7,8,9, table 2) [.]. The enhancement of pathologic findings, the inhomogeneity and the delineation of tumour borders, were proved better for hyperbolic-2 (Function F) in a percentage of 39%, 35% and 47% respectively. The image details used for the characterization of a lesion as benign or malignant were also associated with the same filter (Function F) in 40% of the cases, followed by hyperbolic-1 (Function E) with 34%.

In the case of the breast skin, related to infections of subcutaneous fat, sebaceous cysts, hematomas and dermal nevi, the wavelet-based sigmoid filter (Function A) managed to improve the mammogram in a percentage of 55% (see: feature 10, table 2) while the rest failed to improve the original image. Finally, in the cases of lesions in the retro mammary space or axillary lymphadenopathy findings, the sigmoid filter (Function A) achieved significant improvement in 48% over all the test images (see: feature 11, table 2). An example of a real breast’s image processing is illustrated in figures 2, 3, 4, 5, 6, 7 and 8.

Parameters	A	B	C	D	E	F
Improves the contrast between dark and light areas	69	1	38	3	68	91
Improves the images of normal fatty breasts	52	0	33	1	67	88
Improves the images of dense fibro-grandular breasts	29	0	36	2	67	90
Improves the display and delineation of calcifications	4	0	21	0	24	24
Improves the visualisation of vessels, veins, ducts	36	0	1	0	2	8
Improves the visualisation of pathologic findings	9	0	23	2	30	39
Improves the Image-detail visualisation for the characterisation of a lesion as benign or malignant	12	0	26	0	34	40
Improves the accentuation of tumour inhomogeneity	8	0	26	0	30	35
Improves the delineation of tumour borders	12	0	26	1	36	47
Improves the visualisation of breast skin and soft tissues	55	14	0	0	3	0
Improves the visualisation of the thoracic muscle	48	0	0	0	0	1

Table 2: The score % of each filter

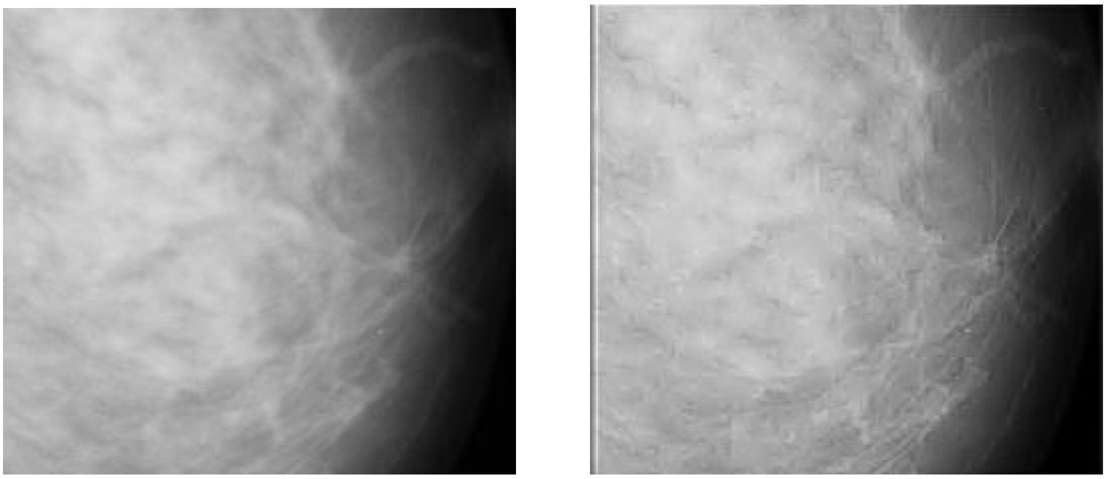

Figure 2. The original and the processed mammogram, using the sigmoid wavelet-based enhancement algorithm. The image size is 256x256x8, the Threshold is 6.6 and the Gain is 0.66.

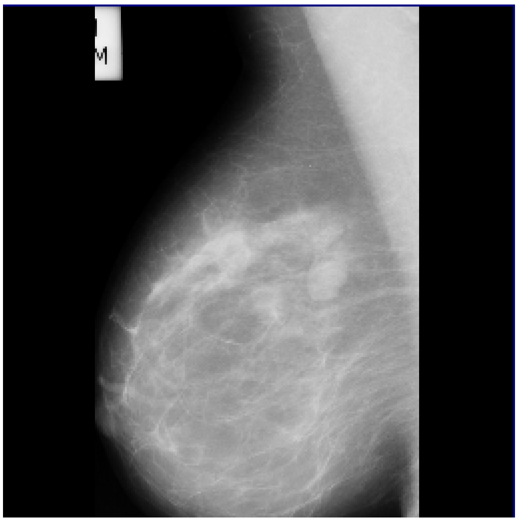

Figure 3. Original image

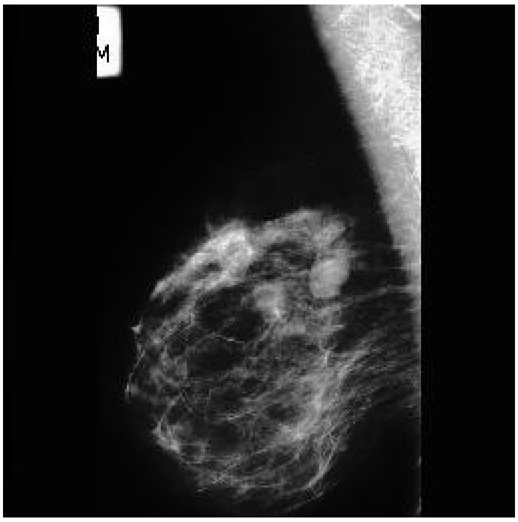

Figure 4. Hyperbolic-2 processed mammogram

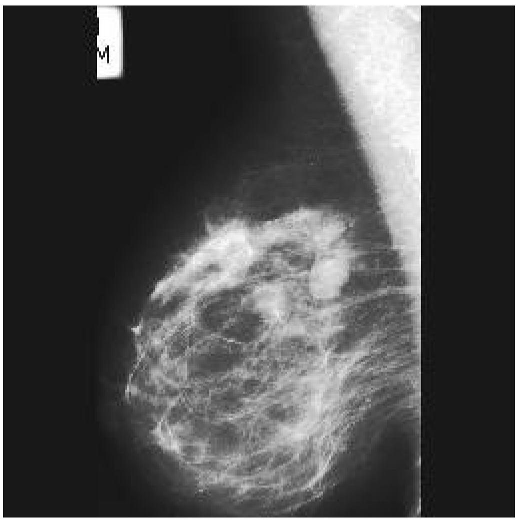

Figure 5. Hyperbolic-1 processed mammogram

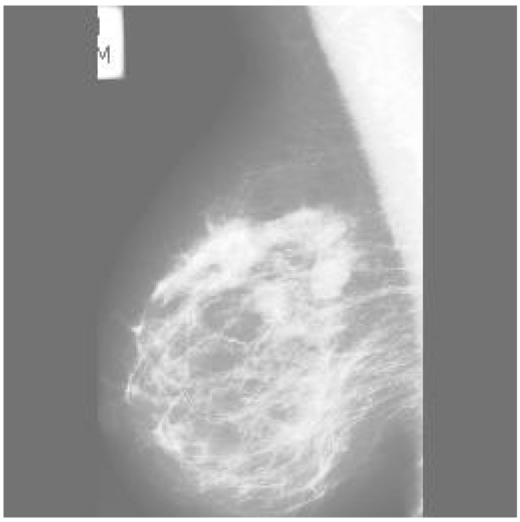

Figure 6. Uniform processed mammogram

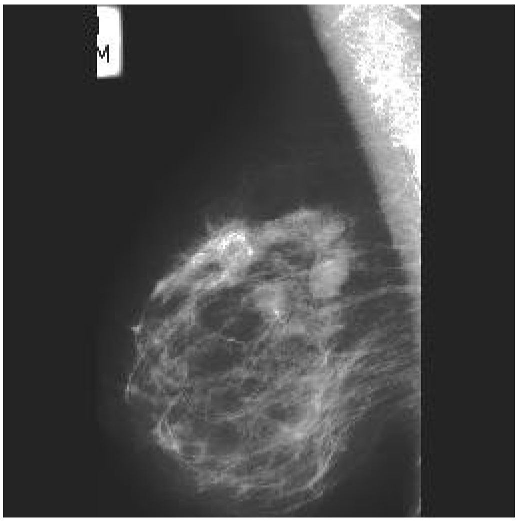

Figure 7. Exponential processed mammogram (c=60)

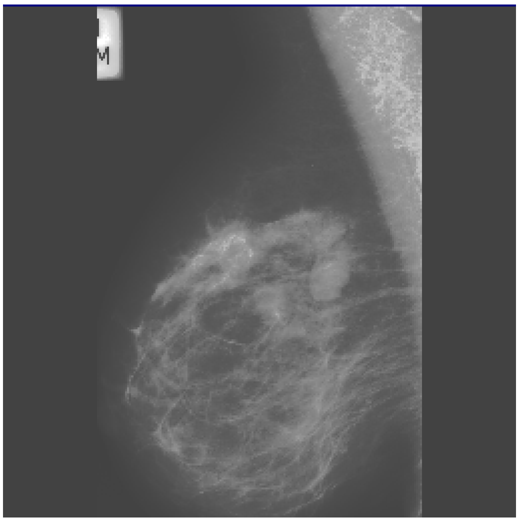

Figure 8. Rayleight processed mammogram (c=60)

4 CONCLUSIONS

According to our study, it was found that the sigmoid wavelet-based filter (Function A) achieved better visualization of the breast skin, the thoracic muscle, vessels, veins, and ducts, while it enhanced the contrast of the image visualization of normal fatty breasts in a satisfactory level. However, significant enhancement was accomplished by the hyperbolic-2 and hyperbolic-1 (Function E, Function F) histogram equalization filters, in cases such us dense or fatty breasts, increasing the overall contrast of the mammogram. Furthermore, tumours and micro-calcifications were better visualized. Thus, the optimal choice for the proper filter is related to the specific application and the image quality specifications of physicians. The process time for all filters took less than 3sec in a typical desktop PC (iPentium-4/2.4GHz, 512MB RAM), proving them plausible for real clinical applications.

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