Contrast enhancement by dyadic wavelet analysis

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ABSTRACT

This paper introduces a method for accomplishing mammographic feature analysis by multiresolution representations of the dyadic wavelet transform. Our approach consists of the application of non-linear enhancing functions within levels of a multiresolution representation. We show that there exists a simple constraint for functions such that image enhancement is guaranteed. Furthermore, a simple case in which the enhancement operator is a constant multiplier is mathematically equivalent to traditional unsharp masking. We show quantitatively that transform coefficients, modified within each level by non-linear operators, can make more obvious unseen or barely seen features of mammography without requiring additional radiation. Our results are compared with traditional image enhancement techniques by measuring the local contrast of known mammographic features.

Keywords–multiscale analysis, contrast enhancement, dyadic wavelets

1 INTRODUCTION

Many cancers escape detection due to the density of surrounding breast tissue. For example, differences in attenuation of the various soft tissue structures in the female breast are small, and it is necessary to use low levels of X-ray energy to obtain high contrast in mammographic film. Since contrast between the soft tissues of the breast is inherently low and because relatively minor changes in mammary structure can signify the presence of a malignant breast tumor, the detection is more difficult in mammography than in most other forms of radiography. The radiologist must search for malignancy in mammographic features such as microcalcifications, dominate and stellate masses, as well as textures of fibrous tissues (fibroglandular patterns). It has been suggested that as normally viewed, mammograms display only about 3% of the information they detect! [1].

In this paper we accomplish mammographic feature enhancement through a dyadic multiresolution representation [2, 3, 4]. By using a multiresolution representation, we decompose an image into a multiresolution hierarchy of localized information at different spatial frequencies. Our approach for mammographic feature enhancement consists of the application of linear and non-linear operators for image enhancement within levels of a redundant multiresolution representation. We show preliminary results that suggest such methods can emphasize significant features in mammography for improved visualization of breast pathology.

2 ONE-DIMENSIONAL DYADIC WAVELET TRANSFORM

The one-dimensional dyadic wavelet transform of a continuous function $f(x)$ at scale 2^k and position x is defined by the convolution of f and ψ as follows [5]

$$W_{2^k}f(x) = f(x) * \psi_{2^k}(x). \tag{1}$$

A function $f(x)$ can then be expressed in term of its wavelet transform as follows

$$f(x) = \sum_{k=-\infty}^{\infty} W_{2^k}f(x)*\chi_{2^k}(x) = \sum_{k=-\infty}^{\infty} f(x)*\psi_{2^k}(x)*\chi_{2^k}(x). \tag{2}$$

For enhancement purposes, we considered a special class of wavelets which satisfied $\psi(x) = \frac{d^2\theta}{dx^2}$. For this specific class of wavelets, Equation (1) can be written as

$$W_{2^k}f(x) = 2^{2k}\frac{d^2}{dx^2}\left[f(x) * \theta_{2^k}(x)\right],$$

and Equation (2)

$$f(x) = \sum_{k=-\infty}^{\infty} \left\{2^{2k}\frac{d^2}{dx^2}\left[f(x) * \theta_{2^k}(x)\right]\right\} * \chi_{2^k}(x).$$

3 LINEAR ENHANCEMENT

We now consider a linear enhancement operator which multiplies transform coefficients of a single channel $m \in$

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Z by a constant $C_m \in \mathrm{R}$. In this case, the "enhanced" function $\tilde{f}(x)$ is

$$\tilde{f}(x) = f(x) - 2^{2m}(C_m - 1)\frac{d^2}{dx^2}\left[f(x) * \theta_{2^{2m}}(x) * \beta_{2^m}(x)\right].$$

In the frequency domain, this is equivalent to a linear system with a transfer function

$$T(\omega) = 1 + 2^{2m}(C_m - 1)\omega^2\widehat{\theta}(2^m\omega)\widehat{\beta}(2^m\omega).$$

By choosing *real*, *symmetric* and *positive* $\widehat{\theta}(\omega)$ and $\widehat{\beta}(\omega)$, such a linear operator is guaranteed to enhance a specific range of the frequency domain.

In general, more than one channel may be enhanced (suppressed). Therefore, in its most general form, the system frequency response may be written as

$$T(\omega) = 1 + \sum_{m=-\infty}^{\infty} 2^{2m}(C_m - 1)\omega^2\widehat{\theta}(2^m\omega)\widehat{\beta}(2^m\omega).$$

We call this linear enhancement technique ***Multiscale Unsharp Masking***. A single channel linear enhancement is exactly equivalent to traditional ***Unsharp Masking***.

4 NON-LINEAR ENHANCEMENT

The output of such a system can be described by

$$\tilde{f}(x) = \sum_{k=-\infty}^{\infty} E\left[2^{2k}\frac{d^2}{dx^2}\left[f(x) * \theta_{2^k}(x)\right]\right] * \chi_{2^k}(x).$$

Experimentally, we found the following simple function effective for contrast enhancement

$$E(x) = \begin{cases} kx, & \text{if } |x| < T, \\ x - (k-1)T, & \text{if } x < 0, \\ x + (k-1)T, & \text{if } x > 0, \end{cases}$$

where $k > 1$.

5 EXPERIMENTAL RESULTS

Mathematical models of phantoms were constructed to validate our enhancement technique against false positives arising from possible artifacts introduced by the analyzing functions and to compare our methods against traditional image processing techniques of improving contrast. Our models included features of regular and irregular shapes and sizes of interest in mammographic imaging, such as microcalcifications, cylindrical and spicular objects and conventional masses. Techniques for "blending" a normal mammogram with the images of mathematical models were developed. The purpose of these experiments was to test the *performance* of our processing technique on inputs known "a priori" using mammograms where the objects of interest were deliberately obscured by normal breast tissues. The "imaging" justification for "blending" is readily apparent; a cancer is visible in a mammogram because of its (slightly) higher X-ray attenuation which causes a lower radiation exposure on the film in the appropriate region of a projected image. Our blended mammogram was constructed by adding the amplitude of the mathematical phantom image to a cancer free mammogram followed by local smoothing of the combined image.

A quantitative measure of contrast improvement was defined by a Contrast Improvement Index (CII), $\mathrm{CII} = \frac{C_{\mathrm{Processed}}}{C_{\mathrm{Original}}}$, where $C_{\mathrm{Processed}}$ and C_{Original} were the contrasts for regions of interest in the processed and original images, respectively.

Table 1 shows the contrast values obtained for mammographic features.

Table 1: Contrast values and CII for enhancement by unsharp masking (UNS) and non-linear multiscale enhancement of dyadic wavelet (DYA) coefficients.

Feature	C_{Original}	C_{UNS}	C_{DYA}	$\mathrm{CII}_{\mathrm{UNS}}$	$\mathrm{CII}_{\mathrm{DYA}}$
MMC	0.0217	0.0312	0.1219	1.43	5.61
MC	0.0192	0.0239	0.1225	1.24	6.36
SL	0.0295	0.0351	0.1295	1.19	4.38
AC	0.0204	0.0266	0.1219	1.30	5.97
WCM	0.0277	0.0280	0.0983	1.01	3.55

MMC: Minute microcalcification
MC: Microcalcification
SL: Spicular lesion
AC: Arterial calcification
WCM: Well-circumscribed mass

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