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Contrast Enhancement of Mammograms and Microcalcification Detection

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Abstract*: Mammography is an operative procedure for early detection of cancer present in breast. However, the pathological changes of the breast are difficult to interpret from low contrast mammograms. This research proposes a method to enhance the contrast of the mammogram that uses Non-subsampled contourlet transform (NSCT) based edge information. Instead of a directional filter bank in the conventional NSCT structure, this paper uses multiscale non-separable edge filters. These edge filters outputs intrinsic edge structure information based on simplified hyperbolic tangent function applied with two polarized schemes. This edge information further used to improve the local contrast. Adaptive histogram equalization (AHE) also used to increase the overall contrast of mammogram. Improved detection of microcalcification (MC) from enhanced mammogram images shows the success of this algorithm. This method has better enhancement measure (EME) than AHE and unsharp based mammogram enhancement method.

***Keywords* : Contourlet; Edge information; Hyperbolic Tangent filter; Mammogram Image Enhancement.**

I. INTRODUCTION

A mammogram is a low-dose breast image x-ray film used to display the internal tissue. It can help to identify calcifications and tumors within the breast and to visualize structures inside the breasts. It is one of the simplest effective methods to diagnose the early stage breast cancer. However, due to poor visibility and noisy nature due to low contrast of mammograms, it is challenging to understand the pathological changes of the breast. In particular, microcalcifications (MC) in the form of tiny spots cannot be easily visualized. Therefore, it is very important to provide better visibility by means of mammogram image contrast enhancement. After this enhancement, calcification detection method can apply to provide better MC visualization.

In human perception, weak identification of edges present in an image is felt as lack of details. Therefore many image enhancement approaches emphasis on the edges. In this background, this paper also laid emphasis on the detection of efficient edge information and uses for image enhancement. However, it is difficult task and no single method at present. has devised, which will successfully determine all type of edges. In a mammogram image, visually important intrinsic edge features exist in any possible scale, direction and position. Conventional algorithms uses high pass filters are sensitive to the fine edges and difficult to distinguish the weak edges from noise.

This paper proposes a non-separable method to gather the fine intrinsic features along with various directions and scales. Even though isotropic Laplacian of Gaussian (LoG) is common edge detection (ED) operator [1], its level of smoothness affects the visually important texture regions [2] in mammogram images. Wavelets are worthy in isolating the edge points at various scales and directions, therefore, wavelet-based ED is impressive and their usefulness is shown in [3-4]. However, they capture limited directional information of edges and do not perceive smoothness due to the usage of separable wavelets. Separable wavelets often have blurred regions in diagonal orientations and 2D non-separable multi-resolution filters [5-8] removes such effect. In particular, a simplified version of Gabor wavelets (SGW) for extracting the edge information for efficient ED has proposed in [9]. Contrast improvement is an essential technical image processing tool in biomedical applications where human perception remains the primary approach to extract relevant information. Many image contrast enhancement methods are previously published [10-13] in the past. Some research works on mammogram to enhance the image contrast for cluster of MC and masses associated with breast cancer presented in [14-15]. In addition to that, wavelet transform based enhancement algorithms also found in the literature [16-19]. Though wavelet based image processing is common, the wavelets characteristics (i.e.) isotropic and limited directivity are the main drawbacks. Therefore, anisotropic transforms such as curvelets [20-21], contourlets [22-24] based algorithms are used in medical imaging. Mammogram enhancement algorithm proposed in [25] utilizes tilted and stretched 'Haar' basis functions for sharpening process. Two stage histogram equalization approaches [26] also used for mammogram enhancement. Though, various methods are present in the literature, enhancing the contrast of the mammogram images having fine details is still in research [27].

The contributions of this work has twofold

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1) This paper introduces a modification in the conventional Non-subsampled Contourlet (NSCT) structure [7] in which directional filters (DF) follows the Non-subsampled pyramid (NSP) decomposition. Instead of DF in NSCT, this paper employs two orthogonal polarized schemes of non-separable multiscale simplified 2D hyperbolic tangent directional edge filters (HTDE) for gathering efficient edge information.

2) In order to improve the overall contrast, a novel method which assimilates the above edges to sharp and apply the histogram equalization adaptively (AHE) on a mammogram. This yields noteworthy improvements in edge detection and hence contrasts. The noise effect due to high pass characteristics of the HTDE are suppressed by incorporating scale multiplication. (i) Anisotropic edge features at various scales and (ii) preservation of intrinsic edge features while enhancing are the main benefits of this proposed scheme.

II. MATERIALS AND METHODS

Fig.1. depicts the NSP followed by HTDE for contrast enhancement procedure and resembles NSCT structures in which NSP followed by DFB. A hyperbolic based tangent function for simple non-separable edge patterns for different scales and orientations are defined. They are applied to detect the edge features by applying on high-frequency band of NSP. Thus the NSP collected locally correlated points and HTDE seizes the linear edge structure along with directions.

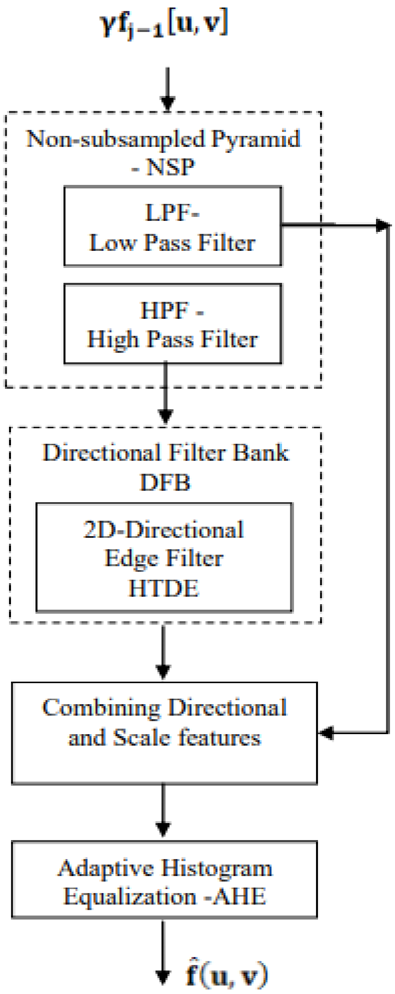

Figure.1 Block diagram proposed mammogram enhancement

The responses of HTDE filter are joined in a novel way to provide a sharpened mammogram image. In order to further enhance the global contrast, the histogram of the sharpened image is adjusted. The design of HTDE filter uses hyperbolic tangent function (HBT) has better localization characteristics than Gaussian. Fig.2 (a) compares the 1D profile of Difference of Gaussian and HTDE. From the Fig.2 it is seen that HTDE has narrow 1D profile and provides better localization. Let consider HBT function $G(x) = \begin{cases} \frac{1-e^{-\sigma_w x}}{1+e^{-\sigma_w x}}, & |x| \leq W \\ 0 & \text{otherwise} \end{cases}$. The filter $G(x)$ is odd symmetric nature with zero crossing at the origin and slope at the zero crossing point given by $\sigma_w/2$ with the W filter width. The 1D profile of $G(x)$ for $W = 2$; second-order differential is shown in Fig.2 (a). To obtain the HTDE filter coefficients, the 1D profile of HBT is quantized to a required number of quantization levels. If the total number of quantization levels is (i.e.) five, then two levels are positive, two levels are negative and one level for zero are considered as in Fig.2 (b). Since the function is anti-symmetrical, it is preferable to take the odd number of levels. If more and more quantization levels are employed, the simplified filter look like HBT profile in continuous domain. Determination of quantization levels for HBT is same as in [8]. Suppose the number of uniform quantization levels is denoted as r_l and the number of quantization levels becomes $2r_l + 1$. The quantization levels for corresponding largest magnitude L_{max} is $p(k) = \frac{L_{max}}{2r_l+1} 2k$ and $qn(k) = \frac{-L_{max}}{2r_l+1} 2$, where $k = 1,2,\ldots j_l$ and $qp(k), qn(k)$ are positive and negative quantization levels. Fig.3 shows the grey scale masks of 2D filters for various directions. For five quantization levels $[qp_1, qp_2, q_0, -qn_2, -qn1_1]$, the simplified HBT filter coefficients are [0.015, 0.03, 0, -0.03, -0.015] in the same way. Since edges are typically present in an image as localized information, a smaller window size of the directional patterns can be chosen (i.e.) 3x3 or 5x5. Moreover, the masks are 2D non-separable, and effectively capture linear edge structures from the edge information.

In order to capture smooth contours in images, the NSCT uses elongated basis functions with different aspect ratios using multiscale NSP and DFB combination. Let an image $\gamma(f_{j-1}[u,v])$ is decomposed into $\{f_j[u,v], c_j[u,v]\}$ coefficients by the discrete NSCT for level j where, $f_j[u,v] = \gamma f_{j-1}[u,v] * \phi_a^L$ and $c_j[u,v] = \gamma f_{j-1}[u,v] * \psi_a^L * \psi_{a,\emptyset}^D$. ϕ_a^L and ψ_a^L are coefficients of low, and high pass filter of NSP with scale $a = 1,2,3 \ldots N$. are coefficients of low, and high pass filter of NSP with scale $a = 1,2,3 \ldots N$. $\psi_{a,\emptyset}^D$ is the HTDE coefficients, which can be used to obtain the oriented filter responses for the $\emptyset$ angle with scale $'a'$. $'\gamma'$ is the parameter which can be used to adjust the perceived naturalness of the mammogram. Also, in our scheme $\psi_{a,\emptyset}^D$ is operated on

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the image data in two polarized schemes $' + D'$ and $' - D'$ which are described as in [27]. Let two functions are, $\psi_{a,\emptyset}^{+D}$ and $\psi_{a,\emptyset}^{-D}$ and the edge information from HTDE based NSCT are computed by $E_{a,\theta}^{D} = \sqrt{(E_{a,\emptyset}^{+D})^2 + (E_{a,\emptyset}^{-D})^2}$, where $E_{a,\emptyset}^{D+} = \gamma\, f_{j-1}[u,v] * \psi_a^L * \psi_{a,\emptyset}^{D}$ and $E_{a,\emptyset}^{D-} = \gamma\, f_{j-1}[u,v] * \psi_a^L * (-\psi_{a,\emptyset}^{D})$. The enhanced image $\hat{f}(u,v)$ from $E_{a,\emptyset}^{D}$ is defined as

$$\gamma\, \hat{f}(u,v) = f(u,v) + \alpha \prod_{a=1}^{N} \left\{ \sum_{\emptyset=1}^{\Theta} \left| E_{a,}^{D}(u,v) \right|^2 \right\}^{\frac{1}{2}} \quad (1)$$

$f(u,v)$ is the low pass filtered image, α is the parameter used to determine the amount of edge information that is to be processed for enhancement.. The total response is determined from summing the all polarized (oriented) responses. Efficient noise control [29] is achieved through the scale multiplication of edge responses in various scales 'a'.

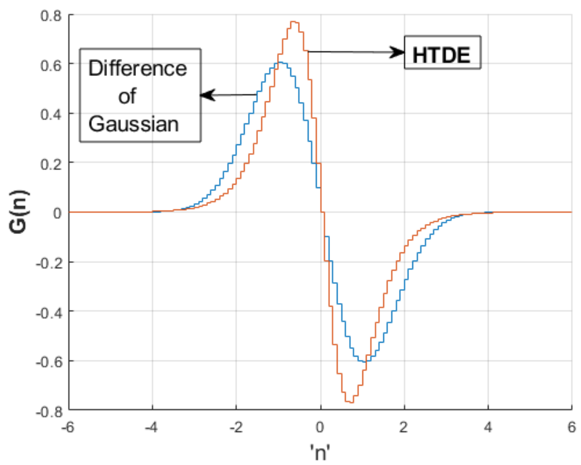


Figure.2. (a) One dimensional spatial profile of Difference of Gaussian and HTDE filter

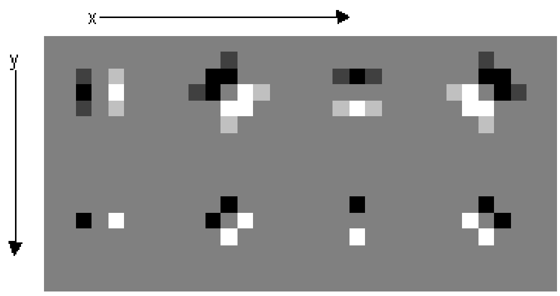


Figure.3. Simplified HBT filters. First row: Filter length of five with four directions. Second row: Filter length of three with four directions

The weighted HPF and the sum of multiscale anisotropic edge information represents through the second term in Eq.1. Superimposing of the original mammogram with HTDE responses improves the sharpening process. These HTDE responses are optimum intrinsic line structures and edges from the mammogram to be enhanced. This method efficiently improves the contrast especially near to object boundary. The benefit of the proposed technique by Eq.1 not only improves the contrast (contrast enhancement) but also successfully suppress the noise. Sum of all oriented responses or maximum of absolute (modulus maxima) provides the multiscale and multidirectional HPF responses that correspond to HF components.

The sharpened mammogram image, which is generated by Eq.1, is processed by AHE. For better and further visual quality than the original, AHE is used to generate a contrast enhanced mammogram by making histogram uniform. The mammogram is contrast enhanced by transforming the grey pixel values to obtain the histogram matched image. Clip Limited AHE (CLAHE) is a commonly used method for contrast enhancement. It divides the mammogram image into related constitutional regions and applies AHE to make image features more visible which are all hidden.

III. RESULTS AND DISCUSSIONS

The proposed mammogram enhancement algorithm tested on 23 X-ray mammograms images available in MIAS [30] database in calcification category. This proposed technique comprises two steps (i) accumulating the edge information from new anisotropic NSCT decomposition and (ii) using the same in local and global contrast of the mammogram improvement. HPF and LPF are applied on X ray mammograms. As described in section II the proposed method can use any one of (i) spectral filter which is described in [31] that have better localization, without subsampling (un decimation) output (ii) LPF and HPF used in á trous algorithm and (iii) decomposition filter which is non-sub sampled. The above filters are used to ensure the shift invariance by retaining all samples without discarding which is a beneficial property for feature detection in features. This paper uses the non-subsampled version of the spectrally designed filter. They not only have the advantage using 'raised cosine transition that helps to collect more correlated edge information' but also 'without aliasing'. The suitable correlated edges like features are masked with HTDE directional filters. These directional masks are capable to remove the blurred regions in diagonal orientations and they are non-separable 2D patterns as depicted in Fig.3. The enhanced images are obtained by Eq.1. The proposed contrast improved results are compared with adaptive histogram equalization and nonlinear unsharp masking (NLUSM) as described in [26]. In order to demonstrate the effectiveness of proposed mammogram contrast enhancement algorithms, Fig.4 presented with some of the enhanced results. It is recognized that the proposed algorithm make available more reliable sharpened edge structure with well controlled noise effect and strong contrast enhancement than AHE and NLUSM. Also, this technique provides promising enhancement results while preserving local information of the original image. As expected, AHE technique provided strong contrast enhancement, it is not so successful to preserve local information in the input X ray mammogram image.

The new method brings out the fine hidden details. Performances are compared using discrete entropy (H) and Enhancement Measure (EME) [32] parameters. Table 1 tabulates the computed entropy and EME parameters of various techniques. Superior contrast enhancement of the mammogram by the proposed method recognized by the improved entropy and EME measures.

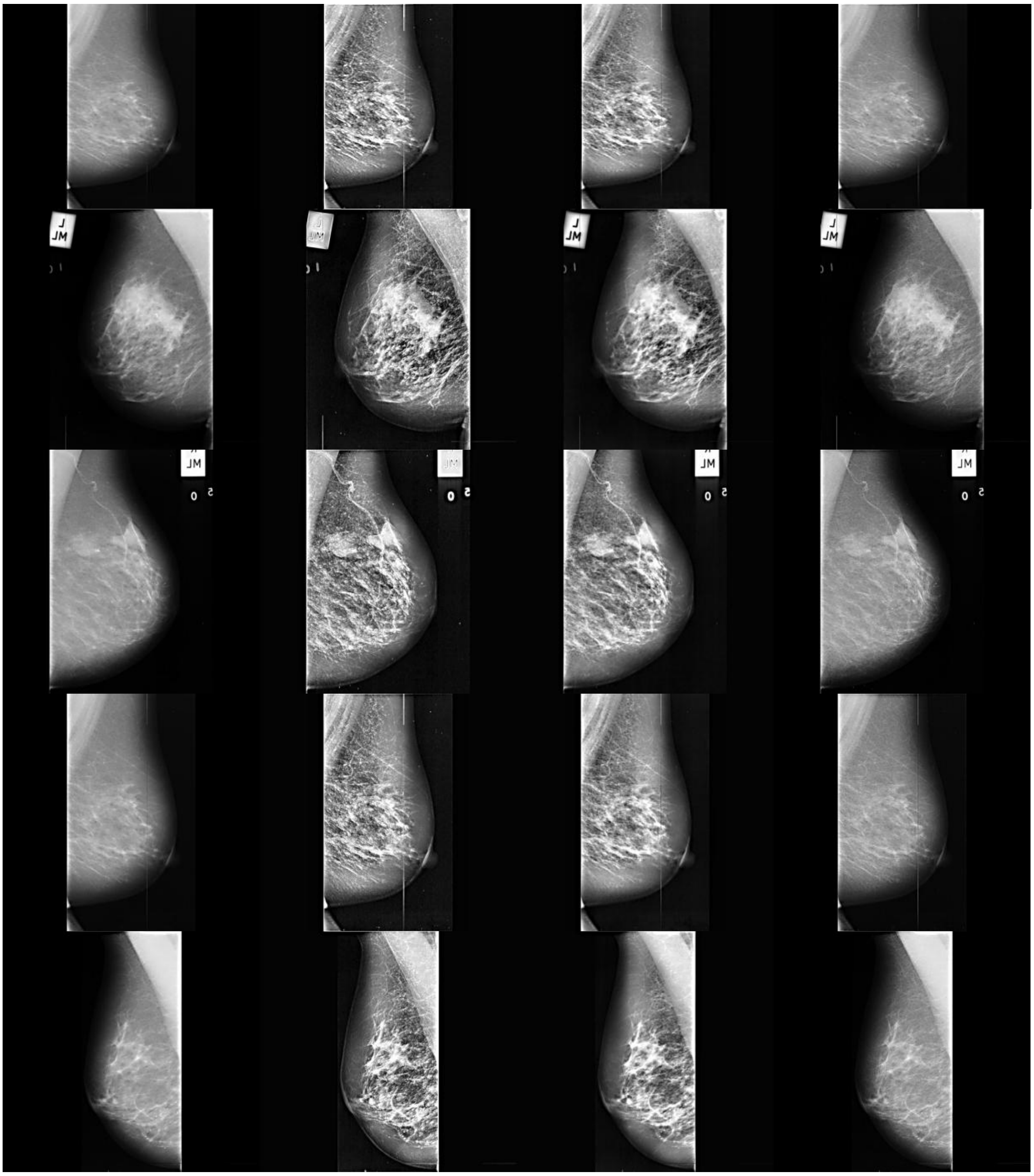


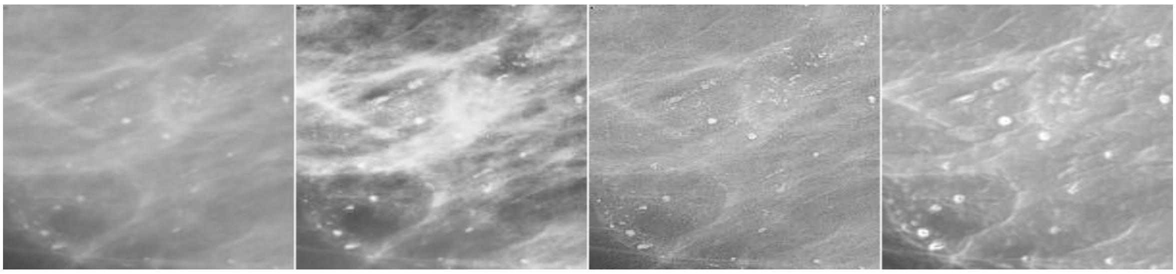
Figure 4. Comparison of Various Enhancement Algorithm: Column '1' original images. Column '2' Proposed Method. Column '3' AHE. Column '4' NLUSM

Detection of Microcalcification (MC): The cluster of MC indicates the early sight of cancer. In the detection process of MCs, low contrast and small sized MCs could be misinterpreted or missed by medical experts. Mammogram image enhancement technique is utilized by radiologist to characterize and detect the MC that can be seen on a mammogram. A threshold is applied to various cropped parts of enhanced images shown in Fig.5. After the application of threshold on Fig. 5 are given in Fig.6.

From the results, the proposed method offers noticeably improved MC detection ability over the AHE and NLUSM techniques.

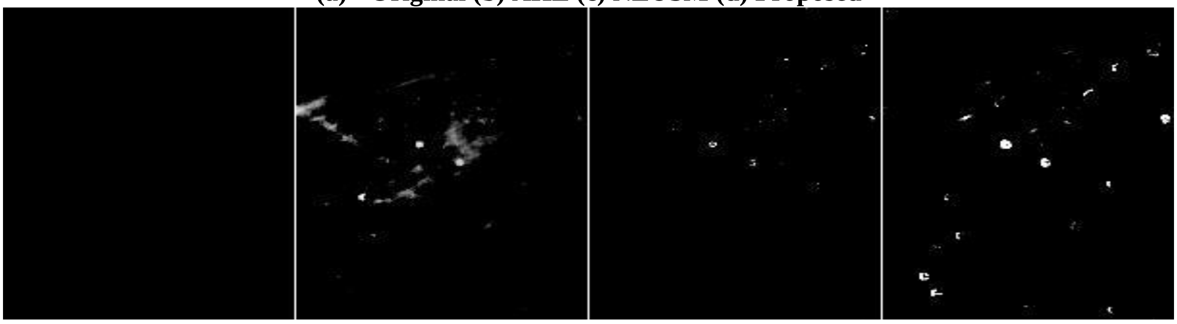
Table 1 Performance Comparison of various Enhancement Methods

Image	EME				Entropy			
	Original	AHE	NLUSM	Proposed	Original	AHE	NLUSM	Proposed
mdb209	3.63	7.36	5.28	10.99	5.03	5.35	5.00	5.85
mdb211	2.00	4.79	3.98	7.95	4.41	4.96	4.41	5.39
mdb213	1.81	3.69	5.42	5.70	3.75	3.87	3.84	4.18
mdb216	2.84	5.15	4.69	8.00	5.00	5.33	4.97	5.70
mdb218	2.91	5.87	10.49	9.41	5.18	5.51	5.34	5.92
mdb219	2.50	5.71	4.65	8.38	5.45	5.58	5.44	5.96
mdb222	2.78	3.95	5.91	7.47	4.55	5.27	4.57	5.60
mdb223	1.69	3.72	4.92	5.85	3.67	3.89	3.76	4.18
mdb226	2.80	5.29	3.79	9.47	4.13	4.75	4.09	5.22
mdb227	1.58	3.67	2.95	5.68	3.67	4.10	3.67	4.38
mdb231	3.93	6.37	5.03	9.76	5.34	5.60	5.38	6.06
mdb233	2.22	4.34	3.93	7.11	4.18	4.69	4.16	5.06
mdb236	2.83	5.81	9.84	9.49	5.12	5.48	5.32	5.94
mdb238	2.09	3.97	7.35	7.54	4.36	5.07	4.51	5.45
mdb239	3.62	5.81	6.19	8.47	5.35	5.68	5.41	6.09
mdb240	3.18	5.01	6.28	8.02	5.35	5.71	5.41	6.09
mdb241	1.61	3.50	4.69	5.49	3.61	3.89	3.70	4.19
mdb245	1.94	5.45	3.61	4.07	3.82	3.93	3.81	4.22
mdb248	4.38	9.80	6.32	6.74	5.11	5.62	5.48	5.34
mdb249	2.58	7.55	4.70	5.32	4.55	5.33	5.21	4.84
mdb252	2.73	7.92	4.28	6.89	4.33	5.23	5.10	4.65
mdb253	2.82	7.94	5.44	9.42	5.20	5.73	5.62	5.63
mdb256	2.75	8.79	5.73	4.90	4.98	5.59	5.36	5.29



(a) (b) (c) (d)

Figure 5: Enlarged images obtained from various enhancement techniques.
(a) Original (b) AHE (c) NLUSM (d) Proposed



(a) (b) (c) (d)

Figure 6: Microcalcification detection of images in Fig 5 using fixed threshold
(a) original (b) AHE (c) NLUSM (d) Proposed

IV. CONCLUSION

This paper proposed a method to enhance the contrast of the mammograms and applied to detect MC.

The mammogram edge feature information is computed by applying newly designed directional edge filter on the decomposition stage of the non-subsampled contourlet transform (NSCT) structure. The simple non-separable patterns of directional edge filters that are derived from the simplified hyperbolic tangent function are used as filter banks of NSCT structure. The proposed enhancement technique uses the linear structures captured by NSCT. These geometrical directional edge features are combined in a new way and added with original followed by histogram equalization to enhance the mammogram image contrast. The proposed enhancement method has improved Enhancement Measure (EME) than method common adaptive histogram equalization and nonlinear unsharp masking based. Also as an application, the detection of microcalcification (MC) from our enhanced mammogram is superior to other methods.

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