

Fractional Order Filter based Enhancement of Digital Mammograms

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Abstract—Abnormality detection in low contrast mammogram images is a challenging task. Enhancement of mammograms is necessary to increase the visibility of the abnormalities present in the mammograms. This paper proposes a fractional order differential based filter (FDD) to enhance low contrast mammogram images. Enhancement is performed for nine orders of derivative. Two enhancement performance parameters are computed to analyze the results. Performance of the proposed enhancement method is compared with the histogram equalization, contrast limited adaptive histogram equalization, and unsharp masking methods. Analysis of both quantitative as well as visual results shows that the proposed algorithm performs better as compared to other existing techniques. Proposed algorithm is validated on Digital Database for Screening Mammography (DDSM) and mammogram images of Mini-Mammographic Image Analysis Society (mini-MIAS) databases.

Index Terms— Breast Cancer Detection, Image Enhancement, Fractional Order differential, Histogram Equalization, Unsharp Masking

I. INTRODUCTION

Early detection and treatment of breast cancer is effective approach to reduce the mortality ratio of women due to cancer. Several image modalities namely ultrasound, magnetic resonance imaging (MRI), positron emission tomography (PET), computerized tomography (CT), and X-ray imaging (mammography) are used to detect breast cancer. Mammography is considered as effective imaging technique for screening and early detection of breast cancer. However, it is difficult to detect abnormalities present in the low contrast mammograms. This work aims to develop a technique for enhancement of low contrast mammogram images.

Several image enhancement techniques have been used in literature for contrast enhancement and noise filtering of mammograms. Dhawan et al. proposed an adaptive neighborhood processing approach that uses the knowledge of desired features to design the contrast enhancement function [1]. Region based contrast enhancement is proposed by Morrow et al. [2]. Enhancement of mammographic features using multi-resolution technique is given by Laine et al. [3]. Qian et al. used tree structured non-linear filter for noise removal of mammograms [4]. Adaptive density weighted contrast enhancement filter for mammographic breast mass detection is proposed by Petrick et al. [5]. Unsharp masking technique for mammogram

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enhancement is used by several authors [6]-[8]. Fuzzy logic approach for contrast enhancement is proposed by Cheng et al. [9], [10]. Integration of fuzzy logic with structure tensor for mammogram contrast enhancement is applied by Jiang et al. [11]. Wavelet based techniques are also used by many authors [12], [13]. Wavelet based technique for micro-calcification enhancement in mammograms is proposed by Heinlein et al. [14]. Anisotropic diffusion filtering for medical image enhancement is proposed by George et al. [15]. Homomorphic filtering for mammogram image denoising is used by Yoon et al. [17]. Pisano et al. applied contrast limited adaptive histogram equalization (CLAHE) method for enhancement of the abnormality in dense mammogram [18]. Kim et al. proposed the first derivative and local statistics to remove film artifacts and mammographic feature enhancement [19]. Noise suppression and contrast enhancement of mammograms in wavelet domain is applied by Scharcanski et al. [20] and Tang et al. [21]. Nonlinear unsharp masking is used by Panetta et al. [22]. Lai et al. concluded that median filters with 5×5 mask perform better for image enhancement and noise removal [23].

Singh et al. proposed a fractional order differential based filter (FDD). They used Chebyshev polynomials to approximate the filter function [24]. The present work introduces a fractional order derivative based mask for mammograms enhancement. The mask coefficients are calculated by using Chebyshev polynomial based approximation.

The structure of this paper is as follows. Section 2 discusses the proposed algorithm and design of Chebyshev polynomial based fractional order mask. Section 3 describes experimental results and discussion followed by conclusions reported in Section 4.

II. PROPOSED ENHANCEMENT ALGORITHM

Consider two higher order differentiable functions in R as $Y(t)$ and $\tilde{Y}(t)$ which are observed and original functions, respectively. The observed function in terms of original function and error $\xi(t)$ can be given as [24]:

$$Y(t) = \tilde{Y}(t) + \xi(t) \quad (1)$$

The present work encompasses smoothing of observed function by the use of n^{th} order derivative, L point filtering window, and n -degree polynomial approximation. Any function $Y(t)$ can be obtained by polynomial expansion expressed as:

$$Y(t) = \sum_{k=0}^n c_k T_k(t) \quad (2)$$

here $t = 1, 2, 3, \dots, L$ denotes the position of the t^{th} point in the filtering window and c_k represents the k^{th} coefficient of

polynomial function. Least-square method is used to estimate coefficients c_k . Equation (2) can be expanded as:

$$\begin{aligned} T_0(1)c_0 + T_1(1)c_1 + T_2(1)c_2 + \dots T_n(1)c_n &= y_1 \\ T_0(2)c_0 + T_1(2)c_1 + T_2(2)c_2 + \dots T_n(2)c_n &= y_2 \\ T_0(3)c_0 + T_1(3)c_1 + T_2(3)c_2 + \dots T_n(3)c_n &= y_3 \\ \dots \\ T_0(L)c_0 + T_1(L)c_1 + T_2(L)c_2 + \dots T_n(L)c_n &= y_L \end{aligned} \quad (3)$$

$Y = [y_1, y_2, \dots, y_L]^T$ denotes function points measured in the filtering window. T is a matrix of order $L \times (n+1)$ defined as:

$$T = \begin{bmatrix} T_0(1) & T_1(1) & T_2(1) & \dots & T_n(1) \\ T_0(2) & T_1(2) & T_2(2) & \dots & T_n(2) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ T_0(L) & T_1(L) & T_2(L) & \dots & T_n(L) \end{bmatrix} \quad (4)$$

The elements of matrix T are computed by using Chebyshev polynomial [25]:

$$T_{n+1}(t) = 2tT_n(t) - T_{n-1}(t), \quad T_0(t) = 1, \quad T_1(t) = t \quad (5)$$

The polynomial coefficients C are computed as:

$$C = (T^T T)^{-1} T^T Y \quad (6)$$

Solving (3) by using (5) and (6), the resultant equation is expressed as:

$$\hat{Y} = TC = T(T^T T)^{-1} T^T Y = WY \quad (7)$$

here W denotes window coefficient matrix. Smoothing operation is performed by using different window coefficient matrix [26]. Riemann-Liouville fractional order derivative can be expressed as:

$${}_0 D_x^\alpha Y(t) = \frac{1}{\Gamma(l-\alpha)} \frac{d^l}{dt^l} \int_0^x (t-x)^{l-\alpha-1} f(x) dx \quad (8)$$

here $0 \leq l-1 < \alpha < l$, and $\Gamma(l-\alpha)$ is the Gamma function of $(l-\alpha)$. α is the positive order of differentiation and its value lies between $l-1$ to l . The fractional order differentiator, corresponding to window coefficient matrix W , can be obtained by (8). Different properties of fractional order differentiation [27], [28] are applied on (7) and generalized form of resultant equation is expressed as:

$$\hat{Y}_t^\alpha = T_t^\alpha C = W_t^\alpha Y = c(T^T T)^{-1} T^T Y \quad (9)$$

here \hat{Y}_t^α denotes α^{th} derivative of the t^{th} point in the filtering window, W_t^α denotes α^{th} derivative coefficient vector of the t^{th} point in the filtering window, and c is given as:

$$c = \left[\frac{1}{\Gamma(1-\alpha)} i^{-\alpha}, \frac{\Gamma(2)}{\Gamma(2-\alpha)} i^{1-\alpha}, \frac{\Gamma(3)}{\Gamma(3-\alpha)} i^{2-\alpha}, \dots, \frac{\Gamma(n+1)}{\Gamma(n+1-\alpha)} i^{n-\alpha} \right]$$

The defined fractional order mask W is used for mammogram enhancement. The mask W is convolved with the input image I . Moving window concept is applied in convolution.

The algorithm can be expressed as follows.

Algorithm (L, n, α, h_0, I_E)

Input: L, n, α

L : Length of differentiator

n : Order of polynomial

α : Order of derivative

T : Matrix

a : Constant

W : Window matrix

Γ : Gamma function

Output: h_0, I_E

begin

for $i \leftarrow 1$ **to** L

for $j \leftarrow 0$ **to** n

 // Calculate matrix $T(i, j)$

$T(i, j) = 2iT(i, j) - T(i, j-1)$

 // Here $T(i, 0) = 1, T(i, 1) = i$

end for

end for

for $i \leftarrow 1$ **to** L

for $j \leftarrow 0$ **to** n

 Calculate $a = \left[\frac{\Gamma(n+1)}{\Gamma(n+1-\alpha)} i^{n-\alpha} \right]$

$W_i^{(\alpha)} = a(T^T T)^{-1} T^T$

end for

end for

$I_E = \text{convolution}(I, w)$

end

III. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed algorithm is validated with publicly available mini-MIAS [30] and Digital Database for Screening Mammography (DDSM) [31] datasets. MIAS consists of 322 (117 abnormal and 206 normal) MLO views mammogram. The size of images is 1024×1024 pixels. DDSM contains images of 2620 cases with the contrast resolution of 12-bits and 16-bits. The proposed algorithm is validated on all mammograms of MIAS and 300 randomly chosen mammograms of DDSM dataset. The proposed mask is designed for different order of differentiation. The degree of Chebyshev polynomial is taken as $n = 2$ and size of the mask is taken as 3×3. Enhancement is applied for nine different order of differentiation, i.e., $\alpha = [0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1]$. The performance of the proposed algorithm is compared with the existing enhancement techniques, i.e., histogram equalization (HE), CLAHE, and unsharps masking [32]. Experimental results obtained with three randomly chosen mammograms from MIAS and DDSM datasets are shown in Fig. 1 and Fig. 2.

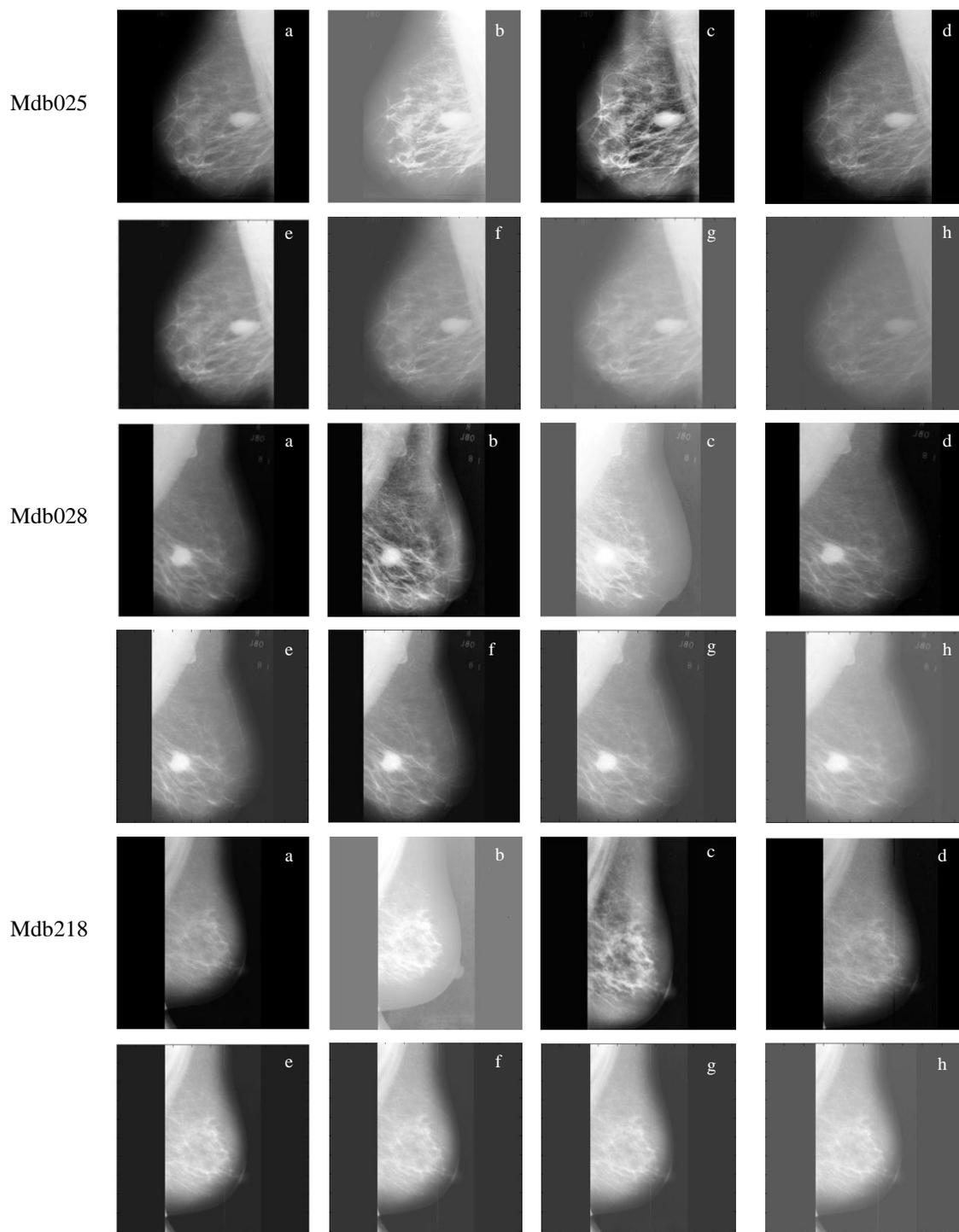


Fig.1. Enhancement results for sample images from MIAS dataset (a) original image, (b) HE, (c) CLAHE, (d) unsharp masking, (e)-(h) proposed fractional differential order technique with $\alpha=0.2$, $\alpha=0.3$, $\alpha=0.4$, and $\alpha=0.5$.

The results show that the enhanced mammograms using HE and CLAHE method are over-enhanced. The visual quality of mammogram is marginally improved by unsharp masking. It is clearly observed from the experimental results that contrast of mammograms are better for $\alpha=0.2$ than any other values of α visually. The order of differentiation plays a significant role in image enhancement. Mammograms are enhanced when the order of differentiation varies from 0.2 to 0.5. The quality of enhancement degraded for $\alpha>0.5$, thus, the enhancement results of only four order of differentiation $\alpha= [0.2, 0.3, 0.4, 0.5]$ are presented in Fig. 1 and 2.

Quantitative analysis of the proposed enhancement algorithm is done by using two enhancement measurement parameters, i.e., contrast improvement index (CII) and second derivative like measurement (SDME) [22]. CII measures the contrast improvement of original image as:

$$CII = \frac{C_{enhanced}}{C_{Original}}, C = \frac{f - b}{f + b} \quad (10)$$

here f and b represents the average pixel intensity of foreground and background images, respectively.

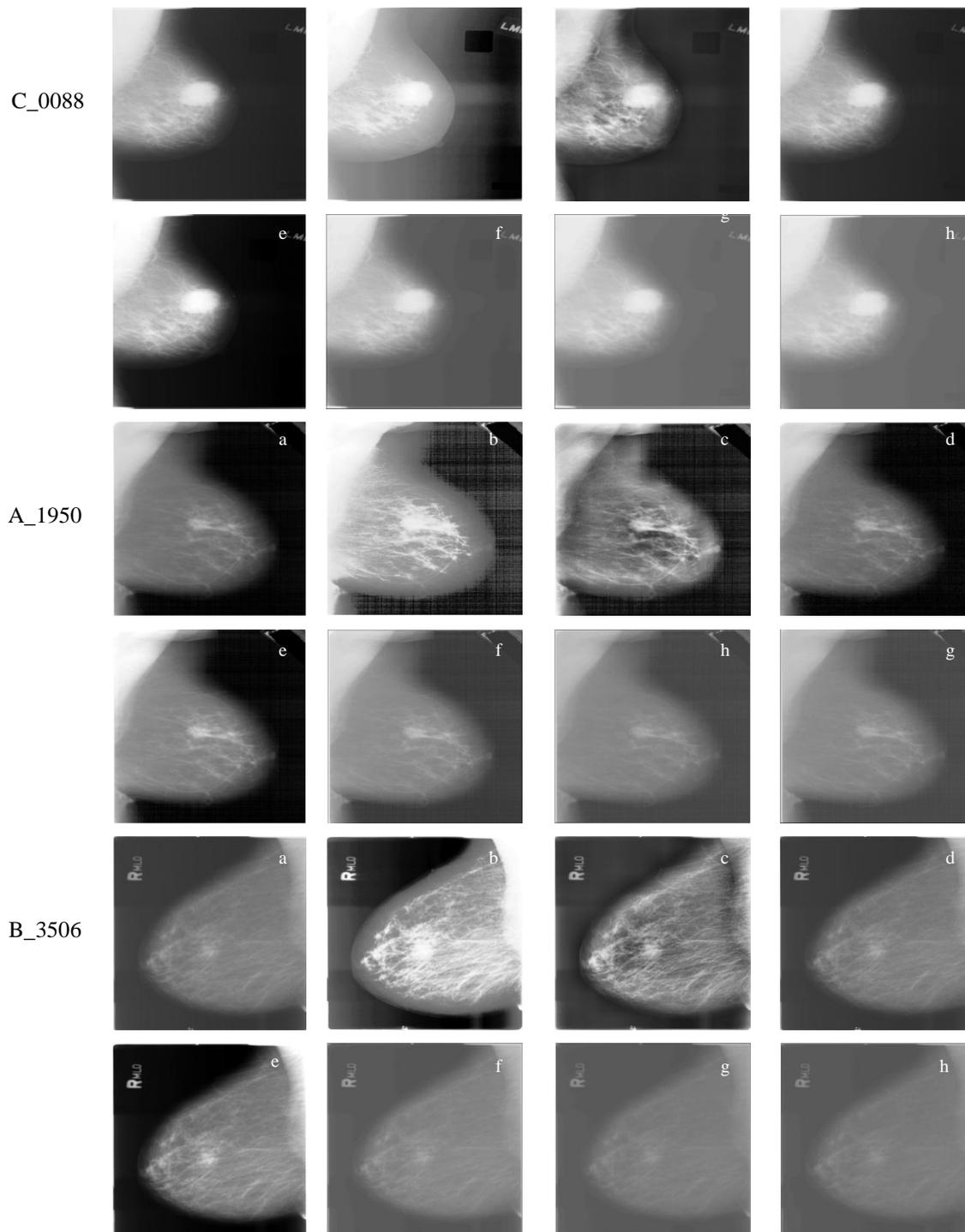


Fig. 2. Enhancement results for sample images from DDSM dataset (a) original image, (b) HE, (c) CLAHE, (d) unsharp masking, (e)-(h) proposed fractional differential order technique with $\alpha=0.2$, $\alpha=0.3$, $\alpha=0.4$, and $\alpha=0.5$.

SDME parameter is represented as:

$$SDME = -\frac{1}{w_1 w_2} \sum_{m=1}^{w_2} \sum_{l=1}^{w_1} \left| 20 \ln \frac{\max(I(l, m)) - 2center(I(l, m)) + \min(I(l, m))}{\ln \max(I(l, m)) + 2center(I(l, m)) + \min(I(l, m))} \right| \quad (11)$$

Images are partitioned into blocks of size $w_1 \times w_2$. Maximum, minimum, and center pixel intensity values of each block are represented by $\max(I(l, m))$, $\min(I(l, m))$, and

$center(I(l, m))$, respectively. Higher values of SDME and CII show better enhancement of images.

Table I and II show CII and SDME values of three randomly chosen sample images of MIAS and DDSM dataset using HE, CLAHE, unsharp masking, and FDD methods,

respectively. Average values of CII and SDME parameters of all 322 mammograms of MIAS dataset and 300 mammograms of DDSM dataset are presented in Table III and IV, respectively. As shown in Fig. 1 and 2, the quality of results obtained with the proposed approach decreases with increasing value of order of differentiation, i.e., α . Quantitative results given in Table I and II also confirm it. Values of CII and SDME decrease with increasing value of α with highest value observed for $\alpha=0.2$. However, the values of CII parameter obtained with HE method for images from MIAS dataset are greater as compared to the proposed FDD Algorithm but the resultant images are over-enhanced as shown in Fig. 1. The values obtained for SDME

parameter are greater than the HE, CLAHE, and Unsharp masking technique for $\alpha = 0.2$.

Fig. 3 shows the effect of the order of differentiation on the value of SDME for seven mammograms. The value of SDME is 49.319 and 49.305 at $\alpha= 0.2$ and 0.3 respectively for Mdb025. SDME decreases with the increasing order of differentiation. SDME continually decreases for order of differentiation $\alpha > 0.2$. The value of SDME is greater for $\alpha=0.2$ as compared to HE, UM, and CLAHE methods. Hence, it can be concluded that fractional order differential based filter (FDD) is better as compared to HE, UM, and CLAHE for image enhancement.

TABLE I
CII VALUES OF RANDOMLY CHOSEN SAMPLE IMAGES FROM MIAS AND DDSM DATASETS

Sample Images	HE	CLAHE	UM	Proposed FDD Algorithm with various values of order of differentiation								
				$\alpha=0.2$	$\alpha=0.3$	$\alpha=0.4$	$\alpha=0.5$	$\alpha=0.6$	$\alpha=0.7$	$\alpha=0.8$	$\alpha=0.9$	$\alpha=1$
Mdb025	2.22	0.42	0.38	1.18	0.95	0.96	0.68	0.54	0.37	0.22	0.10	0.04
Mdb028	2.17	0.41	0.36	1.05	0.86	0.91	0.63	0.51	0.35	0.21	0.10	0.03
Mdb218	3.55	0.41	0.42	1.03	0.89	0.93	0.68	0.56	0.39	0.24	0.11	0.03
C_0088	0.59	0.40	0.35	1.87	0.82	0.80	0.73	0.80	0.67	0.49	0.26	0.03
A_1950	0.51	0.42	0.59	1.95	0.92	0.90	0.85	0.80	0.82	0.72	0.49	0.07
B_3506	0.43	0.37	0.36	1.94	0.89	0.87	0.79	0.79	0.65	0.46	0.24	0.03

TABLE II
SDME VALUES OF RANDOMLY CHOSEN SAMPLE IMAGES FROM MIAS AND DDSM DATASETS

Sample Images	HE	CLAHE	UM	Proposed FDD Algorithm with various values of order of differentiation								
				$\alpha=0.2$	$\alpha=0.3$	$\alpha=0.4$	$\alpha=0.5$	$\alpha=0.6$	$\alpha=0.7$	$\alpha=0.8$	$\alpha=0.9$	$\alpha=1$
Mdb025	41.18	36.34	41.80	49.31	49.30	48.67	48.29	35.16	35.39	19.74	0	0
Mdb028	44.18	37.95	44.20	47.17	47.79	47.54	47.71	34.83	33.63	18.20	0	0
Mdb218	45.26	36.95	44.90	46.25	46.90	46.75	45.17	33.35	31.22	17.58	0	0
C_0088	41.05	41.45	37.57	43.50	40.68	37.49	36.75	28.84	33.39	29.98	20.89	0
A_1950	41.32	41.25	36.10	42.23	31.30	30.39	29.41	28.67	28.35	27.60	15.80	0
B_3506	32.14	31.50	26.97	35.36	29.82	29.43	25.68	18.49	17.07	12.39	4.83	0

TABLE III
AVERAGE VALUES OF CII AND SDME FOR MIAS DATASET

Average	UM	HE	AHE	$\alpha=0.2$
CII	0.33	3.36	0.43	1.99
SDME	43.15	43.94	33.06	46.12

TABLE IV
AVERAGE VALUES OF CII AND SDME FOR DDSM DATASET

Average	UM	HE	AHE	$\alpha=0.2$
CII	0.42	0.49	0.46	1.76
SDME	36.16	40.38	42.29	44.12

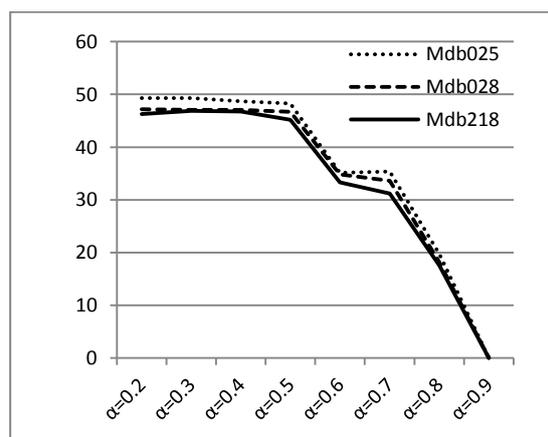


Fig. 3. Plot of SDME of Sample Images of MIAS dataset.

IV. CONCLUSIONS

The present work investigates fractional order differential based filter (FDD) to enhance low contrast mammogram images. Subjective as well as objective analysis of FDD is performed in comparison with HE, CLAHE, and unsharp masking methods. Enhanced images using HE and CLAHE

show over-enhancement and distortion of breast tissues. Also, the visual quality of unsharp masking is poor as compared to HE, CLAHE, and FDD filter. The proposed FDD filter improves the visual quality of mammogram images without affecting the existing breast tissues structures and abnormal regions for differential order $\alpha=0.2$.

Quantitative values of CII and SDME parameter are also better for differential order $\alpha=0.2$ as compared to other values of α . In future, the proposed algorithm will be used as pre-processing step for computer-aided breast cancer detection system and enhancement of other medical images.

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