Image Contrast Enhancement by Scaling Reconstructed Approximation Coefficients using SVD Combined Masking Technique

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Abstract—**The proposed method addresses the general issues of image contrast enhancement. The input image is enhanced by incorporating discrete wavelet transform, singular value decomposition, standard intensity deviation based clipped sub image histogram equalization and masking technique. In this method, low pass filtered coefficients of wavelet and its scaled version undergoes masking approach. The scale value is obtained using singular value decomposition between reconstructed approximation coefficients and standard intensity deviation based clipped sub image histogram equalization image. The masking image is added to the original image to produce a maximum contrast-enhanced image. The supremacy of the proposed method tested over other methods. The qualitative and quantitative analysis is used to justify the performance of the proposed method.**

Keywords—Standard intensity deviation clipped sub image histogram equalization; discrete wavelet transform; singular value decomposition; masking technique

I. INTRODUCTION

The image enhancement has many practical applications. There has been continuous research on developing new algorithms for different applications. In an image analysis, intensity-based enhancement techniques like contrast enhancement help to improve the clarity of the image [1]. The intensity enhancement in an image has been realized through techniques based on the histogram, transform domain filtering and masking approaches. Histogram equalization (HE) or generalized histogram equalization (GHE) [2], are simple approaches as these techniques stretch the gray values effectively but give over enhancement. Some of the methods employed to preserve the brightness are, Bi-histogram, Brightness preserving bi-histogram equalization (BBHE) [3] and dualistic sub image histogram equalization (DSIHE) [4], but these methods fail to suppress noise artifacts. Exposure-based sub image histogram equalization (ESIHE) [5] is best suited for low exposure image but less fit to contrast enhancement of medical images.

The discrete cosine transform (DCT) domain, provide spectral separation [6]. However, there are few drawbacks in transforming the image using block DCT. Therefore, discrete wavelet transform (DWT) has found application in contrast enhancement [7]. Wavelet coefficients have inherent qualities such as sparsity and decomposition [8]. The DCT-SVD and DWT-SVD based illumination enhancement presented by updating singular value matrix of singular value decomposition (SVD). In these methods, the low-low subband of the input image is considered by applying DWT [9], [10].

Recent algorithms for contrast enhancement are based on masking techniques [11]-[14]. In these methods, filtered version of original image have internal scaling processes, and the drawback of these approaches is the use of fixed scale value, irrespective of the input image. The scale values are selected randomly.

In this paper, we tried to address over enhancement issue using effective sub image histogram equalization process. We tried careful rescaling of the reconstructed approximation coefficients using SVD approach to achieve better results. Also, the minute details of the image and sensitive edges are preserved with the help of masking approach.

This work partially motivated by Un-sharp masking technique [11], an excellent result of SVD in contrast enhancement [15] and standard intensity deviation based clipped sub image histogram equalization (SIDCSIHE) [16]. We have used SVD to select intensity information of the SIDCSIHE and reconstructed approximation coefficients. In this paper, we tried to improve upon our previous work [17], the paper is structured as follows: Section 2 contains the proposed method and in Section 3 we discuss experimental results. The conclusions are given in Section 4.

II. PROPOSED METHODOLOGY

The medical image analysis depends upon quality; therefore contrast enhancement is often desirable for

interpretation and diagnosis. This paper presents an improved contrast and enhancement in image quality by using DWT, SIDCSIHE, and SVD along with masking approach.

A. Discrete Wavelet Transformation

The low contrast image is subjected to DWT. The DWT decomposes the image into frequency sub-bands, namely, low low (LL), low high (LH), high low ((HL) and high high (HH) subbands as shown in Fig. 1. The LL subband is approximation coefficients and contains illumination information and image features. The decomposed approximation coefficients are obtained from (1) and its reconstruction is achieved by using inverse discrete wavelet transformation (IDWT) as given by (2).

$$W_\varphi(j_0,m,n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \varphi_{j_0,m,n}(x,y) \quad (1)$$

$$f_{(x,y)}^A = \frac{1}{\sqrt{MN}} \sum_m \sum_n W_\varphi(j_0,m,n) \varphi_{j_0,m,n}(x,y) \quad (2)$$

where, $W_\varphi(j_0,m,n)$ is the approximation coefficient, $f(x,y)$ is the input time domain image of size M x N with discrete variable (x, y). $\varphi_{j_0,m,n}(x,y)$, is the scale function and $f_{(x,y)}^A$ is the reconstructed approximation coefficient [2]. The wavelet function (db1) is used for wavelet decomposition of image.

Fig. 2 shows the LL, LH, HL and HH subbands of the brain_MRI image. Here, the reconstructed LL subband intensity information is used to find the best scale with respect to the input image. The other subbands contain edge information and details of the image as it contains high frequency. The illumination improvement can be achieved by scaling the coefficients of the LL subband.
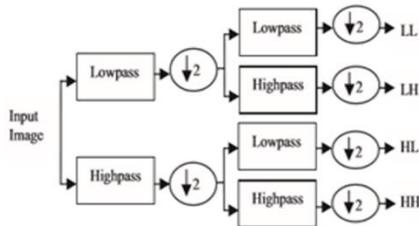

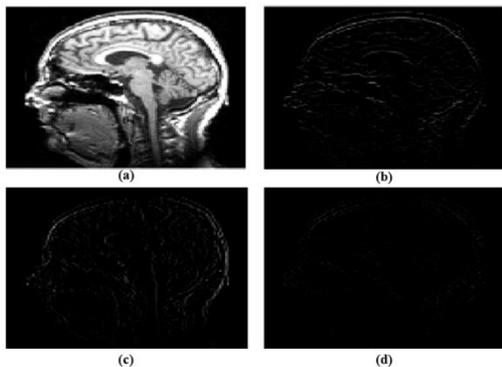Fig. 1.   Block diagram of DWT filter banks of level 1.

Fig. 2.   Results of DWT decomposition of Brain_MRI image (a) Low Low subband; (b) Low High Sub band; (c) High Low subband; (d) High High subband.

B. Standard Intensity Deviation based Clipped Sub Image Histogram Equalization (SIDCSIHE)

Standard intensity deviation value is defined in (3) by using standard deviation function σ as shown in (4) [18].

$$X_{SIDV} = L * \left(1 - \left(\frac{\sigma}{L}\right)\right) \quad (3)$$

$$\sigma = \left(\frac{\sum_{i=1}^L (i - H_\mu)^2 x\, h(i)}{\sum_{i=1}^L h(i)}\right)^{1/2} \quad (4)$$

The H_μ, is a mean of the input image histogram is given by (5).

$$H_\mu = \frac{\sum_{i=1}^L h(i)\, i}{\sum_{i=1}^L h(i)} \quad (5)$$

where $h(i)$, is image histogram with its corresponding intensity i and L is its total number of gray levels.

To prevent over enhancement clipping histogram T_c is calculated as in (6) and (7).

$$T_c = \frac{1}{L} \sum_{K=1}^L h(k) \quad (6)$$

$$h_c(k) = T_c \text{ for } h(k) \geq T_c \quad (7)$$

$h_{c(k)}$, is the clipped histogram and it is computationally efficient [19]. Based on standard intensity deviation value X_{SIDV}, the clipped histogram is divided into two sub-images I_{low} and I_{up} with ranges varying from 0 to X_{SIDV} and X_{SIDV} +1 to $L-1$ respectively. The cumulative distribution function $C_{low}(i), C_{up}(i)$ of each sub-image can be defined as

$$C_{low}(i) = \sum_{i=0}^{X_{SIDV}} h_c(i) \Big/ N_{low} \, for \, 0 \leq i \leq X_{SIDV} \quad (8)$$

$$C_{up}(i) = \sum_{i=X_{SIDV}+1}^{L-1} h_c(i) \Big/ N_{up} \, for \, X_{SIDV} \leq i \leq L-1 \quad (9)$$

where N_{low} and N_{up} are the total numbers of pixels in each sub-image. The histogram equalization is done individually for two sub-images using the transfer function $F(i)$ as expressed in (10) and sub-images are combined into one final image by the transfer function $F(i)$ [16].

$$F(i) = \begin{cases} X_{SIDV} * C_{low} & for\, 0 \leq i \leq X_{SIDV} \\ (X_{SIDV}+1) + (L - X_{SIDV}+1)*C_{up} & for\, X_{SIDV+1} \leq i \leq L-1 \end{cases} \quad (10)$$

The input image is preprocessed by SIDCSIHE that provides the equalized image and its intensity information helps to enhance the image contrast.

C. Masking Technique

In the masking approach, the reconstruction approximation coefficients and SIDCSIHE processed images are considered for masking formulation. The contrast of the reconstructed

low pass signal is enhanced by using SVD and it helps to avoid information loss and better visual result. The SVD decompositions of the reconstruction approximation (I_1) and SIDCSIHE images (I_2) i.e. :

$$I_1 = U1 \times S1 \times V1 \qquad (11)$$

$$I_2 = U2 \times S2 \times V2 \qquad (12)$$

Here U1, V1, U2, and V2 are the orthogonal matrices identifies as left, right singular matrices of I_1 and I_2 . S1 and S2 are sorted singular value of diagonal matrices, contain intensity information about the images I_1 and I_2. Any changes in the singular matrix will affect the image intensity. The most promising approach of the image contrast enhancement is altering the image intensity information stored in the singular value [20]. To modify the intensity information of the reconstructed approximation coefficients, the S1 matrix is altered by using proper weighting (w) value. The highest singular value of I_1 and I_2 is used to calculate weighting value as shown in (13).

$$w = \frac{max(S1) + max(S2)}{2\,Xmax(S2)} \qquad (13)$$

The new reconstruction approximation RA is obtained by modifying the S1 matrix as given in (14).

$$RA = U1 \times (w \times S1) \times V2 \qquad (14)$$

The formulated mask, which gives the residual intensity information between RA and reconstructed low pass signal. This mask image added to original image and output will be the contrast-enhanced image. The entire process of the method is shown in Fig. 3. The following steps the computational process of the proposed algorithm.

Step 1. Low contrast image was taken for processing.

Step 2. Equalize the image using standard intensity deviation based clipped sub image histogram equalization.

Step 3. Compute 1 level DWT to decompose the image into four sub-band.

Step 4. Perform reconstruction of the approximation coefficients.

Step 5. The SVD is applied to SIDCSIHE image and reconstructed approximation for getting $U1 \times S1 \times V1$ and $U2 \times S2 \times V2$ then max($S1$) and max($S2$) obtained.

Step 6. Calculate weighting value w by using (13).

Step 7. New reconstruction approximation coefficient is obtained by $RA = U1 \times (w \times S1) \times V2$.

Step 8. Subtract the RA from reconstruction approximate matrix [mask].

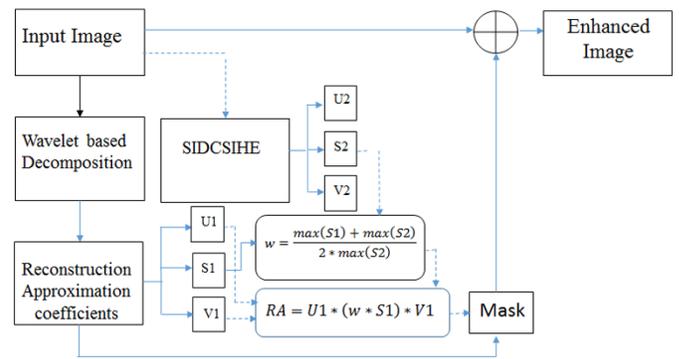**Step 9.** Add the mask with original image to get enhanced output image.

Fig. 3.   Block diagram of the proposed method.

III.   EXPERIMENTAL RESULTS

The supremacy of the proposed method is illustrated by comparing both qualitative and quantitative analysis with well-known existing methods like HE, BBHE, DSIHE, ESIHE. As far as qualitative analysis is concerned, the performance of the proposed method is judged by visual quality inspection. As far as quantitative analysis of the proposed method is measured in terms of AMBE, entropy, PSNR and SSIM values and are compared with other methods.

The proposed algorithm performance is evaluated using (15)-(18). Given that MN is the size of the image, I_{in} is input image, I_e the enhanced image, Max_{in} the maximum possible pixel value of the input image. The PSNR is representing a measure of the peak error between the input and enhanced image.

$$MSE = \frac{1}{(MN)} \sum_{i=1}^{M} \sum_{j=1}^{N} \left(I_{in}(i,j) - I_e(i,j)\right)^2 \qquad (15)$$

$$PSNR = 10\,log_{10}\left(\frac{Max_{in}^{\ 2}}{MSE}\right) \qquad (16)$$

$$AMBE = |I_{in} - I_e| \qquad (17)$$

Entropy means average information content and is defined in (18).

$$Entropy(p) = -\sum_{k=0}^{L-1} p(k)\log p(k) \qquad (18)$$

Where $p(k)$, is probability density function at the intensity level k and L is the total number of gray levels of the image.

A. Qualitative Analysis

The performance of the proposed method is well analyzed with medical images (Brain_MRI, Face X-ray, MRI, Ribs X-Ray) [1] and mammogram images (mdb011, mdb013, mdb209, mdb211, mdb213) [2].

Fig. 4(a-f), (g-l), (m-r), (s-x) are the results of the proposed method steps from the input image to the contrast-enhanced

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[1] https://medpix.nlm.nih.gov/home
[2] http://www.mammoimage.org/databases

image of (brain_MRI, Ribs X-Ray, mdb013, mdb212). The enhancement provided by SIDCSIHE method as shown in Fig. 4(b, h, n, t). Fig. 4(c, i, o, u) are reconstructed approximation coefficients, it contains necessary illumination information. The scaled reconstructed LL subband based SVD method can be seen in Fig. 4(d, j, p, v). The mask image contains residual intensity information clearly observed in Fig. 4(e, k, q, w). In Fig. 4(q), (w) shows the edge information and extracted intensity residual information. Fig. 4(f, l, r, x) are resultant, contrast-enhanced image with better visual quality than the original image.

The pleasant effect in the appearance of the contrast-enhanced image can be seen in the face X-ray image as in Fig. 5. The HE, BBHE, DSIHE are over enhanced. The proposed image has good contrast enhancement result over ESIHE image.

The MRI image in Fig. 6 is the proposed method that yields contrast-enhanced image. The HE, DSIHE shows over-enhancement and BBHE is dark in nature.

Fig. 6. Results of different methods for the MRI image (a) Low contrast input image; (b) HE; (c) BBHE (d) DSIHE; (e) ESIHE; (f) proposed method.

The analysis of the mammogram image (Fig. 7 and 8) supremacy of the proposed method is to show normal fatty tissue, dense breast tissue and infected area clearly.
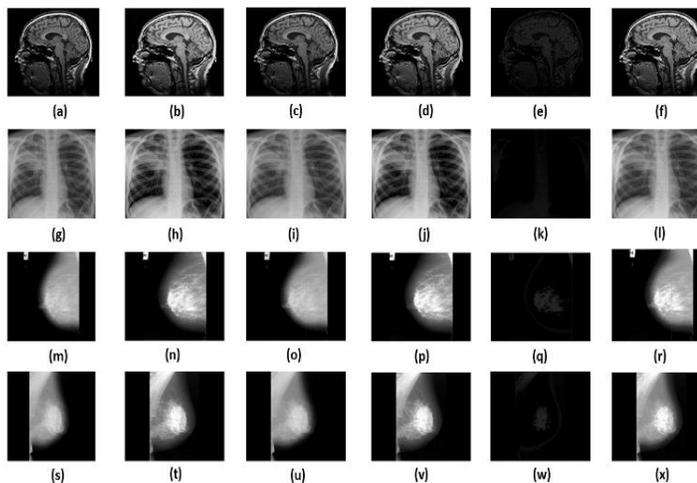

Fig. 4. Results of different stages of proposed method (a,g,m,s) input images; (b,h,n,t) SIDCSIHE ; (c, i, o,u) Reconstructed Approximation coefficient; (d,j,p,s) RA image (e, k,q,w) Mask image; (f,l,r,x) Output image.

Fig. 7. Results of different methods for the mammogram (mdb011) (a) Low contrast input image; (b) HE; (c) BBHE (d) DSIHE; (e) ESIHE; (f) proposed method.
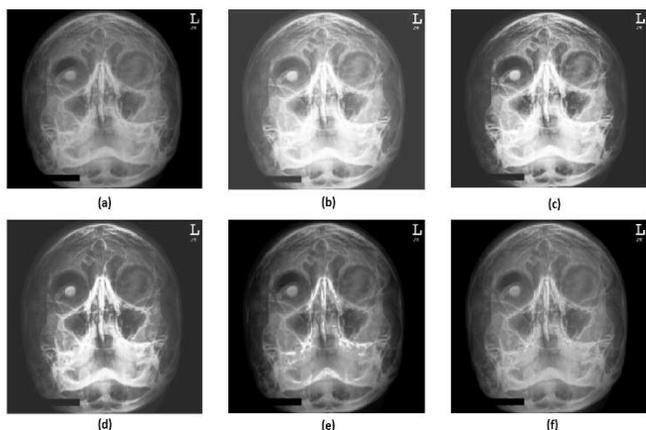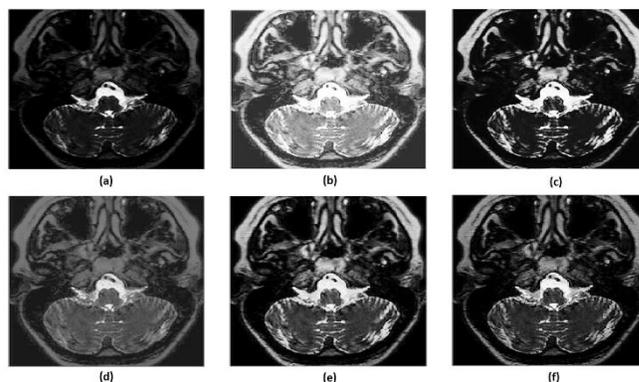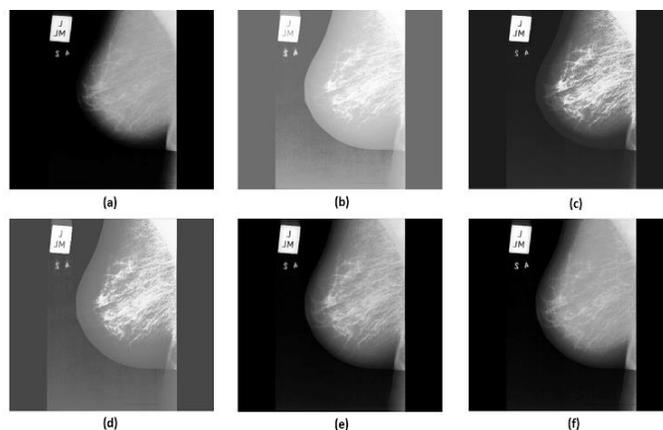

Fig. 5. Results of different methods for the Face X-Ray image (a) Low contrast input image; (b) HE; (c) BBHE (d) DSIHE; (e) ESIHE; (f) proposed method.
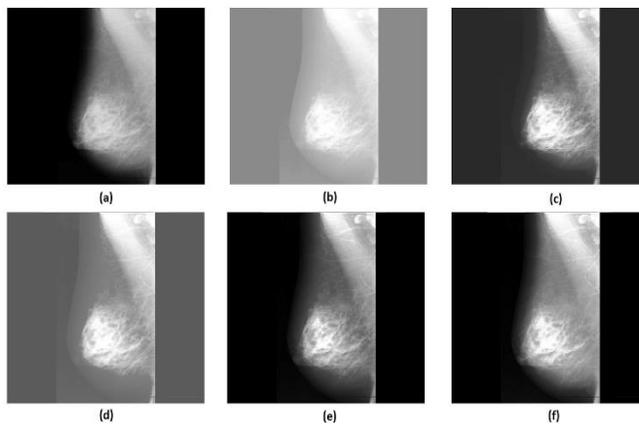

Fig. 8. Results of different methods for the mammogram (mdb211) (a) Low contrast input image; (b) HE; (c) BBHE (d) DSIHE; (e) ESIHE; (f) proposed method.

As compared to other methods in Fig. 7, proposed method clearly highlights the required region. The HE and DSIHE images are over enhanced. The dark image obtained by BBHE method. In Fig. 8, HE, BBHE and DSIHE are over enhanced

and proposed method image provided acceptable visual information than the input image.

B. Quantitative Analysis

To evaluate the performance of the proposed method, quantitative analysis has studied in terms of AMBE, entropy, PSNR, and SSIM.

The quality of the proposed method is provided by AMBE values, which is tabulated in Table I. The average AMBE value lesser than other contrast enhancement technique shows the quality of the contrast improvement. The entropy values of all the input image are tabulated in Table II. The highest entropy value indicates more information content of the image. As compared to HE, BBHE, DSIHE, ESIHE, the proposed has greater entropy value.

The SSIM values also encourage the performance of the proposed method is shown in Fig. 9. To check noise artifacts produced and over enhancement, PSNR values of the enhancement results are compared and shown in Fig. 10. The average PSNR value produced by the proposed method for all images is greater than HE, BBHE, DSIHE, and ESIHE.

TABLE I. AMBE VALUES OF THE COMPARED METHODS FOR CONTRAST ENHANCEMENT

Test Images	HE	BBHE	DSIHE	ESIHE	PROPOSED
Brain_MRI	89.529	29.611	31.566	24.019	**13.600**
Face X-Ray	57.059	36.221	22.554	5.242	**1.987**
MRI	103.587	27.551	42.799	32.576	**18.754**
Ribs X-Ray	11.601	9.941	4.390	2.860	4.498
mdb011	103.552	21.866	62.995	4.279	4.307
mdb013	118.487	27.789	74.376	6.045	**4.316**
mdb209	102.731	25.904	50.772	3.883	4.375
mdb211	112.495	27.558	68.075	4.377	4.402
mdb212	114.276	24.981	69.593	4.136	4.309
Average	90.369	25.713	47.458	9.713	**6.728**

TABLE II. ENTROPY VALUES OF THE COMPARED METHODS FOR CONTRAST ENHANCEMENT

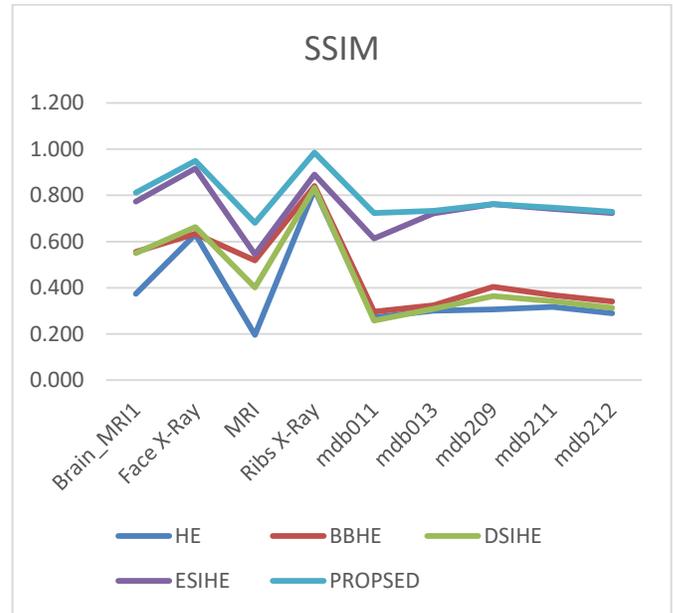| Test Images	HE	BBHE	DSIHE	ESIHE	PROPOSED
Brain_MRI1	5.021	5.859	5.886	6.161	**6.656**
Face X-Ray	4.991	6.113	6.095	6.298	**6.522**
MRI	5.045	5.551	5.613	5.817	**6.205**
Ribs X-Ray	5.980	7.157	7.173	7.216	**7.449**
mdb011	3.742	4.371	4.318	4.587	**4.736**
mdb013	3.001	3.780	3.722	3.970	**4.125**
mdb209	3.842	4.758	4.667	4.943	**5.110**
mdb211	3.107	4.146	4.098	4.329	**4.648**
mdb212	3.223	4.038	4.022	4.240	**4.450**
Average	4.217	5.086	5.066	5.285	**5.545**

Fig. 9. SSIM values of the compared methods for contrast enhancement.
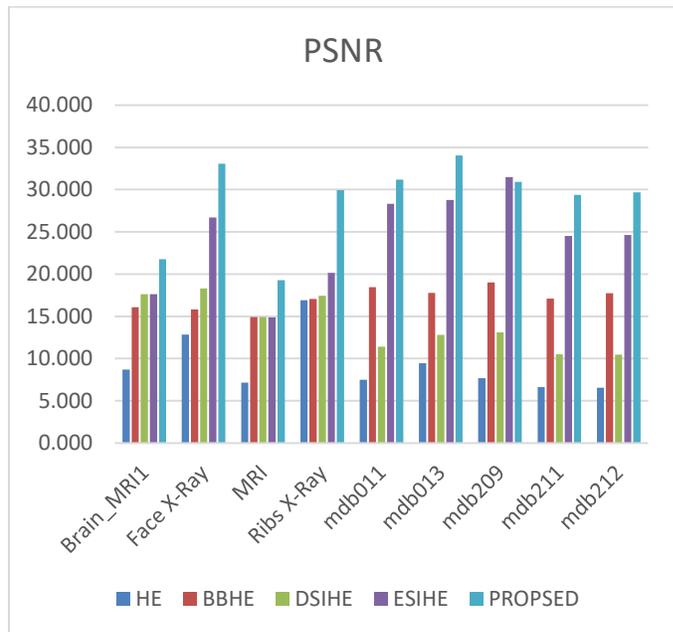

Fig. 10. PSNR values of the compared methods for contrast enhancement.

C. Summary of Analysis and Discussion

The objective of this paper is to obtain improved contrast enhancement by incorporating SIDCSIHE, DWT, SVD and masking technique. The main advantage of this paper is applying SVD technique effectively on SIDCSIHE image and reconstruction of LL image. The masking helps in providing residual information, which can be added to the original image for achieving maximum contrast enhancement. The proposed algorithm has been implemented in MatlabR2010, running on Windows PC with Intel i3 at 1.90GHZ and 4GB RAM.

After qualitative and quantitative analysis it can be concluded that

- Proposed method improves image contrast in comparison to other methods.

- The proposed method provides minimum AMBE vale, it shows the quality of contrast improvement.

- The proposed method provides the highest entropy among other methods, it shows the richness of details.

- Proposed method provide better PSNR and SSIM value, it shows over enhancement control and structural similarity.

- Proposed method produces an image with good contrast enhancement.

IV. CONCLUSION

In this paper, we tried to develop a method to address general issues of the image contrast enhancement. The proposed method effectively used masking approach to collect the sensitive edge information as residual intensity information. The method uses standard intensity deviation based clipped sub image histogram equalization to enhance contrast by controlling over enhancement. The SVD method helps to modify the intensity information. The experimental result shows the robustness of the proposed method as compared to the existing algorithm for the variety of images.

However, the proposed method does not consider the problem of noise enhancement, as the DWT method is shift variant. The work can be improved by using shift invariance transform along with the noise eliminating filter, to suppress the noise during enhancement. We have considered SVD to calculate scale value. The optimized algorithm can incorporate to find scale value. In this work contrast enhancement is achieved, this can be extended into resolution enhancement by using better interpolation algorithm.

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