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Image Contrast Enhancement in Wavelet Domain

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Abstract

In literature, different image contrast enhancement techniques by using Discrete Wavelet Transform (DWT) and Singular Value Decomposition (SVD) were proposed. The existing methods give better performance for low contrast images with low or mid inte**n**sities. In this paper, we proposed a modified algorithm, through which better performance can be achieved for low contrast images with low and mid intensities. The proposed technique considers the weighted sum of singular value matrices of LL sub band image of low contrast image and LL sub band image of General Histogram Equalized image. The proposed method is compared with General Histogram Equalization (GHE), Contrast-Limited Adaptive Histogram Equalization (CLAHE) and existing DWT-SVD methods. The proposed technique gives better performance subjectively and objectively in terms of mean, standard deviation and entropy.

Keywords: Contrast, DWT, SVD, GHE, CLAHE.

1. INTRODUCTION

Image Enhancement is the pre - processing step in different image processing applications for better perception, analysis, representation and diagnosis. Image contrast is defined as the difference in intensity between highest and lowest intensity levels in an image [1]. Low contrast images can result from poor illumination, lack of dynamic range in the imaging sensor or even the wrong setting of a lens aperture during image acquisition. In low contrast images all the information is concentrated over a narrow range; hence information may be lost in the remaining areas. In order to represent all information present in an image, contrast enhancement is necessary [3]. The high contrast image has great deal of grey level detail and has high dynamic range. GHE is one of the most well known methods for contrast enhancement. It is useful for image with poor intensity distribution, but it over saturates several areas of the image. Histogram Equalization always results uniform probability distribution independently of the form of the input probability distribution function (PDF). But for some applications PDF shape preservation is important.

SVD has been used for the image contrast enhancement [2]-[5]. By using SVD, an image which is represented as a matrix of size *M X N,* can be represented as the product of three matrices – an orthogonal square matrix U_{MXN}, a diagonal matrix Σ_{MXN}, and the transpose of an orthogonal square matrix V_{MXN}. SVD of an image (I) of size *M X N* can be represented as follows:

$$I = U_I \Sigma_I V_I^T \qquad (1)$$

The diagonal matrix, Σ_I contains singular values in sorted order on its main diagonal. The singular value matrix (Σ_I) contains the intensity information of the image [6], hence intensity of the input image can be changed by modifying singular values.

2. EXISTING METHOD

In [2], illumination problem was dealt using SVD. The method uses the ratio of the largest singular value of the generated normalized matrix, with mean zero and variance of one, over a normalized image which can be obtained by using the following equation [2]:

$$\xi = \frac{\max(\Sigma_{N(\mu=0, var=1)})}{\max(\Sigma_I)} \qquad (2)$$

Where $\Sigma_{N(\mu=0,\ var=1)}$ is the singular value matrix of the synthetic intensity matrix. Equalized Image (I_E) can be regenerated using the following equation [2]:

$$I_E = U_I (\xi\, \Sigma_I) V_I^T \qquad (3)$$

In the DWT–SVD technique [3], GHE is applied on low contrast input image, I and obtained histogram equalized image, $\hat{I}$. LL sub band images of I and $\hat{I}$ are obtained by applying DWT. LL sub band was chosen for processing, since illumination information was concentrated in LL sub band. Edge information was present in high frequency sub bands, which are not disturbed and output image will be sharper and with improved contrast. Singular value matrices of LL sub band images of both I and $\hat{I}$ are obtained by using SVD. The correction coefficient for the singular value matrix was obtained by the following equation [3]:

$$\xi = \frac{max(\Sigma_{LL_{\hat{I}}})}{max(\Sigma_{LL_I})} \quad (4)$$

Where $\Sigma_{LL_{\hat{I}}}$ is singular value matrix of LL sub band image of histogram equalized image, $\hat{I}$ and Σ_{LL_I} is singular value matrix of LL sub band of the input image, I. The new LL sub band image was obtained by the following equations [3]:

$$\overline{\Sigma_{LL_I}} = \xi \Sigma_{LL_I} \quad (5)$$

$$\overline{LL_I} = U_{LL_I} \overline{\Sigma_{LL_I}} V_{LL_I}^T \quad (6)$$

The enhanced image (I_E) was obtained by applying Inverse DWT on four sub band images $\overline{LL_I}$, LH_I, HL_I, and HH_I.

The low contrast images can fall into three ranges [5] – low contrast images with low intensity (dark), low contrast images with mid intensity (grey), low contrast images with high intensity (bright). The image with high intensity values has maximum singular value when compared with that of low intensity image [2]. For low intensity images $\xi > 1$, for mid intensity images $\xi \approx 1$ and for high intensity images $\xi < 1$ [5].

The methods proposed in [2] and [3], which are based on scaling the singular values are not suitable for low contrast images with mid range of brightness since correction coefficient (ξ) is close to 1 and hence singular value matrix does not change significantly [4]. So, there is no significant improvement in the intensity of input image. To overcome this problem, weighted sum of singular value matrices of both images ($\Sigma_{LL_{\hat{I}}}$ *and* Σ_{LL_I}) are considered and the equation (5) was modified as follows [4]:

$$\overline{\Sigma_{LL_I}} = 0.5(\xi \Sigma_{LL_I} + \frac{1}{\xi} \Sigma_{LL_{\hat{I}}}) \quad (7)$$

3. PROPOSED METHOD

The method proposed in [3] gives better performance for images with low intensities, but has poor performance in terms of mean, standard deviation and entropy for images with mid intensities. The method proposed in [4] gives better performance for images with mid range of brightness, but has poor performance in terms of mean, standard deviation and entropy for dark images. To overcome this problem, a new algorithm is proposed by modifying procedures of [3] & [4] as

$$\overline{\Sigma_{LL_I}} = \left(\frac{\xi}{1+\xi}\right)\left(\xi \Sigma_{LL_I} + \frac{1}{\xi} \Sigma_{LL_{\hat{I}}}\right) \quad (8)$$

The Flow chart for image contrast enhancement using DWT-SVD method with modified equation for obtaining singular value matrix was shown in Fig. 1.

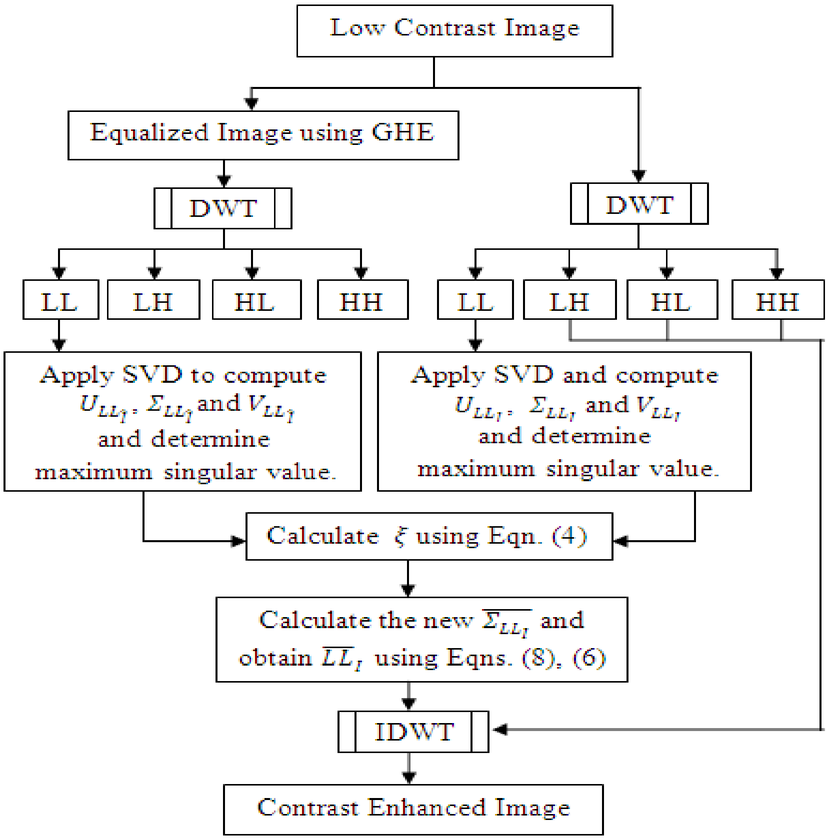
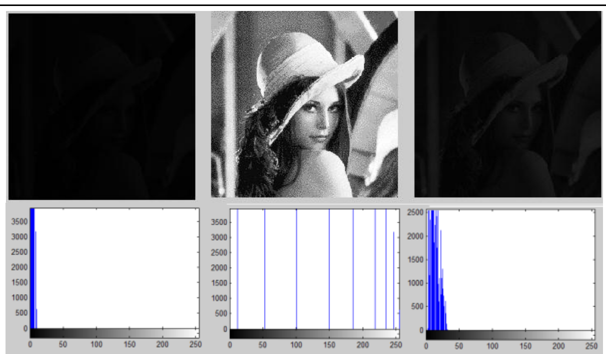
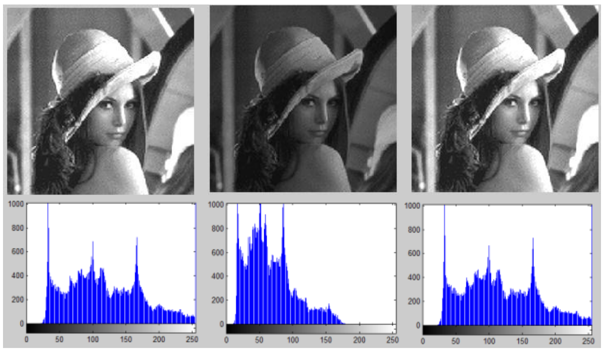


Fig.1 Flow chart of the modified DWT – SVD algorithm.



(a)	(b)	(c)



(d)	(e)	(f)

Fig. 2 Input low contrast image and Output images of different methods with their corresponding histograms.(a) Input low contrast image (b) GHE (c) CLAHE (d) DWT-SVD [3] (e) DWT-SVD [4] (f) DWT-SVD (Proposed method).

4. PERFORMANCE MEASURES USED

Mean (μ) and Standard Deviation (σ) are commonly used metrics for brightness and contrast assessment respectively. For an image (I) of size

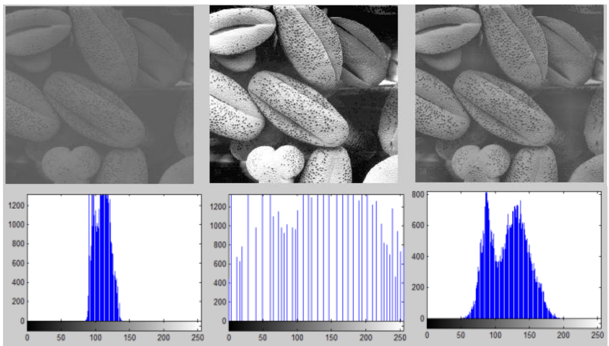
M x N, the mean and Standard Deviation is obtained by using following equations [1]:

$$\mu = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} I_{i,j} \qquad (10)$$

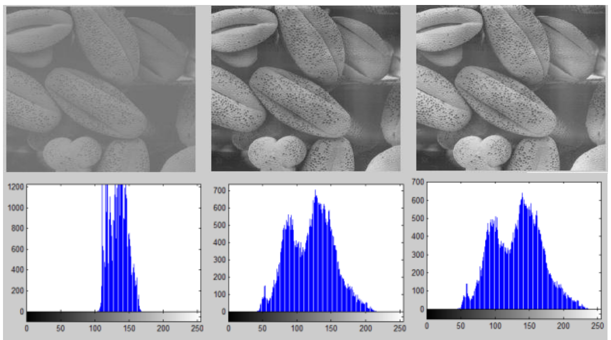
$$\sigma = \sqrt{\frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} (I_{i,j}-\mu)^2} \qquad (11)$$

With these metrics, GHE can achieve the best performance quantitatively, even though it results visual artefacts with unnatural look [4]. In this paper, the quantitative measures such as mean, standard deviation, Entropy were used, in addition to visual results. Wavelet function db.9/7 was used as the mother wavelet for obtaining DWT.

Entropy is the measure of average information content in the image. Any pixel of an image can be considered as a random variable. The entropy of an image is given by the following equation [1].



(a)	(b)	(c)



(d)	(e)	(f)

Fig. 3 Input low contrast image and Output images of different

methods with their corresponding histograms. (a) Input low contrast image (b) GHE (c) CLAHE (d) DWT-SVD [3] (e) DWT-SVD [4] (f) DWT-SVD (Proposed method).

$$E = -\sum_{k=0}^{L-1} \mathrm{P_r}(r_k)\log_2 \mathrm{P_r}(r_k) \qquad (12a)$$

Where r_k is discrete random variable in the interval [0, L-1], occurs with a probability of $\mathrm{P_r}(r_k)$ in an image of size M x N.

$$\mathrm{P_r}(r_k) = n_k / MxN \quad , \quad k=0, 1, 2\ldots L-1 \qquad (12b)$$

n_k is the number of times the k^{th} intensity appears in an image with L number of intensity values.

5. RESULTS AND DISCUSSION

The original low contrast images are enhanced by using proposed method and compared with well known GHE, CLAHE technique and existing DWT and SVD based techniques proposed in [3] & [4]. Obtained output images with their corresponding histograms are shown in Figs. 2 and 3. The quantitative results such as mean, standard deviation and entropy were computed and tabulated in Table 1 for images shown in Figs. 2 and 3.

The Fig. 2 is dark image whose histogram was concentrated on low values of the gray scale. By applying the proposed technique histogram was spread over wide range of the gray scale with more details when compared with [4] and improved performance over [3]. The Fig. 3 has mid range of brightness, whose histogram was concentrated in the middle of the gray scale. By applying the proposed technique histogram was spread over wide range of the gray scale with more details when compared with [3] and improved performance over [4].

Table 1. Mean, Standard Deviation and Entropy Values

Images in Fig. / Method	Mean (μ)		Standard Deviation (σ)		Entropy	
	2 $\xi = 33.3033$	3 $\xi = 1.2179$	2 $\xi = 33.3033$	3 $\xi = 1.2179$	2 $\xi = 33.3033$	3 $\xi = 1.2179$
Input	3.8597	109.0904	2.1376	11.2948	2.8975	5.3464
GHE	127.3571	127.5676	74.4257	74.9094	2.8972	5.2440
CLAHE	12.4233	118.5792	6.5795	27.5278	4.3445	6.7052
DWT-SVD [3]	126.1221	132.8528	64.0000	13.6569	7.4528	5.5731
DWT-SVD [4]	66.1998	120.9621	35.8095	32.4893	6.9347	7.0048
DWT-SVD (Proposed)	126.1211	132.8494	64.0206	35.6720	7.4529	7.1398

From Table. 1, it can be observed that the proposed method gives better results. Mean values obtained using the proposed method and GHE are closer to the ideal mean for the gray level range.

6. CONCLUSIONS

In this paper, modified equation for obtaining weighted sum of singular values of LL sub band images of input low contrast image and histogram equalized image was proposed. The proposed method was compared with GHE, CLAHE and specified existing DWT – SVD methods. Mean, Standard Deviation, Entropy are used for objective analysis. Histogram plots and subjective results are also compared. From the results it is evident that the proposed method achieves better contrast enhancement for images with low and mid range of intensities.

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