A Novel Approach for Contrast Enhancement and Noise Removal of Medical Images

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***Abstract*—This paper presents the application of two different image enhancement techniques to medical images and the comparison of these techniques with traditional Histogram Equalization (HE) method. The proposed method uses Weighted Histogram Equalization (WHE) and transform domain approach to enhance medical images. Simulation results shows that Perona-Malik filter (PM filter) can be used to remove the noise from the enhanced image without impacting the image contrast. Peak Signal to Noise Ratio (PSNR) values shows that the use of Perona-Malik filter can improve both the methods. The proposed WHE method with PM filter shows better PSNR values than the transform domain approach with PM filter.**

***Index Terms*—Image enhancement; Weighted histogram equalization; Perona-Malik filter**

I. Introduction

Medical image enhancement enables identification of the desired region in the image by amplifying the required regions. Different approaches possible for image enhancement [6]-[9] are based on spatial and frequency domain. Histogram equalization [4] is the most commonly used technique for image enhancement. This enhances the contrast of image by expanding the dynamic range. Over-enhancement of regions of the image is the main drawback associated with this technique. An approach of adaptive histogram equalization [5] involves the histogram formation from the localized data but requires high computing power. Transform domain image enhancement technique converts the input image into the required transform domain by using 2-D Discrete Cosine Transform (DCT), Fourier transform etc. Introduction of certain objectionable artifacts is the main drawback of transform based image enhancement methods. Therefore further processing is required to remove these artifacts. In the proposed method, Perona-Malik filter is used for noise removal of enhanced image.

The rest of the paper is organized as follows. Section II presents theoretical background including Weighted Histogram Equalization (WHE), transform domain approach and Perona-Malik filter. Section III discusses the implementation of the proposed method. In section IV, experimental results and comparison of proposed method with traditional Histogram Equalization is discussed. Finally, section V concludes the paper.

II. Background

A. Weighted Histogram Equalization (WHE):

Weighted Histogram Equalization is an image enhancement technique [2] in which the curve shape of the output mapping function is adjusted by the weighted combination of the null mapping function shown in Fig.1c and the normal mapping function from conventional histogram equalization method shown in Fig.1b. The concept of WHE method is shown in Fig.1. Fig.1a shows the histogram of the input image, Fig.1b shows the HE mapping function, Fig.1c represents the null mapping function, Fig.1d gives an idea to calculate θ and Fig.1e is the final mapping function which is the weighted combination of HE mapping function and null mapping function. The mapping function is given in (1).

$$f(k) = w.m(k) + (1 - w).n(k) \tag{1}$$

where $m(k)$ is the normal mapping function from the conventional histogram equalization method, $n(k)$ is the null mapping function, and w is the weighting value. The null mapping function $n(k) = k$. where $k = 0, \dots, 255$. The weighting value can be calculated using (2).

$$w = \begin{cases} 0, & \text{if } \theta \leq \theta_{ext} \\ (\theta - \theta_{ext})/(\theta_{max} - \theta_{ext}) & \text{otherwise} \end{cases} \tag{2}$$

The slope θ can be calculated by

$$\theta = \tan^{-1}(y/x) \tag{3}$$

The maximum degree θ_{max} and the extreme degree θ_{ext} can be pre-defined.

B. Transform domain approach:

An important image enhancement technique in this area is based on non-linear technique and logarithmic transform coefficient histogram matching [1].

The DCT of the input image is initially calculated and logarithmic transform is applied on the magnitude of orthogonal transformed values. The phase of the transformed image is preserved by creating a matrix which is used later to restore the phase information of the coefficients. In parallel with this, a sigmoid transfer function is applied to the original image which undergoes histogram equalization and orthogonal transform. Log transform is then applied to the magnitude of

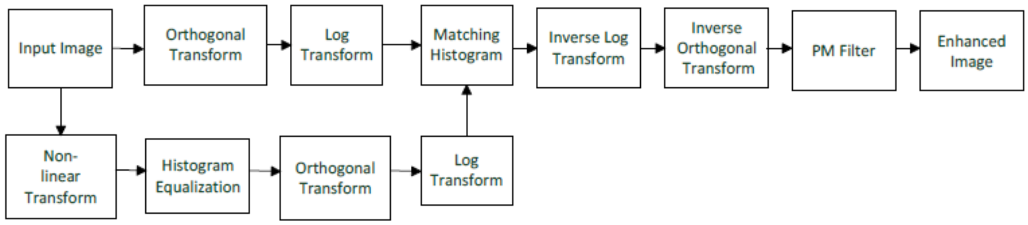

Fig. 2. Proposed method in the transform domain approach

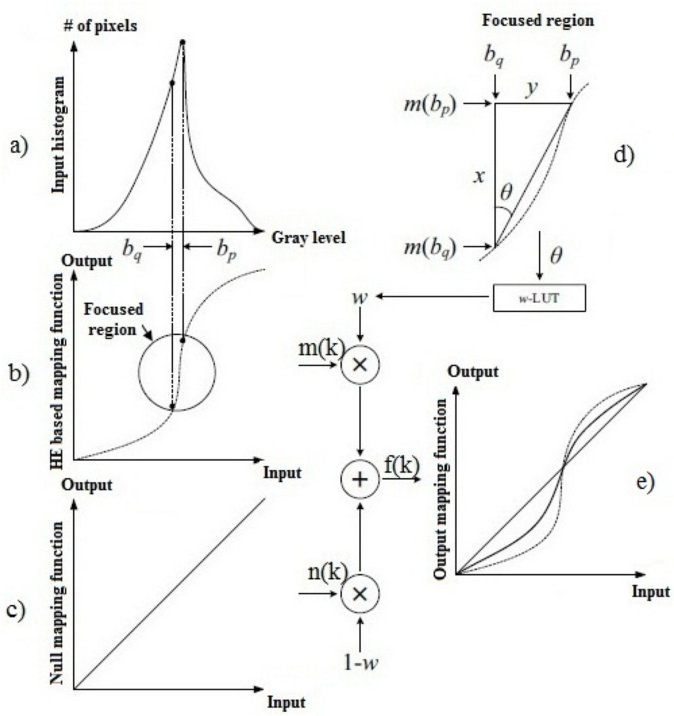

Fig. 1. Concept of WHE

orthogonal transformed values. The transformed data of the original image is matched to the transformed data of histogram equalized image by using histogram matching. The matched data are exponentiated and the phase extracted in the initial phase is used to obtain complete information. Finally, inverse orthogonal transform is applied to obtain enhanced output image.

C. Perona-Malik filter (PM filter):

Perona and Malik developed non-linear anisotropic filtering method [3],[10] which is a smoothing and edge detection scheme. The smoothing process is similar to that of the diffusion process. Hence its mathematical basis is derived from the diffusive process. The direction of diffusion is controlled by intensity gradients. The mathematical expression for this process is given by

$$\partial_t I = div(C.\nabla I) \tag{4}$$

where I represents the signal intensity and ∇I represents the intensity gradient and C represents the conduction coefficient. $C = g(\nabla I)$ is a function of image intensity gradient. The advantage of this filtering method is that it can smooth small discontinuities caused by background noise and can preserve large intensity variations caused by edges. This enables localized smoothening within regions enclosed by the edge structures. This is implemented by setting the conduction coefficient equal to 1 within the enclosed region and equal to 0 at the edges. The conduction coefficient C can be defined by using different functions of the gradient. The function of image intensity gradient $g(\nabla I)$ can have different forms. The most common form is

$$g(\nabla I) = e^{(-(\|\nabla I\|/K)^2)} \tag{5}$$

$$g(\nabla I) = \frac{1}{1 + \left(\frac{\|\nabla I\|}{K}\right)^2} \tag{6}$$

where the parameter K is used as the control parameter. When ∇I takes large values both the above functions have values close to zero. Similarly, when the gradients are small these functions produce values close to unity. Thereby enabling smoothening of background noise and preserving edges.

Finally,the discretized form of (4) is given by

$$I_{i,j}^{t+1} = I_{i,j}^{t} + \lambda[C_N.\nabla_N I + C_S.\nabla_S I + C_E.\nabla_E I + C_W.\nabla_W I] \tag{7}$$

where $0 \leq \lambda \leq 1/4$. N, S, E and W represents North, South, East and West. $\triangledown$ is the gradient operator.

III. Proposed Methods

A. WHE in combination with Perona-Malik filter

Weighted Histogram Equalization method is normally used to improve the contrast of color images. In the proposed method weighted histogram equalization applied to medical images for improving the image contrast. But noise is also amplified in the enhanced image. In order to remove the noise, Perona-Malik filter is used. The main feature of this filter is that it can smooth small discontinuities caused by background noise and can preserve large intensity variations caused by edges. Experimental results show that the proposed method can effectively remove the noise while preserving the contrast. PSNR values also show that the proposed method produces better results than other image enhancement techniques like Histogram Equalization.

B. Transform domain approach with Perona-Malik filter

Transform domain methods operate on transforms of the image such as 2-D discrete cosine transform (DCT), Fourier transform etc. One of the important property of orthogonal transform is that DC values are formed in the top left corner and high frequency content in the bottom right corner. Orthogonal transform makes the coefficients more independent and redundant data becomes less [1]. Introduction of certain non-tolerable artifacts is the main drawback of transform based image enhancement methods. The application of this technique results in the amplification of noise. Therefore further processing is required to remove these artifacts and Perona-Malik filter helps to reduce the noise in the final enhanced image.

In the proposed method as shown in Fig. 2, the DCT of the input image is initially calculated and logarithmic transform is applied on the magnitude of orthogonal transformed values. Here, the phase of the transformed image is preserved by creating a matrix which is used later to restore the phase information of the coefficients. In parallel with this, a sigmoid transfer function is applied to the original image.

$$I_{x,y} = \frac{2}{1+e^{-2\tau_{x,y}/\rho}} - 1 \tag{8}$$

where $\tau_{x,y}$ is the gray level and $0 \leq \tau_{x,y} \leq 255$. The parameter ρ controls the curvature of the hyperbolic tangent function.

$$\rho = (255 - K)\left[\frac{r_{x,y}}{255}\right] + K \tag{9}$$

where, $r_{x,y}$ is the local mean of an image and K is the bias pixel intensity value equal to 3. The local mean of the image can be calculated by

$$r_{x,y} = c\, e^{-(x^2+y^2)/\sigma^2} * \tau_{x,y} \tag{10}$$

where, σ is the standard deviation of the Gaussian distribution, c is selected so that $\int\int r_{x,y}dxdy = 1$. After applying sigmoid transfer function, histogram equalization and orthogonal transform is performed. In histogram equalization the cumulative density function of the histogram is used as the mapping function.

Probability Density Function (PDF) is given as

$$p(k) = \frac{n_k}{N} \tag{11}$$

Cumulative Density Function (CDF) is described as

$$C(k) = \sum_{i=0}^{k} p(i) \tag{12}$$

Transform function is

$$T(k) = C(k).255 \tag{13}$$

For $k = 0, 1, \ldots, 255$, where n_k represents the total number of occurrences of the level k in the input image and N is the total number of elements in the input image.

Log transform is then applied to the magnitude of orthogonal transformed values. The transformed data of the original image is matched to the transformed data of histogram equalized image by using histogram matching. The matched data are exponentiated and previously separated phase is restored. Then, inverse orthogonal transform is applied which gives output enhanced image. Finally, Perona-Malik filter is used to remove the artifacts occurring in the enhanced image. The proposed method resulted in an effective removal of artifacts in the image. At the same time the application of the filter does not adversely impact the contrast of the image. The proposed method gives better PSNR values compared to other methods like Histogram Equalization.

IV. Experimental Results

The applications of two different image enhancement methods to medical images are compared. The proposed method utilizes Perona-Malik filters for noise removal from the enhanced image. Inclusion of PM filter results in noise removal from the enhanced images for both the methods. Experimental results show that the application of image enhancement technique together with the PM filter can improve the quality of medical images. Peak Signal Noise Ratio was used for comparison of the proposed method with other commonly used HE methods.

$$PSNR = 10.log_{10}(\frac{Max_I^2}{MSE}) = 20.log_{10}(\frac{Max_I}{\sqrt{MSE}}) \tag{14}$$

where Max_I is the maximum possible pixel value in the image and MSE is the mean squared error.

The comparison between WHE and Transform domain approach with Histogram Equalization method are shown in Fig. 3 and Fig. 4. From Fig.3, it is clear that traditional HE method is ineffective in preserving the local information. HE method produces over-enhancement and the local information is completely lost. The loss of image data could mean the loss of clinical information. This undesirable effect can be eliminated by the use of WHE method. In this method, the output mapping function is adjusted by the proper combination of mapping function from the HE method and the null mapping function. The use of WHE method with PM filter can improve the contrast while preserving the local information as shown in Fig.3d. Similarly it also shows the improvement in the PSNR values.

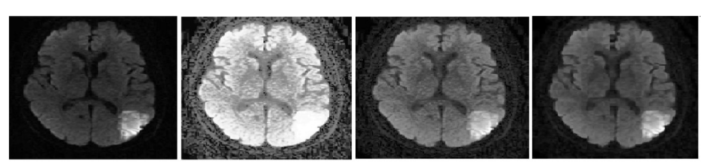

Fig. 3. a) Image 1 b) HE method c)WHE method d)Proposed method

Fig.4 shows the improvement in contrast by Transform domain approach. This improvement in contrast is higher than that obtained using HE. It is observed that in both methods the noise is also amplified in the enhanced image. These artifacts are removed using the PM filter as explained in the

TABLE I
COMPARISON OF PSNR VALUES OF PROPOSED METHOD WITH OTHER METHODS

Input image	Methods	PSNR (dB)	Improvement in PSNR (dB)
Image 1	Histogram Equalization	10.49	9.09
	WHE with PM filter	19.58	

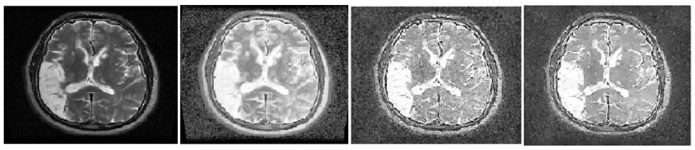

Fig. 4. a) Image 2 b) HE method c) Transform domain approach d) Proposed method

TABLE II
COMPARISON OF PSNR VALUES OF PROPOSED METHOD WITH OTHER METHODS

Input image	Methods	PSNR (dB)	Improvement in PSNR (dB)
Image 2	Histogram Equalization	10.12	0.3
	Transform domain approach	10.42	

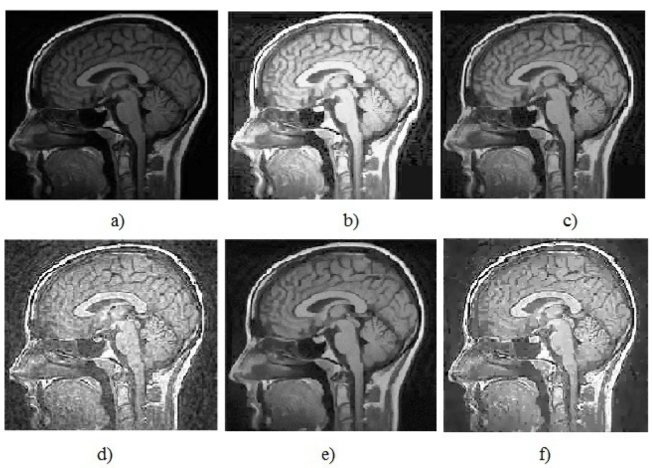

Fig. 5. a) Image 3 b) HE method c)WHE method d)Transform domain approach e)WHE method with PM filter,f)Transform domain approach with PM filter

TABLE III
COMPARISON OF PSNR VALUES OF PROPOSED METHOD WITH OTHER METHODS

Input image	Methods	PSNR (dB)
Image 3	Histogram Equalization	8.232
	Transform dimain approach with PM filter	8.895
	WHE with PM filter	13.14

proposed methods (Fig.3d and Fig.4d). This method has been tried on various other images (eg. Fig.5) and similar results were observed.

In comparison with HE method, WHE method and transform domain approach gives higher PSNR values. An improved PSNR can be obtained by the use of proposed methods. WHE method with PM filter produces better PSNR values than the proposed method in the transform domain. As shown in Fig.3 the WHE method with PM filter is capable of preserving the local information and it effectively eliminate the over-enhancement problem.

V. CONCLUSION

The application of two different image enhancement techniques to medical images and the noise removal of enhanced images obtained from these methods is presented in this paper. Simulation results shows that both transform method and weighted histogram equalization method can produce considerable enhancements to medical images. Additionally, using Perona-Malik filter on such enhanced images effectively removes artifacts. Experimental results show that the proposed method can effectively remove the artifacts while preserving the contrast. The application of the image enhancement technique together with the PM filter can thus improve the quality of medical images. The proposed techniques outperforms (both quantitatively and qualitatively) the commonly used enhancement techniques (such as histogram equalization) as evident from the experimental results. PSNR values shows that the proposed WHE method with PM filter performs better than the transform domain approach with PM filter.

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