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Medical Image Contrast Enhancement using Range Limited Weighted Histogram Equalization

Monika Agarwal[a] and Rashima Mahajan*[b]

[a]*Dept. of ECE, G.D. Goenka University ,Gurugram,122102, India*
[b]*Dept. of CSE, Manav Rachna International Institute of Research and Studies, Faridabad, India*

Abstract

Contrast enhancement and brightness preservation are the crucial steps for image quality control for developing informative and visually pleasing images. Histogram equalization based image enhancement tool does not provide the brightness preservation and better contrast enhancement. This may cause loss in diagnostic information in case of medical images. An attempt has been made to integrate range limited and weighted histogram equalization with adaptive gamma correction followed by homomorphic filtering to study the improvement in contrast as well as to preserve the essential details of the image. An image segmentation based on an efficient Otsu's method has been implemented. The experimental results obtained are found to be optimal for generating enhanced images according to both quantitative estimation and qualitative human visual inspection. An excellent performance in terms maximum entropy preservation, better contrast enhancement and the best visual appearance of low contrast medical images has been achieved.

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*Keywords:*Medical Image; Contrast Enhancement; Histogram Equalization; Adaptive Gama Correction; Homomorphic Filtering; Weighted Distribution; Probability Density function

1. Introduction

Recent advances in medical imaging techniques have led to an increased interest in digital image processing. Image contrast enhancement is a preprocessing step and most important issue in the field of image processing. The main aspiration of image contrast enhancement is to enlarge the intensity difference between the objects and their background. This enlargement in intensity difference can be obtained by stretching more frequent gray levels to a greater extent. Image contrast enhancement is extensively used in numerous applications such as digital photography, satellite imaging, face recognition, medical image processing, iris detection followed by certain

*Dr. Rashima Mahajan, rashimamahajan@gmail.com

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applications in LCD display processing [1]. Histogram equalization is the most admired and widely used contrast enhancement technique due to its accuracy and easy implementation. It is achieved by normalizing the intensity distributions using its cumulative density function so that improves the contrast of an input image and resultant image may have a uniform intensity distribution.

In recent years, many researchers proposed various global histogram equalization methods to deal with the mean shift problem in the output image. Initially a novel method was proposed known as brightness preserving bi histogram equalization (BBHE) to preserve the mean brightness and for contrast enhancement of an input image [2]. A similar technique dualistic sub image histogram equalization (DSIHE) was proposed by Wang et. al. which incorporates segmentation based on the median value [3], [4]. On the basis of experimental results DSIHE gives better results as compare to BBHE in terms of brightness preservation and entropy. To remove the problem of annoying side effects two techniques recursive mean separate histogram equalization (RMSHE) [5] & recursive sub image histogram equalization (RSIHE) [6] were proposed. Both techniques are recursive algorithms of previous techniques BBHE and DSIHE. Then further research investigates a new approach named as recursively separated weighted histogram equalization (RSWHE) based algorithm to enhance the image contrast. This method is exactly similar to RMSHE and RSIHE, the difference is that in RSWHE the normalized power law function is applied [7]. These multiple HE methods RSIHE, RMSHE and RSWHE provides good contrast enhancement and acceptable level of brightness preservation, but generates the over enhancement problem in resultant image. To remove these drawbacks a group of researchers presented another new automatic transformation technique named as adaptive gamma correction with weighted distribution (AGCWD) [8]. This technique increases the brightness level of a low contrast image by applying the Gama Correction and thus modifying the probability distribution of luminance pixels. This is followed by the another research which involves the combination of bi level weighted histogram equalization and adaptive gamma correction to achieve the good brightness preservation and contrast enhancement but this method creates the problem of uneven illumination [9]. Thus these latest findings investigate another efficient AGC based method to make the balance between the high level visual quality and low computational cost. This method is the hybrid of range limited bi-histogram equalization (RLBHE) and AGC techniques [10]. On the basis of experimental results this proposed method more efficiently enhances the low contrast images as compare to RLBHE & adaptive gamma correction with weighted distribution (AGCWD).

Table 1.Literature Summary of Various Contrast Enhancement Techniques

Author Name& Year	Method	Performance Measurement Parameters	Remarks
Kim (1997)[2]	BBHE: Division based on the mean brightness	Images& respective Histograms	Over enhancement& over brightness along with annoying artifacts
Wang et. al.(1999)[3]	DSIHE: Same as BBHE but division based on the median	Mean, Entropy & Background gray level	Over enhancement but preserves the entropy more than BBHE
Chen (2003)[5]	RMSHE: Recursive segmentation based on the mean brightness	Visual quality assessment	removes the problem of over enhancement and preserves the more brightness
Sim (2007)[6]	RSIHE: Same as RMSHE but division based on the median.	MSSI & PSNR	Preserves more brightness, good contrast enhancement and better MSSI and PSNR.
Kim & Chung (2008)[7]	RSWHE: Same as RMSHE & RSIHE, difference is including the weighting process	AMBE, PSNR and Entropy	preserves good brightness as compare to RMSHE & RSIHE with better contrast enhancement
Haung et. al. (2013)[8]	AGCWD: AGC with WD applied to the V component of the colour image	AMBE and Colour distortion	less distortion for both colour images and video sequences
J. Baby andV.Karunakaran (2014) [9]	Apply constrained PDF and weighted PDF to the color components of the input image followed by the AGC method	PSNR, AMBE	Combined the bi-level weighted histogram equalization with AGC for better brightness preservation and contrast enhancement.
C. Gautam and N. Tiwari (2015) [10]	Hybrid of range limited bi-histogram equalization method (RLBHE) and adaptive gamma correction	AMBE	Make the balance b/w high level visual quality and low computational cost but

	(AGC)		with large value of AMBE
Proposed Technique	RLWHE: Segmentation based on the Otsu's method , Weighted HE with RLBHE analysis, AGC followed by homomorphic filtering	Entropy, PSNR & Visual Quality Assessment	Effective contrast enhancement of medical images with best visual appearance, maximum entropy & brightness preservation.

Above mentioned techniques BBHE, DSIHE, RLBHE, RLBHE with AGC and AGCWD are not provide the better contrast enhancement and maximum entropy preservation. Most of the techniques were not addressed the low contrast medical image enhancement problems. Thus these drawbacks of existing techniques motivate us to design a new algorithm for the enhancement of low contrast gray scale medical images. This paper presents a new weighted histogram equalization algorithm called range limited weighted histogram equalization with adaptive gamma correction & homomorphic filtering (RLWHE) to enhance the medical images with better contrast, best visual appearance and maximum entropy preservation.[8], [10].

Organization of rest of this paper is as follows: - section 2 describes the proposed methodology based on RLWHE in detail. Section 3 describes the experimental results obtained using proposed method and their analysis followed by conclusion in section 4.

2. Materials and Methods

This section provides the methodology followed to implement the proposed medical image contrast enhancement algorithm based on range limited weighted histogram equalization with adaptive gamma correction and homomorphic filtering (RLWHE). Medical image contrast enhancement process improves the visual appearance and identifies the desired region of an image. This enhancement process plays a very important role in modern diagnosis and it is also very helpful for radiologists and surgeons to detect the abnormal regions. But any noise or low contrast in the images can lead towards an incorrect diagnosis of disease, thus it is very necessary to improve the quality of low contrast medical images [3]. Therefore this paper presents an efficient technique to enhance the low contrast medical images with better contrast, maximum entropy and brightness preservation along with control on over enhancement problem.

Detailed description of each step of the proposed method is given in the following sub sections. Block diagram of the proposed method is shown in Fig. 1

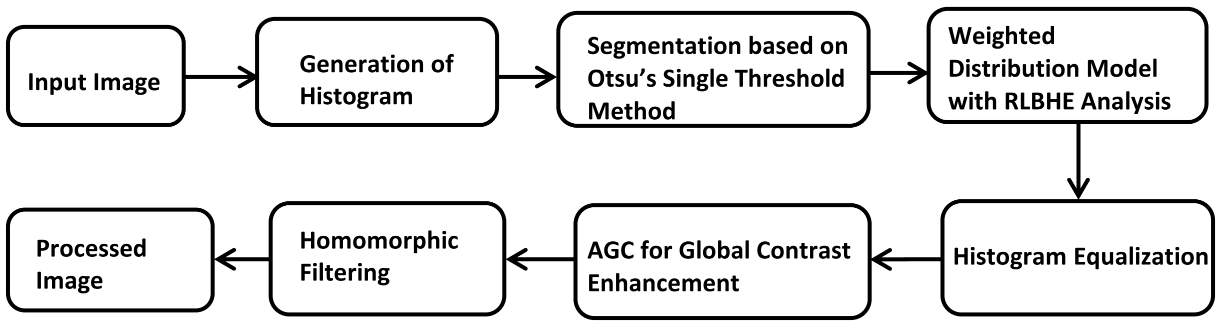


Fig. 1.BlockDiagram of Proposed Range Limited Weighted Histogram Equalization with AGC & Homomorphic Filtering Technique.

2.1. Acquisition of Image

The proposed RLWHE technique and other six HE based techniques including GHE, BBHE, DSIHE, AGCWD, RLBHE and RLBHE with AGC for comparison are tested with seven low contrast MRI medical images obtained from national brain research center (NBRC), Manesar and other images are downloaded from public image database. All images are gray scale images of size 256 x 200.

2.2. Generation of Histogram

Histogram of an image is a frequency distribution graph which shows the no. of pixels in an image at every different intensity value. MATLAB inbuilt function imhist () is used to generate the histogram which defines the n equally spaced bins, each represents the range of data values [4].

2.3. Segmentation of Input Image Histogram based on Otsu's Threshold

Thresholding segmentation is the best technique for extracting the object from the background of an image. In this technique optimal threshold i.e. between the lower gray level of the object and higher gray level of the background is used to divide the histogram into two parts that are the target region and the background region. Both the parts can be equalized separately so that contrast of the target region and background region can both be effectively improved [10].

Otsu's method automatically performs the histogram shape based image thresholding. Otsu's method searches the threshold value that minimizes the intra class variance and it is defined as a weighted sum of variance of two classes [10], [11].

$$X_0 = \underset{X_T}{\mathrm{ArgMax}} \left\{ W_L(E(I_L) - E(I))^2 + W_U(E(I_U) - E(I))^2 \right\} \tag{1}$$

where X_T is the optimum threshold. W_L and W_U are the PDF of sub images I_L and I_U. E (I_L) and E (I_U) are defined as the mean brightness of the sub images and E (I) is the mean brightness of the whole image.

2.4. Histogram Weighted Model

After Otsu's thresholding a series of *n* sub histograms has been obtained. The range of input image histogram is [0 255]. Let H_i, i = 0, 1, 2…..L-1 is the i^{th} sub histograms of image X (i, j) and its range is [a_i, b_i] where a_i and b_i are the lowest and highest intensity value of sub histogram [8].

The probabilities P(k) of each sub histogram $H_i(k)$ are modified with weighted probabilities $P_w(k)$ as per the equation (2)

$$P_w(k) = P_{max} \left(\frac{P(k) - P_{min}}{P_{max} - P_{min}} \right)^{d_i} \qquad a_i \leq k \leq b_i \tag{2}$$

where P_{max} and P_{min} are the maximum and minimum probabilities of input image histogram and d_i is the accumulative probability density of i^{th} sub histogram.

The resultant weighted probabilities P_w (j) have been normalized using the following equation (3)

$$P_{w_n}(j) = \frac{P_w(j)}{\sum_{j=0}^{L-1} P_w(j)} \tag{3}$$

where Pw_n is the normalized weighted probability of input image histogram.

2.5. Histogram Equalization

Histogram equalization provides a uniform distributed histogram by using cumulative density function of the input image. For each sub histogram *i* with range [a_i, b_i], the equalization takes place according to the following equation (4) [6]

$$Y_i(k) = a_i + (b_i - a_i) * C_{w_n}(k) \qquad 1 \leq i \leq n \tag{4}$$

2.6. Adaptive gamma correction for global contrast enhancement

Histogram equalization process limits the brightness of low contrast images so only this process is not sufficient for the enhancement of low contrast medical images. Especially for medical images good contrast enhancement and maximum information preservation both are very necessary for the correct diagnosis of disease [8].

To achieve this objective adaptive gamma correction technique has been used for further enhancement of low contrast medical images as per the following equation (5)

$$T(l) = l_{max} \left(\frac{l}{l_{max}}\right)^{r} \tag{5}$$

Where l and l_{max} represents the intensity and maximum intensity of an input image; r is the varying adaptive gamma parameter. In adaptive gamma correction technique, by using weighted CDF function parameter r is modified, given by following equation (6)

$$\gamma = 1 - C_{w_n}(l) \tag{6}$$

The superlative part of this adaptive gamma correction technique is that it gradually increases the low intensity pixel values and entirely removes the possibility of decrement of high intensity pixel values.

2.7. Homomorphic Filtering for local contrast enhancement

Adaptive gamma correction process is very important for the further enhancement of medical images. But for low contrast and complex structured background medical images, this process produces some noise artifacts in visually important areas and thus this may lead to incorrect diagnosis of disease. Therefore to remove this problem homomorphic filtering is used. This filtering is operates in frequency domain and very useful for correcting the non uniform illumination artifacts possessed by low contrast image [6].

2.8. Performance evaluation

The performance of proposed contrast enhancement technique RLWHE has been evaluated quantitatively through entropy & PSNR measurement.

2.8.1 Entropy

Entropy is one of the best image quality performance measurement parameter because it measures the richness of information in the image. It is defined as total amount of information content present in the image and measured in bits.

The equation of the Shannon Entropy is given below:

$$E(P) = \sum_{k=0}^{L-1} P(k) * logP(k) \tag{7}$$

Where P(k) is the probability of gray levels with intensity l, L is the total number of gray levels present in the image and E(P) is the entropy of the resultant image [11].

2.8.2 Peak Signal to Noise Ratio

A good image enhancement technique enhances the image with retaining its natural look. Specifically that technique should not magnify the noise level of the input image. PSNR is the ratio between maximum power of the input signal and the power of the corrupting noise. A higher PSNR indicates that the reconstruction is of higher quality [12].

$$PSNR = 10log_{10}\left[\frac{(L-1)^2}{\frac{1}{n}\sum_i\sum_j|x(i,j)-y(i,j)|^2}\right] \tag{8}$$

Where X (i, j) is the intensity of the input image and Y (i, j) is the intensity of the processed image.

3. Results And Discussion

In this section the performance of the proposed contrast enhancement technique is compared with the other existing histogram equalization, RLBHE and adaptive gamma correction techniques. Low contrast test images are utilized for the assessment of visual quality and performance of the proposed technique. This technique has been implemented by using MATLAB signal processing tool version R2012a. Series of experiments has been performed to evaluate the performance and feasibility of the proposed technique. For quantitative evaluation, Table 1-2 shows the result of entropy and PSNR on low contrast images respectively where column corresponds to six HE based methods and row corresponds to six test images. Comparison of visual quality and appearance of the test images are shown in Fig. 2 and 3

3.1. Quantitative Performance Measurement based on the Entropy

To measure the quantitative performance of the proposed contrast enhancement technique entropy is calculated for all the six test images. It is observed that the proposed technique RLWHE gives the larger value of entropy which is approximately equal to entropy of the original input image and higher than entropy of other techniques. The higher value of entropy means lesser intensity saturation effect which produces due to HE. Thus the proposed technique outer performs as compare to other existing contrast enhancement techniques. Therefore it can be concluded that the proposed technique successfully avoids the intensity saturation artifacts along with control on over enhancement problem.

Table 2 Entropy results of image contrast enhancement using different techniques.

Image Name	Original	GHE	BBHE[2]	DSIHE	AGCWD[9]	RLBHE	RLBHE with AGC	Proposed Method (RLWHE)
Palm bone X-Ray	6.58	5.46	6.01	6.15	6.44	5.79	5.93	**6.54**
MRI Knee	6.83	5.49	5.94	6.21	**6.63**	5.32	5.25	6.31
MRI Brain	6.42	5.44	5.64	5.78	6.20	5.46	5.39	**6.58**
MRI Skull	6.94	5.66	6.15	6.32	6.73	5.40	5.34	**7.01**
Coconut Image	7.08	5.89	6.29	6.37	6.84	5.78	5.77	**6.98**
Rice Image	6.96	5.64	5.77	5.66	6.62	5.57	5.57	**6.82**

3.2. Quantitative Performance Measurement based on the Peak Signal to Noise Ratio

Based on simulation results of table 2 a careful examination of the PSNR values reveals that the proposed technique RLWHE produces comparatively better PSNR values from that of other techniques. A higher value of PSNR indicates the better contrast enhancement. Thus according to these results the proposed technique provides the excellent performance in terms of better contrast enhancement and maximum brightness preservation for all types of low contrast medical images.

Table 3 PSNR results of image contrast enhancement using different techniques.

Image Name	GHE	BBHE[2]	DSIHE	AGCWD[9]	RLBHE	RLBHE with AGC	Proposed Method (RLWHE)
Palm bone X-Ray	24.31	24.07	24.07	25.13	26.12	33.35	**34.17**
MRI Knee	24.43	24.06	24.76	24.83	27.79	32.02	**38.53**
MRI Brain	24.59	27.48	25.33	25.65	27.09	30.99	**31.87**
MRI Skull	24.51	25.91	26.71	24.89	32.77	29.74	**41.37**
Coconut Image	24.41	24.08	24.09	24.97	29.69	33.69	**34.07**
Rice Image	27.53	30.09	28.58	25.13	29.16	25.37	**32.41**

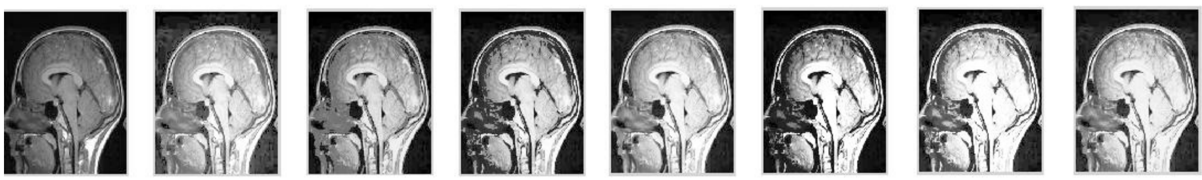
3.3. Qualitative Performance Measurement Based on the Visual Quality of the image

Qualitative evaluation of proposed technique has been done through analyzing visual quality or appearance. Low contrast medical images have been considered to test the robustness and versatility of the proposed enhancement technique. Fig. 2 and 3 shows the visual results of the test images. On the basis of simulation and visual results, proposed technique has revealed its supremacy by controlling the rate of enhancement and avoiding the problem of over enhancement and under enhancement.

Fig. 2 shows the visual results of Palm bone X-ray image & MRI skull image respectively and it is clear that the processed image generated by proposed method RLWHE looks more natural while in case of other methods there are some high unnatural intensities. Fig 3 shows the visual results of MRI knee & MRI brain image respectively. In the results of MRI knee image, other methods shows the over enhancement problem but the proposed method produces more natural and effective image. It gives superior results with maximum entropy and improved contrast as compared to other techniques HE, BBHE, DSIHE, AGCWD, RLBHE and RLBHE with AGC.

For all the test images proposed technique RLWHE produces the highest entropy and better contrast this proves that this technique is considered to be the best for enhancement of low contrast images along with maximum entropy & brightness preservation, better contrast enhancement and also preserves the natural appearance of the image.

(a) (b) (c) (d) (e) (f) (g) (h)



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 2. Contrast Enhancement results of Palm bone X-Ray & MRI Skull image (a) Original (b) GHE (c) BBHE (d) DSIHE (e) AGCWD (f) RLBHE (g) RLBHE with AGC (h) Proposed Method RLWHE.

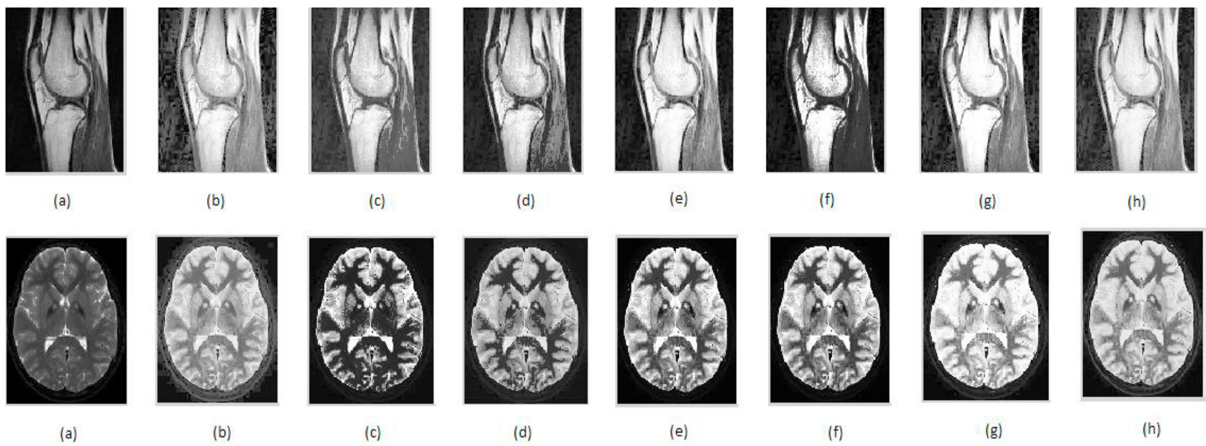


Fig. 3. Contrast Enhancement results of MRI Knee & MRI Brain image (a) Original (b) GHE (c) BBHE (d) DSIHE (e) AGCWD (f) RLBHE (g) RLBHE with AGC (h) Proposed Method RLWHE.

4. Conclusion

In this paper an efficient technique based on range limited weighted histogram equalization (RLWHE) has been utilized for the enhancement of low contrast medical images. This technique is composed of segmentation based on the Otsu's method, weighted HE with RLBHE analysis and AGC with homomorphic filtering that makes the proposed technique superior in terms of entropy, PSNR and visual quality assessments. This hybrid technique powerfully contributes towards the enhancement of low contrast images as compared to individual HE techniques viz., RLBHE, AGCWD and RLBHE with AGC. Based on the entropy & PSNR measurements this method provides the maximum entropy preservation & better contrast enhancement as compared to other methods along with control on over enhancement problem that leads to the natural appearance of the image. The proposed algorithm can effectively be used in video processing, medical image processing and real time processing.

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