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Image Enhancement of Medical Images using Curvelet and Rayleigh CLAHE

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Abstract— *Image enhancement in digital image processing is one of the main issues. The main purpose of image enhancement is to obtain a high quality image after improving the characteristics of the input image so that output image is better than the original one. Often images obtained from medical imaging systems are of low quality. This may be due to the under-utilization of available range of possible gray levels. Thus obtained images may suffer from the problems of underexposure and overexposure. In this paper, a new algorithm has been proposed to enhance the medical images. This paper includes the introduction of image enhancement, an overview of different techniques of image enhancement and the new proposed algorithm for image enhancement of medical images. A comparison of existing image enhancement techniques with the proposed technique based on different performance measures is presented. Experimental results demonstrate that the proposed technique outperforms various existing techniques.*

Index Terms—*image enhancement, histogram equalization (HE), adaptive histogram equalization (AHE), rayleigh distribution, contrast limited adaptive histogram equalization (CLAHE), curvelets.*

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I. Introduction

In digital image processing image enhancement is a standout amongst the most critical application regions. Digital images play an essential role in the daily life applications like medical imaging, satellite imaging, astronomy, real-time applications and in the other areas of research [1]. Whenever an image is converted from one form to another (such as in digital), some sort of degradation may be observed which can be removed by enhancement process. Enhancement of images is also done due to the non-ideal image acquisition process, which may be due to poor illumination. Even in the presence of advance digital technology, many real world images still appear with a low contrast which is unsuitable for human eyes to identify. The main idea behind image enhancement is to improve the quality of the image to make the image better for some particular applications. Different ways to enhance an image are by reducing noise, edge enhancement and contrast enhancement etc [2]. Besides this, the hidden details of the image are important to be brought out. Image enhancement is one of the significant techniques in digital image processing, which plays an important role in many fields like medical image analysis, high definition television (HDTV), industrial X-ray image processing, remote sensing, microscopic imaging etc.

In the past, different image enhancement methods have been defined for enhancement of images. Spatial domain methods represent the image plane and direct operation on the pixels is applied in these methods [3]. One example of spatial methods is point processing. The advantage of spatial domain methods is their simplicity to understand and hence they are favorable for real-time applications. On the other hand frequency domain methods directly operate on the transform coefficients of the image like fourier transform, discrete wavelet transform etc. Frequency domain works with low pass filters and high pass filters [4]. Advantage of using this domain is low computation complexity, ease of manipulating the frequency composition of the image etc. There are various techniques available for image enhancement of digital images.

The most common method used for image enhancement is histogram equalization [5]. This is based on an assumption that the gray scale histogram which is uniformly distributed depicts the best contrast. The technique is suitable for the images which have larger related regions like an image having light background and dark foreground. The contrast is stretched among these local regions thus depicting the hidden details and hence difference in the regions become more observable. Adaptive Histogram Equalization (AHE) is another image enhancement technique which is different from histogram equalization as it computes different histograms related to a particular region of an image and hence reconstructs the brightness values of the image using those histograms [6]. It is therefore useful for increasing local contrast but with a limitation that it over amplifies noise in homogeneous regions of the image. Another method called Contrast Limited Adaptive Histogram Equalization

(CLAHE), an improved version of AHE restrains this problem of amplification with a clip limit criterion [7]. CLAHE has less noise, prevents brightness saturation and gives better results in local areas than other techniques like HE, AHE etc.

A novel image enhancement method, Curvelet based Rayleigh CLAHE (CRCLAHE) is put forward in this paper. According to proposed method, the image is first decomposed into different frequency bands and CLAHE with rayleigh distribution is applied on each of the band. Enhanced image is then analyzed by applying inverse curvelet transform on each frequency sub-band. The goal of proposed technique is to enhance the contrast of the image while preserving the details.

II. Related Work

A simple and effective image enhancement technique for enhancing the contrast of digital images is histogram equalization is presented in [8] where pixels are assumed to be uniformly distributed over the entire image. A survey of local and global image enhancement techniques is available in [9]. Another technique after histogram equalization that reduces the limitation of histogram equalization is adaptive histogram equalization which is presented in [10]. This technique has a limitation of over amplifying the noise in homogeneous regions of the image.

In [11], curvelet based noise reduction methods are carried out on brain computed tomography (CT) images and performance assessment is calculated. The experimental results show that the curvelet based methods outperforms the wavelet based methods. Edge preservation is also focused with noise suppression in this paper. To enhance the quality of digital picture, different image enhancement techniques like contrast stretching, HE, AHE, CLAHE rayleigh are implemented in [12]. These methods are processed on dental imaging. Contrast quality of digital image is evaluated and image quality is obtained by using CLAHE rayleigh method of image enhancement. Objective assessment in this paper shows that CLAHE rayleigh is better than other methods of enhancement evaluated in the paper and it gives more optimal image quality. In [13], the curvelet representation of the image is described and an analysis is made from different angles. It is shown that curvelet transform is useful in position, scale and orientation. The subband concept is useful in representing objects.

Image enhancement methods categorized as spatial domain methods and frequency domain methods are explained in [14]. An extended version of adaptive histogram equalization technique that reduces the limitation of over amplification of noise by applying a clip limit function on the neighbourhood regions is presented in [15]. The contrast limiting property of this technique makes it better than other image enhancement techniques like HE, AHE etc. A method used for preserving the color information of retinal images is proposed in [16] where the intensity component of image is enhanced by using rayleigh CLAHE. This method increases the contrast and improves the overall appearance of the image. CLAHE technique with rayleigh distribution of image enhancement for the improvement of video quality in real time system is presented in [17].

The highlights of different image enhancement techniques that can particularly be used for medical image enhancement is presented in [18]. This paper briefly described the limitations of some existing image enhancement methods. A method to enhance the contrast with the improved contrast-to-noise ratio (CNR) is presented in [19]. To ease the process of disease diagnosis, contrast enhancement is very useful in medical image analysis. In [20], curvelet transform for removal of noise in images is presented. Image denoising is necessary as with the process of receiving and transmission, images suffer from noise content. A new image enhancement method based on curvelet transform to enhance the tumor characteristic in a mammographic image is presented in [21]. The results show that curvelets work better than wavelets for images having little noise, excessive noise or no noise at all. In [22], CLAHE is combined with DWT to improve the problems of contrast overstretching and noise. Experiments show that this novel image enhancement method is better in preserving the image details and suppression of noise.

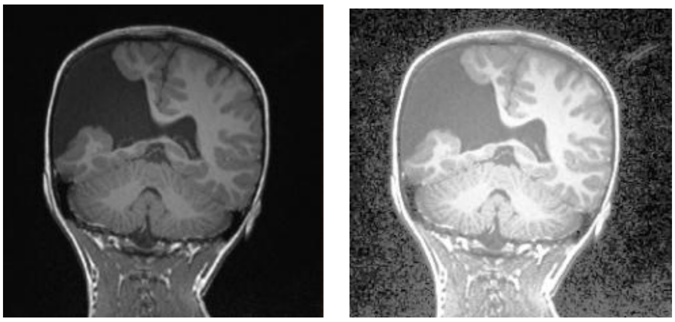
A review about the distinctive image enhancement techniques like HE, BBHE, AHE, CLAHE etc. with their advantages and disadvantages is available in [23]. Different medical images like ultrasound images, X ray images and other images are analyzed in this paper and a study of different contrast enhancement techniques of medical images is carried out in [24]. In [25], an analysis is made about the intensity degradation, geometric and textural features of medical images. This analysis is made in respect to clip limit variation and specified histogram shape. Image contrast enhancement method for cone beam CT (CBCT) images is presented in [26]. This is based on fast discrete curvelet changes (FDCT) that work with unequally spaced fast fourier transform (USFFT). The experimental results show that the curvelet method works better than the wavelet method. A novel image enhancement method is presented in [27] where CLAHE technique for image enhancement is combined with power law transformation. This method is implemented on ultrasonic well logging images. CLAHE technique enhances the intensity component and excessive brightness is prevented in uniform areas. The power law transformation is applied after the CLAHE processing. The experimental results shown in this paper depicts that the proposed technique gives better results for ultrasonic well logging images than other existing techniques presented in the paper.

III. Image Enhancement Techniques

Various image enhancement techniques are available to enhance the images while preserving the brightness and overall appearance.

A. Histogram Equalization

Histogram equalization (HE) is a simple and an effective technique for image enhancement. It stretches the histogram of the input image [28]. In general, the distribution of gray levels in a given input image is referred to as a histogram. The histogram of gray levels provides an overall description of the appearance of the input image. Histogram does not only gives us a general overview on some useful image statistics (e.g. mode, and dynamic range of an image), but it also can be used to predict the intensity characteristic of an image. The histogram of an image shows only a fraction of the total range of gray levels. Proper adjustment of gray levels for a given image can enhance the appearance or contrast of the image. If the histogram is concentrated on the low side of the intensity scale, the image appears dark. On the other hand, if the histogram is concentrated on the high side of the scale, the image appears bright. If the histogram has a narrow dynamic range, the image usually is an image with a poor contrast. Histogram equalization works by flattening the histogram of the input image and stretching the dynamic range of the gray levels by using the cumulative density function of the image [29]. The main goal is to obtain a uniform histogram for the output image.



(a) (b)

Fig. 1: (a) Original image (b) Histogram equalized image (HE)

Figure 1 shows the qualitative result of applying histogram equalization (HE) technique to a MRI image. It is clear from the result of histogram equalized image that pixel intensity is uniformly distributed over the image.

Let $X = \{X(i, j)\}$ denote a given image composed of *L* discrete gray levels denoted as $\{X_0, X_1, ... X_{L-1}\}$ where $X(i, j)$ represents an intensity of the image at the spatial location (i, j) and $X(i, j) \in \{X_0, X_1, ... X_{L-1}\}$. For a given image X, the function called probability density function $p(X_K)$ can be defined as

$$p(X_K) = \frac{n^k}{n} \tag{1}$$

For $k = 0,1,\dots,L-1$, where n^k represents the number of times that the gray level X_k appears in the input image X and *n* is the total number of pixels present in the input image. The value $p(X_K)$ is associated with input image's histogram which represents the number of pixels having specific intensity X_k. A plot of n^k vs. X_k is known as the histogram of X. On the bases of probability density function, the cumulative density function is defined as follows:

$$c(x) = \sum_{j=0}^{k} p(X_j) \tag{2}$$

Where $X_k = x$, for $k = 0,1,\dots,L-1$. The value of $c(X_{L-1})$ is always 1 [30]. Histogram equalization is a scheme that maps the input image into the entire dynamic range, (X_0, X_{L-1}) by using the above defined function called the cumulative density function as the transform function [2, 10]. So, transform function $f(x)$ based on the cumulative density function can be defined as

$$f(x) = X_0 + (X_{L-1} - X_0)c(x) \tag{3}$$

Then the output image of the histogram equalization,

$$Y = \{Y(i, j)\} \tag{4}$$

can be expressed as

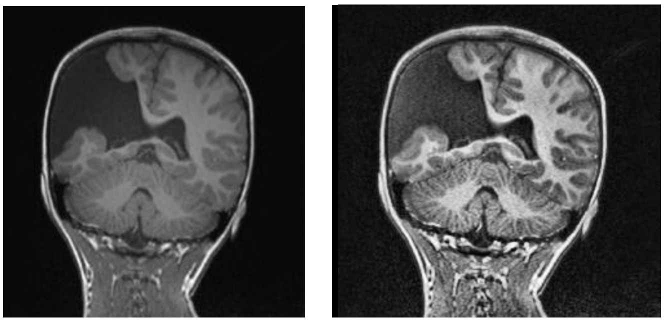
$$Y = f(X) \quad (5)$$

$$= \{ f(X(i,j)) \mid \forall\ X(i,j) \in X \} \quad (6)$$

The histogram equalization spreads out the intensity values along the total range of values in order to achieve a higher contrast. This method is useful when an image is represented by close contrast values, such as images in which both the background and foreground are bright at the same time, or else both are dark at the same time. However, histogram equalization has some drawbacks. First, histogram equalization transforms the histogram of the original image into a flat uniform histogram where mean value lies somewhere in the middle of gray level range. Therefore, the mean brightness of the output image almost lies at the middle. Hence we can say that it does not take into account the mean brightness of the input image [10]. Second, histogram equalization performs the enhancement task globally, i.e. it only highlights the details of the borders and edges of some features but may reduce its local content. Third, this method may result in over enhancement and saturation artifacts due to the stretching of the gray levels over the full gray level range. The major disadvantage of HE is that the brightness of the image is changed after the technique is applied. Nevertheless, HE is not commonly used in consumer electronics such as TV because it may significantly change the brightness of an input image and introduces unnecessary visual deterioration [31]. Histogram equalization is an image-processing technique often used to achieve better quality images in medical applications such as digital MRIs, X-rays and CT scans but due to the above mentioned drawbacks, it is required to use some other histogram based image enhancement techniques.

B. Adaptive Histogram Equalization

Adaptive histogram equalization (AHE) is an excellent technique for contrast enhancement of medical images. Its effectiveness, reproducibility and automatic operation make it broadly applicable. It removes the problem of inability of depicting the full dynamic intensity range in some medical images. It also overcomes the limitations of global HE by providing most of the desired information in a single image that can easily be produced without any manual intervention. This method is sensitive and adaptive to local information present in an image, i.e. it uses the local information of an image to obtain a mapping function from the neighbourhood region called contextual region. Hence contrast is enhanced based on the local area rather than the entire image. The histogram equalization mapping function is applied to each pixel in the contextual region. In its simplest form, each pixel will be transformed based on the histogram of the square surrounding the pixel. To say, AHE and HE are different as AHE computes many histograms as per the contextual regions and utilize them for enhancing the contrast in those regions [10]. The following figures can help to analyze the effect of AHE.



(a) (b)

Fig. 2: (a) Original image (b) Adaptive histogram equalized image (AHE)

Following are the steps for the algorithm of AHE:

Step1: Calculate the size of the contextual region according the dimension of the input image. If size of image is 256x256 then smallest size possible for a contextual region is 32 pixels square.

Step2: Identify all the pixels in this contextual area.

Step3: Each pixel's neighbouring pixels make a contextual region.

Step4: The histogram equalization mapping function is calculated for this region and this mapping is applied to the pixel being processed in this region.

Step5: Step 4 is repeated for all the pixels in the current contextual region and then for all the pixels in similar contextual regions of the image.

Step6: The output image is different and is adaptive to local pixel intensities than the global content of the image.

Step7: As a result, the information of different intensity sub ranges will be visible in the output image.

However adaptive histogram equalization has the following disadvantages. As AHE has to compute histograms for each corresponding contextual region it becomes computationally expensive and time consuming [32]. Also there is some over-enhancement of noise in relatively homogeneous areas. Noise enhancement is a problem for medical images which may result in loss of some information from the image. Hence another variant of AHE called Contrast Limited Adaptive Histogram Equalization (CLAHE) to overcome these disadvantages is given in the following part.

C. Contrast Limited Adaptive Histogram Equalization

Contrast limited adaptive histogram equalization (CLAHE) is an improved version of adaptive histogram equalization. It overcomes the problems possessed by AHE by limiting the amplification of noise in the image so that image has more natural appearance. It seems to be an effective algorithm for obtaining a good quality image and yields optimal equalization. This technique is very useful for video broadcasting where brightness requirement is very high. It enhances the level of brightness to a specific range and hence facilitates the comparison of different areas of an image. CLAHE works by partitioning the image into many non-overlapping regions that have almost equal sizes and HE is applied to each one. This makes the distribution of used gray levels even and hence the hidden features in the image become more visible. In some medical imaging applications, uniform re-distribution in CLAHE is not preferred as the corresponding values are evenly distributed over the entire dynamic range which further amplifies the noise. Therefore, a non-uniform distribution function is utilized. The rayleigh function is a non-uniform distribution function which enhances the contrast in order to accomplish a good background and foreground separation.

Following are the steps for the algorithm of CLAHE using rayleigh function:

Step1: Number of contextual regions (non-overlapping regions) according to the dimension of the input image are calculated.

Step2: Histogram for each of this region is computed.

Step3: A clip limit for clipping of histograms is obtained based on the desired contrast expansion and the size of the neighbourhood region.

Step4: Histogram clipping is performed at this predefined value before computing the mapping function. The intensity values of each histogram are redistributed in a way such that the height of histogram does not go beyond the clip limit.

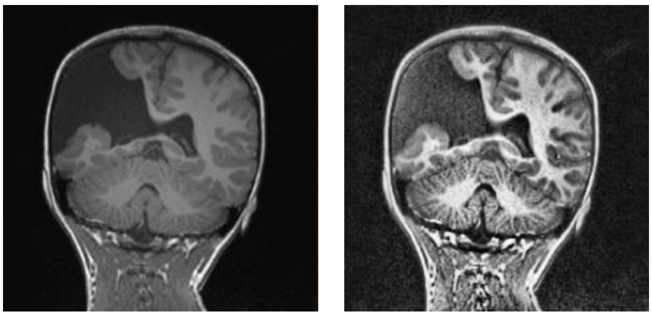
Step5: The transformation function for each clipped histogram is calculated to perform gray scale mapping. Transform intensity values into rayleigh distribution [33]. This is defined mathematically as,

$$g = g_{min} + \quad (7) \quad \left(\frac{1}{1 - P(f)}\right)\Big]^{1/2}$$

where g_{min} is minimum pixel values, α is rayleigh distribution parameter, P(f) depicts cumulative distribution function and g in computed pixel value.

Step6: Finally bilinear interpolation of mapping of each pixel of the neighbouring region is performed to avoid discontinuities or the artificially induced boundaries [10].

Some results for CLAHE technique in Fig. 3 can help to analyze the effect of this technique.



(a) (b)

Fig. 3: (a) Original image (b) Contrast limited adaptive histogram equalized image (CLAHE)

In case of CLAHE, the contrast limiting property is applied for each neighbourhood from which the transformation function is derived. The contrast limiting property is controlled on the histogram equalization process. The naturality of the original image is still preserved. However, this limiting property of CLAHE to enhance the contrast may not allow the observer to clearly depict the presence of some significant gray-scale contrast.

IV. Problem Formulation

It is observed from the past studies that medical images need enhancement due to poor contrast or due to the improper results of the medical imaging systems. The results from these systems get lowered due to the presence of various hard and soft tissues or may be due to high water content in the body. The resulting image suffers from the problems of underexposure and overexposure. The image appears grainy and of low density due to these problems. There is no clarity in the image due to different contrast levels that comes as a result of these imaging systems. To overcome the limitations caused by the imaging systems and the limitations of existing AHE and CLAHE techniques, a new algorithm, Curvelet based Rayleigh CLAHE (CRCLAHE) for image enhancement of medical images is proposed. In this algorithm, the image enhancement of medical images is performed by first decomposing the image into its frequency sub bands by curvelet transform. Then applying enhancement process on each of the sub bands with rayleigh CLAHE technique. The resultant image will be much better than the original one.

The curvelet transform is a multi scale transform used as an effective tool for image enhancement of digital images. The idea behind using the curvelet for image enhancement of medical images is that it has the ability to represent the curves of images at different scales and directions. It can be used in positioning, scaling and orientations. It can represent any discontinuity of the image more effectively than wavelets as curvelets functions in steps like sub band decomposition, smooth partitioning and renormalization. It is more suitable for image processing than wavelets because it can represent both the smooth and the edge parts of the image very well [11,13].

V. Steps Followed For proposed Algorithm

The detailed step wise algorithm of the proposed algorithm Curvelet based Rayleigh CLAHE (CRCAHE) is explained as follows:

Step1: Read the input medical image and determine its size.

Step2: Perform decomposition in the frequency domain by decomposing the input image with the curvelet transform to obtain its different frequency sub bands.

Step3: On each frequency sub band, CLAHE technique for enhancement with rayleigh as a non-uniform distribution function is applied.

Step4: To get the enhanced image as output, inverse curvelet transform is applied on the obtained sub bands.

Step5: Finally, save the output image generated by step 4 to get the results.

The flow diagram for the proposed algorithm is given in Fig. 4.

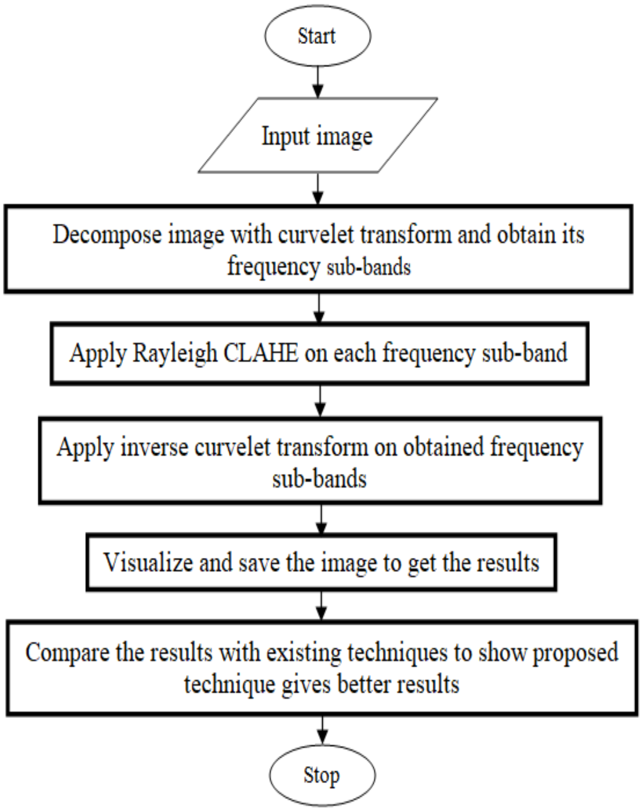


Fig. 4: Flow diagram of proposed method

VI. Experimental Results

Image enhancement on medical images and its performance evaluation is implemented using different image enhancement techniques like HE, AHE, CLAHE and the proposed method CRCLAHE. The analysis is made using different medical images like CT images and MRI images. Here, in this paper, CT image of chest, CT image of head and a MRI image of head are used to show the qualitative and quantitative results. The following figure shows the analysis of CT image of chest.

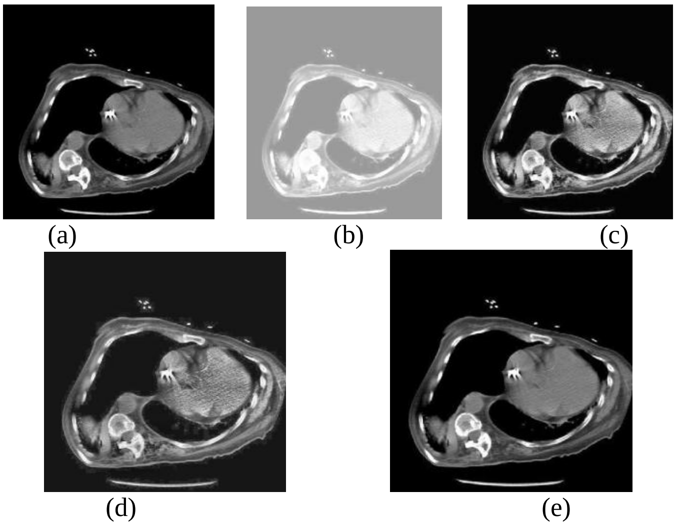


Fig. 5: (a) Original CT image of chest (b) HE image (c) AHE image (d) CLAHE image (e) CRCLAHE image

Table 1: Comparison of proposed technique with the existing techniques on the basis of different image quality measures for CT image of chest

Technique/ Parameter	PSNR	MSE	NAE	MD
HE	5.0853	20162.8076	4.0048	0
AHE	21.6194	447.8621	0.37359	47
RCLAHE	19.9553	656.9802	0.685	43
CRCLAHE	49.7562	0.6878	0.011492	5

Image quality measures like Peak-Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE), Normalized Absolute Error (NAE) and Maximum Difference (MD) are calculated on the images. The calculated values of these measures and their corresponding plots have been shown for all the images taken for the proposed work. The following plot show the qualitative result for CT image of chest. Based on Fig.6, it is clear that proposed method gives much better values for image quality measures.

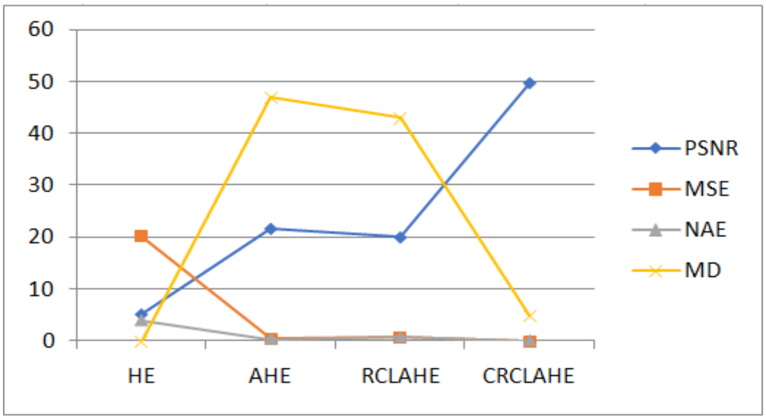


Fig. 6: Plot of objective criterion for CT image of chest

The following plots for PSNR, MSE, NAE and MD for CT image of chest depicts the comparison of existing and proposed technique.

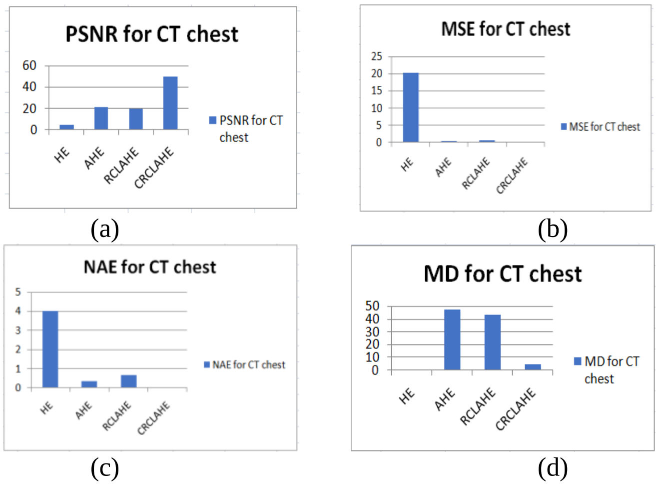


Fig. 7: Image quality measures for CT image of chest (a) PSNR (b) MSE (c) NAE (d) MD

The following figure shows the analysis of existing techniques and the proposed technique for CT image of head.

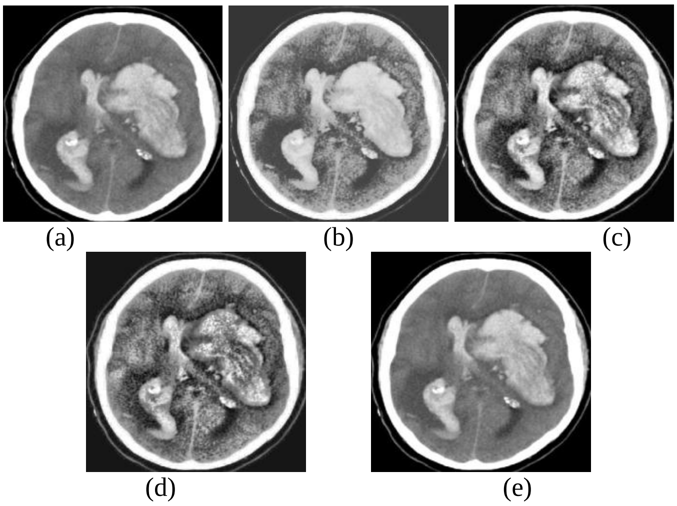


Fig. 8: (a) Original CT image of head (b) HE image (c) AHE image (d) CLAHE image (e) CRCLAHE image

Table 2: Summary of results of image enhancement of CT image of head with existing and proposed techniques on the basis of different image quality measures

Technique/ Parameter	PSNR	MSE	NAE	MD
HE	17.6815	1108.9984	0.24632	25
AHE	21.5311	457.0611	0.138	100
RCLAHE	19.883	668.0056	0.18921	117
CRCLAHE	48.85	0.84739	0.0051977	5

Table 2 represents the summary of implementation results for existing techniques and the proposed technique on input medical image. The graphical analysis is shown in the following plot:

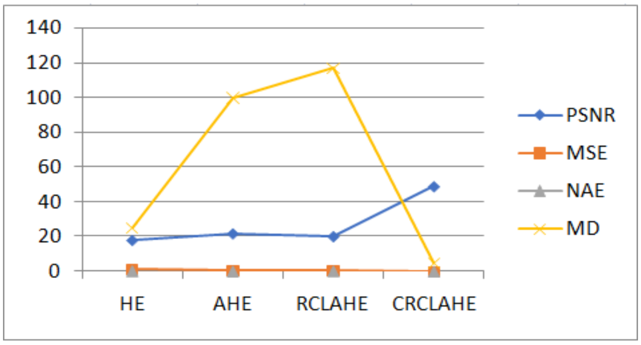
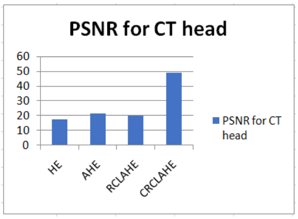
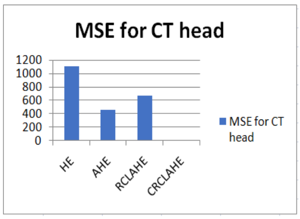


Fig. 9: Plot of objective criterion for CT image of head

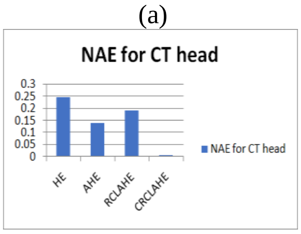
The plot in Fig. 9 shows the results of image enhancement for CT image of head and it is clear that the proposed method gives better results than other image enhancement techniques.



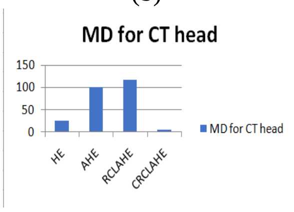
(a)



(b)



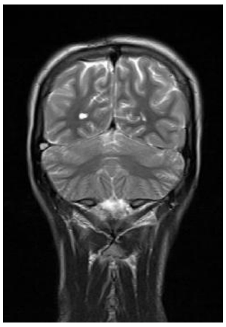
(c)



(d)

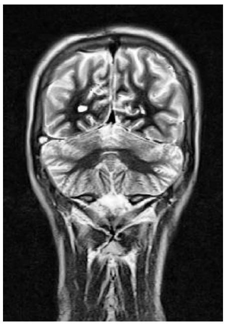
Fig. 10: Image quality measures for CT image of head (a) PSNR (b) MSE (c) NAE (d) MD

The proposed image enhancement method is also carried out on MRI image of head.

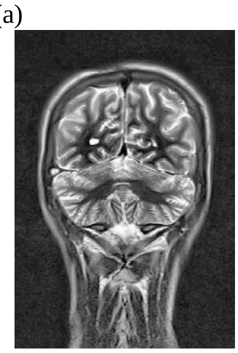


(a)

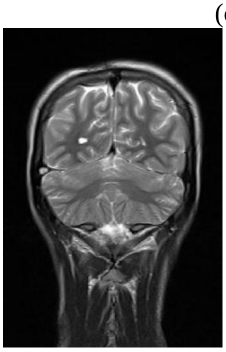
(b)



(c)



(d)



(e)

Fig. 11: (a) Original MRI image of head (b) HE image (c) AHE image (d) CLAHE image (e) CRCLAHE image

Table 3: Analysis of results for MRI image of head with existing and proposed techniques on the basis of image quality measures

Technique/ Parameter	PSNR	MSE	NAE	MD
HE	9.772	6852.9439	1.5095	0
AHE	17.3028	1210.0551	0.51066	68
RCLAHE	16.0409	1618.0487	0.7147	59
CRCLAHE	48.9633	0.82557	0.010963	5

The analysis based on image quality measures is shown in a plot below:

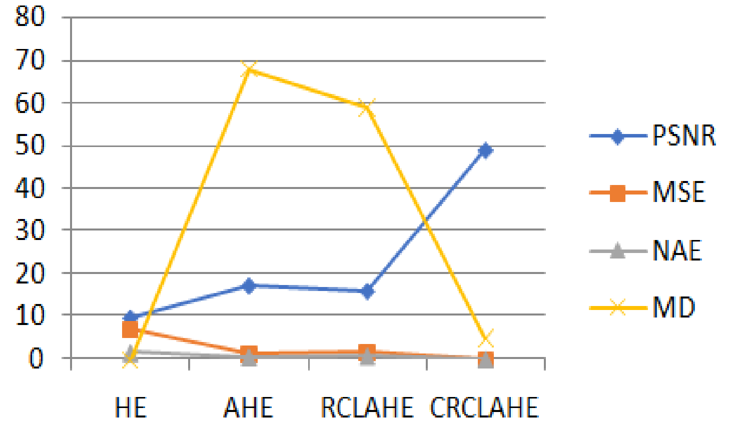
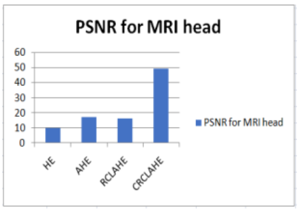
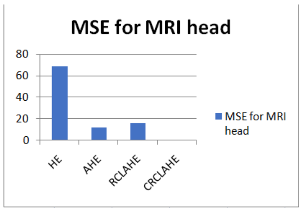


Fig. 12: Plot of objective criterion for MRI image of head

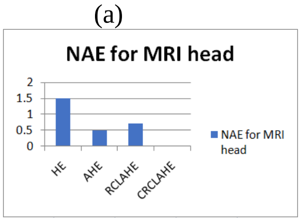
Based on objective criterion plot in Fig.12, it is clear that the proposed technique CRCLAHE gives better results than other existing techniques. The image quality measures depicted in the following figures represents more clear results.



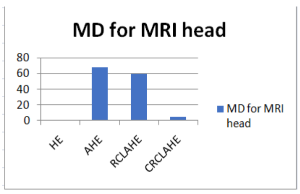
(a)



(b)



(c)



(d)

Fig. 13: Image quality measures for MRI image of head (a) PSNR (b) MSE (c) NAE (d) MD

VII. Conclusion

Image enhancement is an important issue in digital image processing. Histogram equalization is one of the main existing techniques for image enhancement. In this paper, various existing image enhancement techniques like HE, AHE and CLAHE are implemented on medical images and a new method for image enhancement of medical images has been devised to enhance the contrast of images thereby preserving the brightness. The proposed technique is implemented using Matlab. The preferred image quality of medical image is evaluated based on image quality measures like peak-signal-to-noise ratio (PSNR), normalized absolute error (NAE), mean square error (MSE) and maximum difference (MD). It is clear from the quantitative comparison that the proposed method gives higher values of PSNR when tested on different medical images. This is good as higher values of PSNR depicts more good quality image. Other results of objective assessments also show that image enhancement of medical images using the proposed method called CRCLAHE gives more optical quality of image and improves the overall appearance of images than other existing methods evaluated in the paper so that the observer can extract the required information. In the near future, the performance of methods evaluated in this paper could be investigated at a larger scale to other medical images like ultrasound images, X ray images, mammographic images etc. The proposed method may also be tested for medical video which is yet another challenging area.

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