Comparative Study of Different Enhancement Techniques for Computed Tomography Images

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***Abstract*—**One of the key problems facing in the analysis of Computed Tomography (CT) images is the poor contrast of the images. Image enhancement can be used to improve the visual clarity and quality of the images or to provide a better transformation representation for further processing. Contrast enhancement of images is one of the acceptable methods used for image enhancement in various applications in the medical field. This will be helpful to visualize and extract details of brain infarctions, tumors, and cancers from the CT image. This paper presents a comparison study of five contrast enhancement techniques suitable for the contrast enhancement of CT images. The types of techniques include Power Law Transformation, Logarithmic Transformation, Histogram Equalization, Contrast Stretching, and Laplacian Transformation. All these techniques are compared with each other to find out which enhancement provides better contrast of CT image. For the comparison of the techniques, the parameters Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) are used. Logarithmic Transformation provided the clearer and best quality image compared to all other techniques studied and has got the highest value of PSNR. Comparison concludes with better approach for its future research especially for mapping abnormalities from CT images resulting from Brain Injuries.

***Keywords*—**Computed tomography, enhancement techniques, increasing contrast, PSNR and MSE.

I. Introduction

COMPUTED Tomography images assist the radiologists to detect and locate the pathological changes in the brain of the patients more accurately. It is one of the most widely used techniques for the diagnosis of abnormalities of the structure inside the body. CT images are mostly preferred over Magnetic Resonance Imaging (MRI) because of its wider availability, lower cost, higher speed, and sensitivity to early strokes [2]. Identification of such changes in a non-contrast CT is a challenge because of the poor contrast of the image, and hence, it completely depends on the experience and knowledge of the reviewer. Thus, image contrast enhancement is a very crucial stage in the detection and analysis of CT images [3]. The contrast of the CT images should be properly enhanced for proper diagnosis of the abnormalities present in the images. The mapping of the images should be done such that all the abnormalities including the minute variations present must be clearly seen. Either CT images must be mapped with a modified scale or must use a transformation before mapping.

There are various contrast enhancement algorithms available for the contrast enhancement of images. Because of the large dynamic range of the CT images, the use of normal grey scale for mapping would reduce the contrast of the original image. So, the application of enhancement methods before displaying the images would rather increase the contrast of the images. Both linear and non-linear contrast enhancement methods are used usually for contrast enhancement of CT images. Histogram Equalization (HE) is a very popular technique used for contrast enhancement of an image. This is similar to Contrast Stretching (CS) in which the dynamic range of the pixel values of an image is increased [4]. In HE, the grey levels are mapped based on the probability distribution of the input grey levels. Because of the flattening property, HE performs either over or under enhancement. Adaptive HE (AHE) is another mainly used enhancement method for contrast improvement and its idea is different from ordinary HE. In AHE, several histograms are computed, each corresponding to a distinct part of the image. Then, the intensity of the image is redistributed using these histograms. Power Law or Gamma Correction is another method in which the contrast is enhanced based on a value calculated using the cumulative distribution function [5]. But, in the case of CT images depending upon the application, the choice of the enhancement algorithm may vary. The visual quality of the CT images must be improved for clearer visibility of all regions. Hence, contrast enhancement of the CT images is necessary before further processing of the images.

In this paper, a contrast enhancement algorithm for CT images based on logarithmic transformation is proposed. The performance of the proposed method is evaluated with the CT images and found to be satisfactory. A comparison study of this method with some popular methods is also carried out to determine which one provides a better result.

The remaining part of the paper is organized as follows: In Section II, the materials and method used in the proposed method is explained. In Section III, the performance metrics used for comparison, and in Section IV, the results and discussions are explained.

II. Materials and Methods

A. Data Set

The real CT image database obtained from the Rajagiri Hospital includes CT data of more than 10 patients with each dataset containing more than 600 slices per set. The CT images are all obtained in DICOM format. The database contains normal as well as abnormal scan images. Each of the CT image matrixes is of size 512 X 512 and with different dynamic range.

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B. Existing Contrast Enhancement Methods

Contrast enhancement is the process of improving the quality of the image for doing further processing of the images like segmentation and classification [6]. It is playing a vital role in image processing. Some of the popular enhancement techniques like Power law transformation, HE, CS, and Laplacian transformation are widely used.

C. Proposed Enhancement Method

The proposed method is the logarithmic transformation for the contrast enhancement of the CT image. Logarithmic transformation is most often used to brighten the lower intensity values of an image. This transformation is widely used for enhancing dark images. In the case of CT images, the details in the lower intensity regions are not normally seen on the non-contrast CT images. Most of the abnormalities lie in the darker regions as well, especially those related to strokes. Therefore, the darker regions of the CT images must be properly mapped to view the abnormalities present in detail. Logarithmic transformation is a contrast enhancement method that improves the contrast of the darker regions of the images more compared to the brighter regions. Hence, logarithmic transformation can be used for the enhancement of darker regions of the CT images to get the details in the lower intensity regions. The log transformation can be implemented as given in (1) [1]:

$$s = c * \log(1 + double\ (r)) \tag{1}$$

where *s* is the output image, *r* is the intensity of the input medical image, and *c* is a constant and the value depends upon the limit of the grey scale window used. The parameter *c* is used to scale the range of the log function for matching the input domain. The value of *c* varies with the type of image enhanced. For uint8 images c=255/log (1+255) and for double images c=1/log (1+1). By varying the value of the constant *c,* the brightness of the image can be changed. The higher the value of *c* the image will appear brighter. Thus, the *log* function produces too bright values to be displayed. The *log* curve calculated using different bases such as log10, log2, and natural log for matching the domain is same for all. The shape of the logarithmic curve only depends upon the range of values on which it is applied.

The log transformation maps very small range of lower intensity values into a broad range of output values. When the input grey level is extremely large, the logarithmic transformation becomes very useful. The log transformation brings out the details or contrast of darker regions of the image. This is achieved by expanding the dark pixel values and compressing the bright pixel values.

The only problem of the logarithmic transformation is that it overenhances the intensity of the image.

The algorithm for the proposed method is summarized as:

Step1. Let *I (i , j)* be the intensity values of the input CT image.

Step2. Compute the density values of the tissues corresponding to the intensity values of the CT image.

In the second step, the obtained CT image intensity data are converted into the corresponding relative density values (Hounse field Units (HU)) of the tissues. For the conversion, (2) is used:

$$HU = I(i, j) + \text{Intercept} \tag{2}$$

where the intercept value used in the expression can be obtained from the metadata information available in the DICOM header of the CT image data [7].

Step3. Apply the log transformation on the density values of the input CT image obtained in step 2 using (1).

III. Performance Metrics

For comparing the performance of the proposed method with other four popular contrasts enhancement methods two parameters are used. They are PSNR and MSE. Low value of MSE indicates that the error in image is less and high value of PSNR indicates that less noise in the reconstructed image after applying transformation. All the techniques are compared with each other to find which one gives good contrast CT image.

A. PSNR

PSNR is the ratio defined as the ratio of the maximum peak signal power to the corrupting noise power in the case of signals, and in the case of images, it is used to measure the quality of the reconstructed image after image compression. PSNR is mostly defined in terms of the MSE. The expression for PSNR is given by (3) [8]:

$$PSNR = 10 * \log_{10}\left(\frac{MAX^2}{MSE}\right) \tag{3}$$

where MAX denotes the maximum possible value of the pixel. In the normal grey scale, it is 255. Here, PSNR is used for measuring the quality of the reconstructed CT images after applying the contrast enhancement techniques. The higher value of PSNR indicates that the reconstructed image is of good quality.

B. MSE

The errors are normally defined by using MSE. It is the squared difference between the actual image and the reconstructed image.

If an actual grey image is represented by *I* of size *m X n* and its reconstructed image after contrast enhancement is represented by *R*, then the MSE is defined by (4):

$$MSE = \frac{1}{m * n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[I(i, j) - R(i, j)\right]^2 \tag{4}$$

where *i* and *j* are the rows and columns of the image.

By looking at the enhanced image, anyone can determine the difference between the original input image and the enhanced image, and thus, the performance of the enhancement method can be evaluated [9].

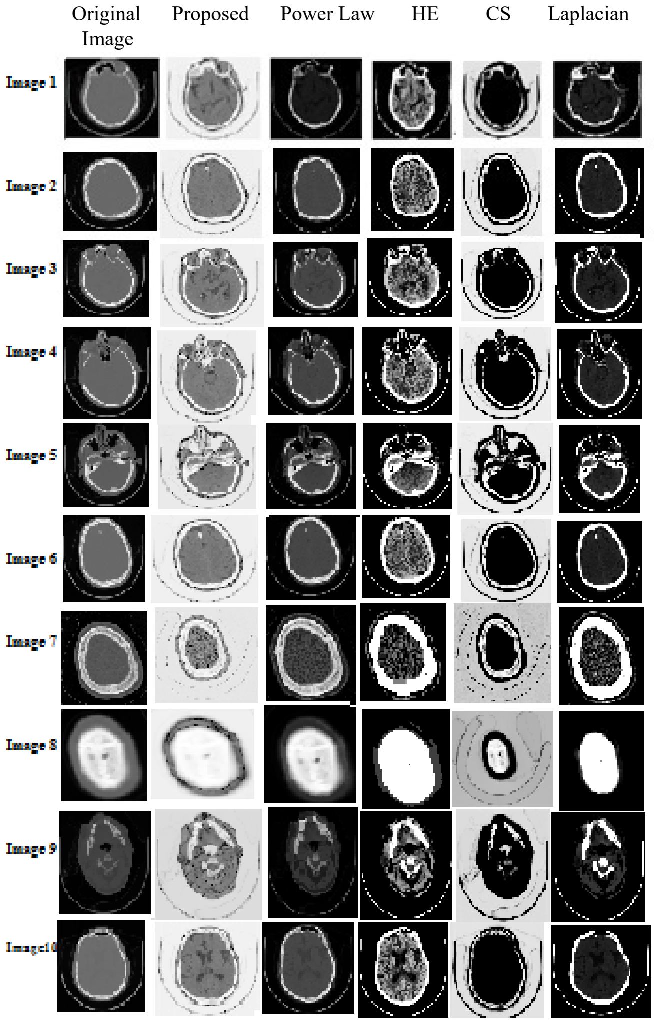

Fig. 1 Results of contrast enhancement. Column 1 Original Image, column 2 enhanced image by proposed method, column 3 by Power Law, column 4 by HE, column 5 by CS, and column 6 by Laplacian method

IV. Results and Discussion

The experiments are carried out by applying the proposed method on the collected CT images. The performance of the proposed method is compared with the existing popular methods of contrast enhancements Power law, HE, CS and Laplacian transformation. Comparison is performed on more than 500 CT images. The comparison results obtained for 10 sample images using the proposed method and existing methods are given in Fig. 1.

By looking into the displayed images, we can see that the logarithmic transformation gives better contrasted CT image with all the details clearly seen.

To compare the performance of the proposed method and the existing methods, the parameters PSNR and MSE are calculated. For all images, the proposed method has got the highest value of PSNR compared to the Power law, HE, CS, and Laplacian enhancements.

The PSNR and MSE values are calculated for each transformation for the comparison and tabulated in Table I.

Low value of MSE indicates less error in the reconstructed image after applying the transformation. High value of PSNR indicates less noise in the reconstructed image after transformation, and thus, the quality of the image is good. In this case, the logarithmic transformation has got the least value of MSE and the highest value of PSNR. Thus, we can say that logarithmic transformation is a good choice for the enhancement of poor contrast CT images for getting better visibility of abnormalities present in the images.

The infarction present in the CT images was clearly mapped with logarithmic transformation. The given results in Fig. 2 show the hypo densities noted in CT images of two patients with logarithmic enhancement.

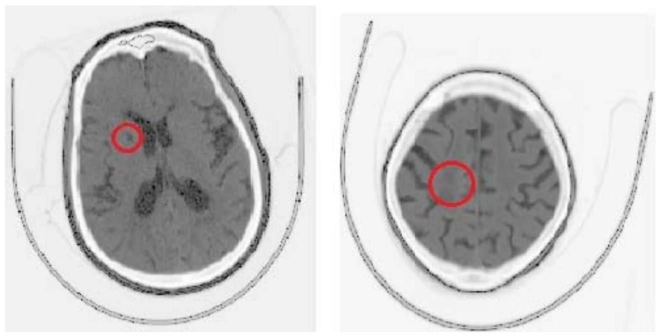

Fig. 2 Hypo densities noted in the CT images after logarithmic enhancement

TABLE I
MSE and PSNR Values for the Enhanced Images

	Proposed		Power law		HE		CS		Laplacian	
	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE
Image1	**41.66**	4.58	21.66	446.59	16.07	1620.8	2.67	35438	14.92	2110.4
Image2	**37.95**	10.51	4.35	24072	16.50	1468	2.54	36494	10.99	5219.9
Image3	**38.83**	8.68	4.69	22244	15.55	1824.1	2.62	35902	10.55	5776.3
Image4	**38.81**	8.62	4.68	22328	15.29	1938.2	2.65	35647	10.79	5464.9
Image5	**38.87**	10.42	4.93	21077	15.06	2045.1	2.73	34983	11.32	4839.5
Image6	**37.99**	10.50	5.56	18214	15.22	1971.6	2.74	34905	11.47	4672.6
Image7	**37.94**	10.52	4.29	24432	16.32	1363	2.53	36503	11.03	5168.1
Image8	**37.89**	10.66	5.23	19637	18.54	917.03	3.11	32021	13.77	2755.5
Image9	**37.82**	10.83	3.24	31061	21.93	420.41	3.57	35680	13.88	2680.7
Image10	**37.99**	10.41	7.78	10936	14.73	2207.3	3.07	30677	15.89	1690.1

The circled region in the contrast enhanced CT images indicates the hypo densities present. Thus, a contrast enhancement technique for proper mapping of the darker regions of the CT images based on logarithmic transformation is proposed in this paper. The abnormalities in the darker regions of the CT images like hypo densities or edema are very clearly observable with the proposed enhancement method. The quality of the enhancement technique is measured using PSNR and MSE. The proposed method has got the least value of MSE and the highest value of PSNR in the range of 35-45. Thus, the proposed enhancement technique is a better choice for proper mapping of the abnormalities present in CT images and would be helpful for the further analysis of the images.

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