Improved Fuzzy Image Enhancement Using L*a*b* Color Space and Edge Preservation

Shruti Puniani and Sankalap Arora

Abstract Image enhancement is a process of improving the perceptibility of an image so that the output image is better than input image. The traditional image enhancement techniques may affect the edges of an image which leads to loss of perceptual information. The existing techniques use primary/secondary color spaces which are device-dependent. This research paper works on these two issues. It uses L*a*b* color space which is device independent. To evaluate fuzzy membership values, L component is stretched while preserving the chromatic information a and b. Moreover, an edge preserving smoothing has been integrated with fuzzy image enhancement so that edges are not affected and remain preserved. The proposed technique is compared with existing techniques such as Histogram equalization, Adaptive histogram equalization and fuzzy based enhancement. The experimental results indicate that the proposed technique outperforms the existing techniques.

Keywords Image enhancement · Fuzzy-logic · L*a*b* color space (CIELAB) · Color images · Edge preservation, histogram equalization

1 Introduction

Image enhancement is defined as a process in which the pixel's intensity is transformed in such a way that the subjective quality of resultant image is better than the original image which provides better processing and machine analysis [1]. The major objective of image enhancement is to provide an image with fine details and information, so that further processing such as segmentation and edge detection becomes fairly easy [2]. In the past, image enhancement has been applied to various fields like medical imaging, astronomical imaging, camera and

S. Puniani(✉) · S. Arora
Department of Computer Science, DAV University, Jalandhar, Punjab, India
e-mail: {puniani.shruti,sankalap.arora}@gmail.com

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video processing, geographical prospecting, ocean imaging etc. Various techniques for image enhancement have been developed so far. These techniques are categorized into two domains: (1) Transform domain methods (2) Spatial domain methods [3]. In the transform domain method, the frequency transform of an image is modified which is achieved by calculating 2-D transform but it consumes more time thus making it unsuitable for real time image processing [4]. In spatial domain methods, the operation is performed on the pixels itself. These include intensity transformation and spatial filtering [5]. Histogram equalization (HE) is a spatial domain technique which is very popular as it is very simple and easy to implement. Though the technique is simple, yet its conventional nature leads to unnatural look of over enhancement. The major drawback of HE is that it gives washed out appearance to an image and focuses on the global contrast enhancement of the image leading to loss of local details which can also lead to over enhancement of an image [6][7]. Adaptive Histogram equalization (AHE) works by transforming every pixel in an image using a transformation function which is produced from a neighborhood area. It improves the local contrast of an image thus preserving all details. Dynamic Histogram Equalization (DHE) technique is a modification of traditional HE in which enhancement is performed without any loss of information in the image [8]. In this, firstly the original histogram is divided into multiple sub-histograms. Then, a dynamic gray level (GL) is allotted to each sub-histogram. This hampers contrast from being dominated and produces a washed out effect. Though these techniques undergo local image enhancement, yet they suffer from drawbacks.

The traditional image enhancement techniques discussed above produce poor illumination in images thus resulting in vagueness [9]. This vagueness is produced due to uncertain boundaries and color values [10]. Thus, to solve this vagueness in images, fuzzy logic was implemented. Fuzzy-logic has been successfully employed in various areas of image processing. According to recent studies [11], fuzzy-logic based techniques have proven to be better than traditional methods of image enhancement. Fuzzy image processing consists of three main steps: (1) Image fuzzification in which spatial domain is converted into fuzzy membership domain, (2) Modification of membership values using Fuzzy rules and (3) Image defuzzification in which fuzzy membership domain is re-converted into spatial domain. After the data of image is transformed to fuzzy membership domain, membership values are altered using fuzzy methods. Examples of such fuzzy methods are fuzzy rule based method, fuzzy clustering, etc. In the fuzzy rule based method, there is an antecedent and consequent and they are modified based on neighborhood pixels [12]. Image enhancement using fuzzy logic helps to overcome shortcomings of traditional enhancement methods discussed earlier. Fuzzy logic handles the uncertainties of an image which a machine cannot understand and helps in automatic contrast enhancement of images.

This paper is organized as: Section 2 gives a detailed explanation about motivations of this research. Section 3 presents the proposed methodology of this paper while a performance evaluation criterion is discussed in section 4. The proposed method is compared with existing techniques such as Histogram equalization, Adaptive histogram equalization and Fuzzy based technique in section 5. Finally, the paper is concluded in section 6.

2 Related Work

Image enhancement is the most important step in digital image processing. It improves the visual quality of an image so that the final image subjectively looks better than the input image thus producing fine details. Image enhancement techniques are categorized as: (1) Transform domain (2) Spatial domain. Since transform domain methods are time consuming as discussed earlier, they are rarely used nowadays. Spatial domain techniques include traditional and advanced techniques. Histogram equalization and adaptive histogram equalization are traditional image enhancement techniques while techniques based on fuzzy logic are advanced techniques. Hasikin, Khairunnisa and Nor Ashidi Mat Isa have discussed an enhancement technique based on fuzzy-logic in which pixels in spatial domain are transformed into fuzzy membership domain using a Gaussian membership function. This function calculates the membership values of pixels so that intensity of dark pixels is increased above a threshold value and that of brighter pixels is decreased [14]. Raju, G., and Madhu S. Nair have discussed a fast and reliable method for enhancing low contrast and low bright color images using fuzzy-logic and histogram. They have mainly focused on converting skewed histogram into a uniform histogram. The input RGB image is converted into HSV so as to stretch the V component preserving the chromatic information. The enhancement of V is done using two parameters i.e. contrast intensification parameter and average intensity value of the image. The technique is comparatively fast when compared to existing techniques [2]. Liejun, Wang, and Yan Ting have introduced fuzzy shrink image enhancement algorithm which enhances remote sensing images suffering from Gaussian noise and edge degradation. The technique is made up of non-sub sampled contour-let transform domain and fuzzy domain. It shows optimal de-noising effect and the finally produced image is almost similar to input image [15]. Alajarmeh, Ahmad et al. have presented a fuzzy based method for video enhancement using dark channel. The technique helps to improve the quality of images and videos taken during natural phenomenon such as rain, fog and haze. This technique is fast and efficient and also suitable for real time applications [16].

Hanmandlu, M. and Jha, D. have produced a Gaussian membership function to convert the spatial domain into fuzzy membership domain. A global contrast intensification parameter contains three parameters t, intensification parameter, f_h , the fuzzifier and u_c, the crossover point to enhance color images. But the major limitation of this method is that it is more time consuming as compared to other fuzzy based methods [1].

Image enhancement has a wide application in medical imaging. Different methods have been proposed for this. Aggarwal, Anshita, and Amit Garg have discussed an enhancement technique for medical images using Adaptive multi-scale thresholding by reducing noise while preserving edges. It removes salt and pepper noise, speckle and random noise while preserving the edges which are damaged due to its grainy appearance [17].

A lot of techniques have been developed based on histogram. Kotkar V.A et al. have proposed Weighted of local and bidirectional smooth histogram stretching (WLBSHS) and Local Bi-histogram smooth Histogram Stretching (LBSHS) which focuses on local and global image enhancement while preserving brightness of an image [18]. Humied I.A et al. have proposed a combined technique for automatic contrast enhancement of digital images to enhance low contrast images by balancing the amplitude of histogram at both the ends. It is achieved by combining Histogram Equalization and gray level grouping. It is fully automatic technique unlike other traditional techniques [19].

3 Proposed Methodology

3.1 Modification of Membership Functions

The existing color image enhancement method based on fuzzy logic considers RGB and HSV color spaces which are both machine dependent which means that a set of parameters produce different colors on different machines [20]. Also, existing image enhancement methods may degrade the edges too. The proposed method deals with these two problems. The RGB color model is converted into L*a*b* color space, (where L is Lightness, a and b are chromatic components) because RGB image contains only color channels and the light channel is mixed in it. The L component is stretched on the basis of X and Y where X is calculated from histogram G(x) using eq.(1), G(x) is number of pixels with intensity value x. Y=128 according to experiments

$$X=\frac{\sum_x xG(x)}{\sum_x G(x)} \tag{1}$$

Histogram is divided into two classes X_1 and X_2 and fuzzy membership values α_1 and α_2 are calculated based on two fuzzy rules.

Rule 1: If the difference between x and X is large, then the intensity of stretching should be small. To implement this rule and to calculate value of α_1 , eq. (2) is used.

$$\alpha_1 = \frac{1-((X-x)}{X} \tag{2}$$

Rule 2: If the difference between x and D is large, then the intensity of stretching should be large. (D is extreme value e.g D =255 for 8-bit images). The value of α_2 is calculated using eqn. (3)

$$\alpha_2=\frac{D-x}{D-X} \tag{3}$$

Then fuzzy enhanced values are evaluated using eq. (4) and (5) where α_e is the enhanced intensity value and original intensity is replaced with enhanced intensity.

$$\alpha_e = x + \alpha_1(Y) \tag{4}$$
$$\alpha_e = x\alpha_2 + D - x\alpha_2 \tag{5}$$

3.2 Edge Preserving Smoothing

Take a small square sliding window of length Z. It has been proved that a small square window yields best possible results in terms of preserving edges and fine details [21]. The value of Z can be evaluated using eq. (6)

$$Z = \begin{cases} 3, & n < 0.5 \\ 5, & 0.5 \leq n \leq 0.6 \end{cases} \tag{6}$$

where n is noise density which can be calculated using eq. (7)

$$n = \frac{L}{RC} \tag{7}$$

where L is total number of zeros and 255 in the image and product RC is number of pixels in image. Then, the most optimum value of a threshold β is evaluated by using eq. (8) where β is a threshold which depends on noise density and characteristics of an image and $\beta \leq Z^2$.

$$\beta = \begin{cases} \lfloor Z^2(n + 0.50) \rfloor & Z = 3 \\ \lfloor Z^2(n + 0.15) \rfloor & Z = 5 \end{cases} \tag{8}$$

where $\lfloor . \rfloor$ is the floor operation.

Table 1 Nomenclature of symbols used in algorithm

Symbols	**Meaning**
X	Average intensity value of input image
Y	Contrast intensification parameter
α_1, α_2	Fuzzy membership value
α_e	Enhanced Fuzzy membership value
D	Extreme value of intensity
G(x)	No. of pixels with intensity value x
Z	Size of square sliding window
n	Noise density
L	Number of 0s and 255s in image
RC	Number of pixels in image
β	Optimum threshold value
A	Average value of local contrast
$\mathbf{T(x,y)}$	Gradient
j_x , j_y	Convolution kernels

The whole process is demonstrated in Figure 1, Table 1 explains all the symbols used in proposed method and the algorithm is explained below:

Algorithm for Image enhancement:

1) Input the given RGB image and convert it to L*a*b*.
2) Calculate the histogram G(x) where $x \in L$.
3) Calculate X using (1).
4) Divide G(x) into two classes X_1 [0, X-1] and X_2[X, 255].
5) Fuzzify L and modify membership functions using (2) and (3).
6) Calculate fuzzy enhanced values using (4) and (5).
7) Convert the enhanced L*a*b* image to RGB.
8) Apply edge preserving smoothing using (6), (7) and (8).
9) Obtain the enhanced output image.

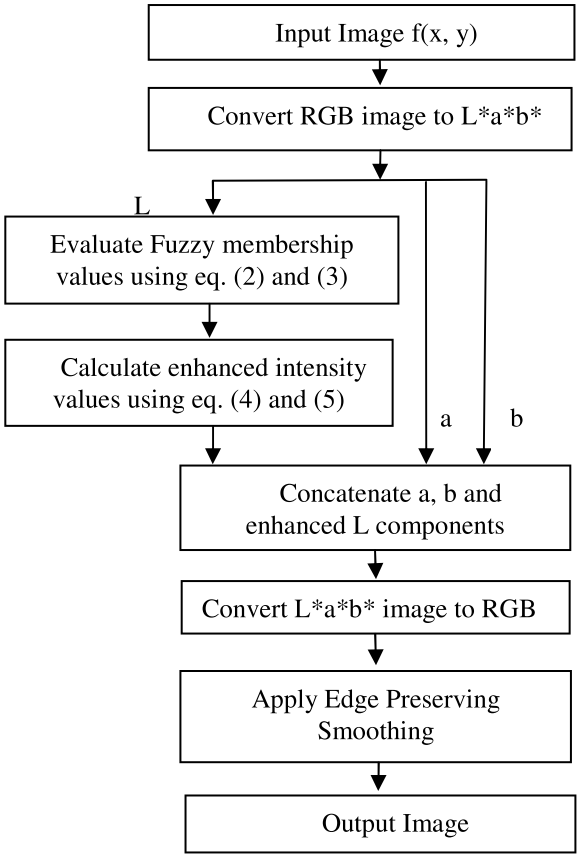

Fig. 1 Flowchart of the proposed method

4 Performance Metrics

To compare different image enhancement techniques, two quantitative performance measures have been taken which are discussed below. Along with these, visual results are also shown.

4.1 Contrast Improvement Index (CII)

It is the most important performance measure for contrast of an image [2]. The higher value of CII indicates higher contrast of an image. The value of CII can be calculated using Eq. (9)

$$\text{CII}=\frac{A_{\text{proposed}}}{A_{\text{original}}} \tag{9}$$

where A is average value of local contrast which is calculated using 3×3 window using eq. (10)

$$\frac{\max - \min}{\max + \min} \tag{10}$$

Where A_{proposed} is average value of local contrast in output image and A_{original} is average value of local contrast in original image.

4.2 Tenengrad Measure

The Tenengrad measure is one of the most robust and precise image performance measures based on gradient magnitude maximization [2]. Its value can be calculated from gradient where partial derivative is calculated using a sobel filter with convolution kernels j_x and j_y. The equation of gradient is given using eq. (11)

$$T(x,y) = \sqrt{(j_x \otimes J(x,y))^2 + (j_y \otimes J(x,y))^2} \tag{11}$$

The value of Tenengrad is given using eq. (12)

$$\text{TGD} = \sum_x \sum_y T(x,y)^2 \tag{12}$$

The higher value of Tenengrad shows that the structural information of an image has been improved.

5 Results and Discussions

The performance of the proposed method has been tested on various color images. The values of performance measures prove that proposed method is superior to traditional methods. In order to prove this fact, two quantitative performance measures have been used. Subjectively, it is hard to find difference between the proposed method and traditional image enhancement methods. Thus, CII and Tenengrad are used to evaluate the performance of different methods.

Figure 2 shows the enhanced color images after applying Histogram Equalization, Adaptive Histogram Equalization, Fuzzy based image enhancement and proposed method on img1.jpg, img2.jpg, img3.jpg, img4.jpg and img5.jpg.

Tables 2-6 show values of performance measures obtained after applying various enhancement techniques on img1.jpg, img2.jpg, img3.jpg, img4.jpg and img5.jpg.

From the tables, it is evident that the proposed method produces higher values of CII and Tenengrad as compared to the traditional techniques. Histogram equalization have yielded very less value of CII and Tenengrad because it focuses on enhancing the global contrast of an image whereas Adaptive histogram equalization has produced more values than Histogram equalization because it focuses on the local contrast of an image. But its value is less than fuzzy method. This is because of the fact that it can't handle vagueness which is introduced in images in the form of imprecise boundaries and color values. The proposed method has proved to be the best out of all these methods because it uses a device independent color space i.e L*a*b* and it also works on preservation of edges.

Table 2 Performance measure values obtained after applying different techniques on img1.jpg

Performance measures	Histogram equalization	Adaptive histogram equalization	Fuzzy method	Proposed Method
CII	0.2398	0.0095	6.3811	**7.6752**
Tenengrad($\times 10^4$)	1.1479	1.7779	3.3985	**4.4017**

Table 3 Performance measure values obtained after applying different techniques on img2.jpg

Performance measures	Histogram equalization	Adaptive histogram equalization	Fuzzy method	Proposed method
CII	0.3187	0.3534	4.0771	**5.7261**
Tenengrad($\times 10^4$)	1.4508	2.6969	3.0366	**3.8710**

Table 4 Performance measure values obtained after applying different techniques on img3.jpg

Performance measures	Histogram equalization	Adaptive histogram equalization	Fuzzy method	Proposed method
CII	0.7187	0.1450	1.1740	**4.9519**
Tenengrad($\times 10^4$)	1.4252	2.1144	4.9108	**5.9423**

Table 5 Performance measure values obtained after applying different techniques on img4.jpg

Performance measures	Histogram equalization	Adaptive histogram equalization	Fuzzy method	Proposed method
CII	0.7881	2.3883	3.3753	**4.8596**
Tenengrad ($\times 10^4$)	1.3341	3.1187	4.7722	**5.8585**

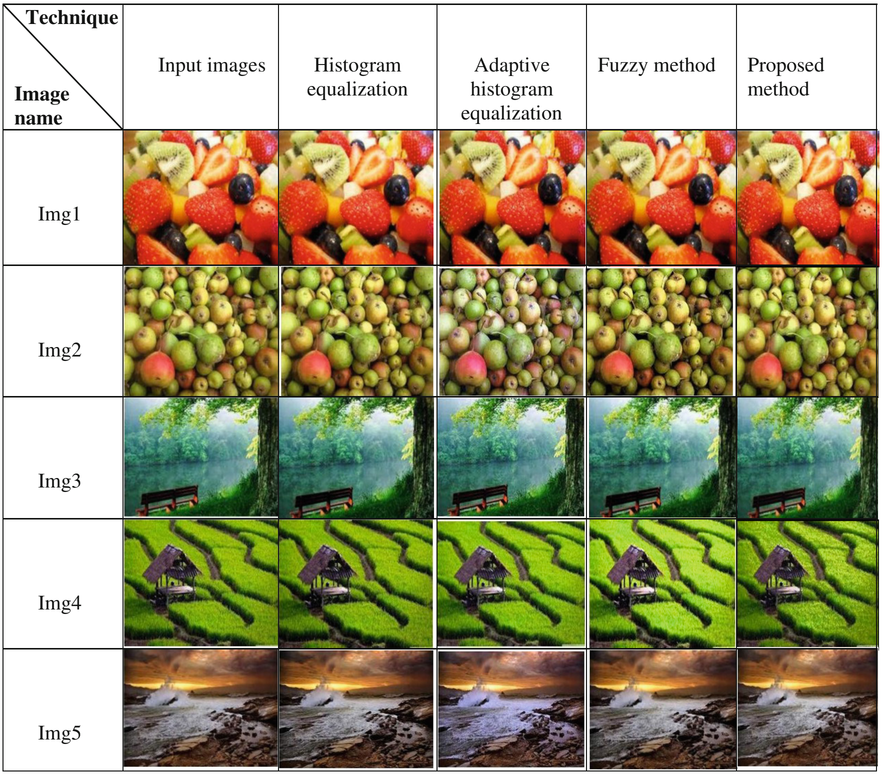

Fig. 2 Results obtained after applying various image enhancement techniques

Table 6 Performance measure values obtained after applying different techniques on img5.jpg

Performance measures	Histogram equalization	Adaptive histogram equalization	Fuzzy method	Proposed method
CII	0.9690	1.4612	2.2261	**4.2930**
Tenengrad($\times 10^4$)	1.6093	3.5179	5.4371	**6.4799**

6 Conclusion

An efficient L*a*b* based Fuzzy image enhancement has been proposed in this paper. The method uses L*a*b* color space which is device independent unlike other color models like HSV, HSI, etc. Since image enhancement may introduce noise in the image leading to degradation of edges, the technique is integrated with an edge preserving smoothing algorithm. The comparison of the proposed method has also been drawn with existing image enhancement techniques to prove effectiveness of contrast enhancement. The results have shown that proposed method improves the values of CII and Tenengrad measure. The L*a*b* based membership function adds to it an advantage of its device independent nature. According to this, the color and contrast of an image will not depend upon whatever device it is being used. Furthermore, an edge preserving smoothing algorithm has been integrated with it so that while applying image enhancement, the edges remain preserved. In this paper the value of Y is fixed. So, in future the value of Y will be calculated adaptively using an optimization algorithm. Also, the proposed method is a little time consuming. Thus, we will try to make it fast in future.

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