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A fast and efficient color image enhancement method based on fuzzy-logic and histogram

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ABSTRACT

A new fuzzy logic and histogram based algorithm for enhancing low contrast color images has been proposed here. The method is computationally fast compared to conventional and other advanced enhancement techniques. It is based on two important parameters *M* and *K*, where *M* is the average intensity value of the image, calculated from the histogram and *K* is the contrast intensification parameter. The given RGB image is converted into HSV color space to preserve the chromatic information contained in the original image. To enhance the image, only the V component is stretched under the control of the parameters *M* and *K*. The proposed method has been compared with conventional contrast enhancement techniques as well as with advanced algorithms. All the above techniques were based on the principle of transforming the skewed histogram of the original image into a uniform histogram. The performance of the different contrast enhancement algorithms are evaluated based on the visual quality, Tenengrad, CII and the computational time. The inter comparison of different techniques was carried out on different low contrast color images. Based on the performance analysis, we advocate that our proposed Fuzzy Logic method is well suited for contrast enhancement of low contrast color images.

1. Introduction

Contrast enhancement enhances the apparent visual quality of an image as well as the specific image features for further processing and analysis by a computer vision system [1]. For segmentation and identification of objects and features in a scene, the information content of the image has to be enhanced for better performance. Although, the techniques of contrast enhancement perform quite well with images having a uniform spatial distribution of gray values, difficulties arise when the background has a non uniform distribution of brightness [1]. Low contrast images with weak edges pose challenges in the fields of computer vision and pattern recognition. A fast and efficient fuzzy based automatic contrast enhancement of low contrast color images has been proposed here, which enables improvement of visual quality of image as well as aid in extraction of the spatial features present in the image. The method is computationally fast compared to other advanced enhancement algorithms such as Gray Level Grouping (GLG) [11] and fuzzy based enhancement technique of [13]. The method is mainly based on two important parameters, one the average intensity value of the image *M* and the other a contrast intensification parameter *K*. The proposed method is applied to the HSV color space so that only the V component is stretched by preserving the chromatic information (H and S).

2. Contrast enhancement techniques

The real world applications of automated image contrast enhancement techniques are many and encompass varied fields like medical imaging, geophysical prospecting, seismic exploration, astronomy, camera and video processing, aerial and ocean imaging, sensors and instrumentation, optics, and surveillance. Conventional techniques for contrast enhancement include gray-level transformation based techniques (*viz.*, logarithm transformation, power-law transformation, piecewise-linear transformation, *etc.*) and histogram based processing techniques (*viz.*, histogram equalization (HE), histogram specification, *etc.* [1]). The most popular method is histogram equalization, which is based on the assumption that a uniformly distributed grayscale histogram will have the best visual contrast. Other advanced histogram based enhancement methods include bi-histogram equalization (BHE), block-overlapped histogram equalization, multi-scale adaptive histogram equalization, shape preserving local histogram

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modification, *etc.* [2–10]. Conventional contrast enhancement techniques have an inherent inability for automation due to the necessity to select specific parameters for enhancement. Other drawbacks include the washed out effect, inability to preserve edges, non-preservation of brightness and the inability to discern localized intensity changes. Recent studies [11–14] stress on the importance and necessity of having automatic methods for contrast enhancement and suggest that the GLG and Fuzzy Logic based methods are better suited for automatic contrast enhancement of images.

The basic objective of Gray Level Grouping (GLG) [11,12,22,23] is to achieve a uniform histogram for a low contrast color image. GLG utilizes the grayscale in a more controlled and efficient manner, thus spreading the components of histogram by grouping the components into a proper number of gray-level bins according to their amplitudes ensuring a reduction in the number of gray bins. This will lead to the redistribution of the histogram components in a set of gray-level bins whose amplitudes are close to each other. Conventional histogram equalization results in under or over contrast image since it leaves too much empty space on the grayscale. In GLG, histogram components in different segments of the grayscale can be grouped using different criteria, so they can be redistributed differently over the grayscale to meet specific purposes, *e.g.*, certain applications may require different parts of the histogram to be enhanced to different extents. The drawback of GLG is that it is not computationally efficient compared to fuzzy-based methods. The quantitative analysis shows that fuzzy-based methods are superior to GLG.

Fuzzy-logic is being efficiently utilized in different areas of image processing. In recent years, fuzzy based algorithms for image enhancement has been developed with better performance compared to conventional and other advanced techniques like GLG. Fuzzy image processing consists of mainly three stages: image fuzzification, modification of membership values, and, if necessary, image defuzzification. The main power of fuzzy image processing is in the middle step (modification of membership values). After the image data are transformed from gray-level domain to the fuzzy membership domain (fuzzification), appropriate fuzzy techniques modify the membership values. This can be a fuzzy clustering, a fuzzy rule-based approach, a fuzzy integration approach and so on. In fuzzy based image enhancement algorithms histogram is used as the basis for fuzzy modeling of images. Two major contributions in the field of image enhancement using the fuzzy framework have been established in recent years. The first contribution deals with basic fuzzy rules for image enhancement [15–17], where in a set of neighborhood pixels forms the antecedent and the consequent clauses that serve as the fuzzy rule for the pixel to be enhanced. The second contribution relates to a rule-based smoothing [18] in which different filter classes are devised on the basis of compatibility with the neighborhood. Recently Hanmandlu et al. [21] has proposed a fuzzy based method in which entropy measure is used as the basic criterion for contrast enhancement.

In the fuzzy method [19] gray tone is modeled into a fuzzy set using a membership function. Here the image is considered as an array of fuzzy singletons having a membership value that denotes the degree of some image property in the range. Applying an intensification operator globally modifies the membership function. Li and Yang [20] have demonstrated an efficient way of contrast enhancement based on the fuzzy relaxation technique with improved speed and quality. Different orders of fuzzy membership functions were tried out by various researchers in order to improve the speed and quality of contrast enhancement based on the fuzzy logic method. Recently, Hanmandlu et al. [21] proposed a new intensification operator, NINT, which is a parametric sigmoid function for the modification of the Gaussian type of membership. The method is based on the optimization of entropy by a parameter involved in the intensification operator which is suitable for gray level images. Hanmandlu and Jha [13] proposed a Gaussian membership function to fuzzify the image information in spatial domain by introducing a global contrast intensification operator which contains three parameters, t, the intensification parameter, f_h, the fuzzifier and μ_c the cross over point – for enhancement of color images. The method is an iterative procedure based on modified univariate algorithm which uses partial differentiation. The drawback of this method is that the procedure is complex and computationally takes more time, though it is better than GLG.

3. Proposed fuzzy-based method

The proposed fuzzy enhancement method uses *HSV* color space where only the *V* component is stretched by preserving the chromatic information such as Hue (*H*) and Saturation (*S*). The method is meant exclusively for enhancing low contrast and low bright color images. Stretching of *V* component is performed under the control of the enhancement parameters *M* and *K*. This stretching will transform the current intensity value x to the enhanced intensity value x_e.

The first step in the proposed method is to convert the given *RGB* image of size $P \times Q$ into *HSV* and then calculate the histogram $h(x)$ where $x \in V$. $h(x)$ indicates the number of pixels in the image with intensity value x. Proposed method uses two intensification parameters M and K, which controls the degree at which the intensity value x has to be intensified. The control parameter M, the average intensity value of the image, can be calculated from the histogram as follows:

$$M = \frac{\Sigma_X X h(X)}{\Sigma_X h(X)} \tag{1}$$

The parameter M divides the histogram $h(x)$ into two classes. The first class C_1 contains pixels values in the range $[0, M-1]$ and the second class C_2 in the range $[M, 255]$. The stretching of *V* component is performed based on two fuzzy membership values μ_{D1} and μ_{D2}, calculated for C_1 and C_2 class of pixels respectively. Parameter M has a significant role in the computation of fuzzy membership values, μ_{D1} and μ_{D2}.

Enhancement parameter K decides the stretching intensity to compute the enhanced intensity values x_e for the two classes C_1 and C_2. Parameter K decides the stretching point to which the intensity values x should be stretched based on the membership values μ_{D1} and μ_{D2}. The value for K can be computed empirically according to what extent the stretching is required. From the experimental analysis, we fixed the value 128 for K, which gives better results for the low contrast and low bright color images.

The fuzzy membership value μ_{D1} for class C_1 is based on the concept of how far the intensity value x is from the parameter M. The fuzzy rule for class C_1 can be represented as follows:

If the difference between x and M is LARGE then the intensity of stretching should be SMALL.

The above rule indicates that the pixels values closer to M will be extended higher whereas values farther from M will be extended lesser. Pixel values in between will be extended proportionately. To implement the above fuzzy rule the following mathematical representation can be used:

$$\mu_{D1}(X) = \frac{1-((M-X)}{M} \tag{2}$$

where $x \in C_1$. Once the membership value for x is obtained, the contrast enhanced or intensified value x_e for class C_1 can be computed as follows:

$$X_e = X + \mu_{D1}(X)K \tag{3}$$

$\mu_{D1}(x)$ decides what amount of stretching parameter K has to be added to x to get the enhanced value x_e.

The fuzzy membership value μ_{D2} for class C_2 is based on the concept of how far the intensity value x is from the extreme value E (for 8-bit image E = 255). The fuzzy rule for class C_2 can be represented as follows:

If the difference between x and E is LARGE then the intensity of stretching should be LARGE.

The above rule indicates that the pixels values closer to E will be extended lesser whereas values farther from E will be extended higher. Pixel values in between will be extended proportionately. To implement the above fuzzy rule the following mathematical representation can be used:

$$\mu_{D2}(X) = \frac{E - X}{E - M} \tag{4}$$

where $x \in C_2$. Once the membership value for x is obtained, the contrast enhanced or intensified value x_e for class C_2 can be computed as follows:

$$X_e = (X\mu_{D2}(X)) + (E - \mu_{D2}(X)K)) \tag{5}$$

$\mu_{D2}(x)$ decides what amount of stretching parameter K and the intensity value x has to be utilized to get the enhanced value x_e.

The replacement of the old x values of the V component with the enhanced x_e values will cause the V component to be stretched resulting in contrast and brightness enhanced component V_e. This enhanced achromatic information V_e can be combined with the preserved chromatic information (Hue and Saturation components) to obtain enhanced image HSV_e which is finally converted to enhanced RGB_e image. The flowchart of the proposed method is shown in Fig. 1.

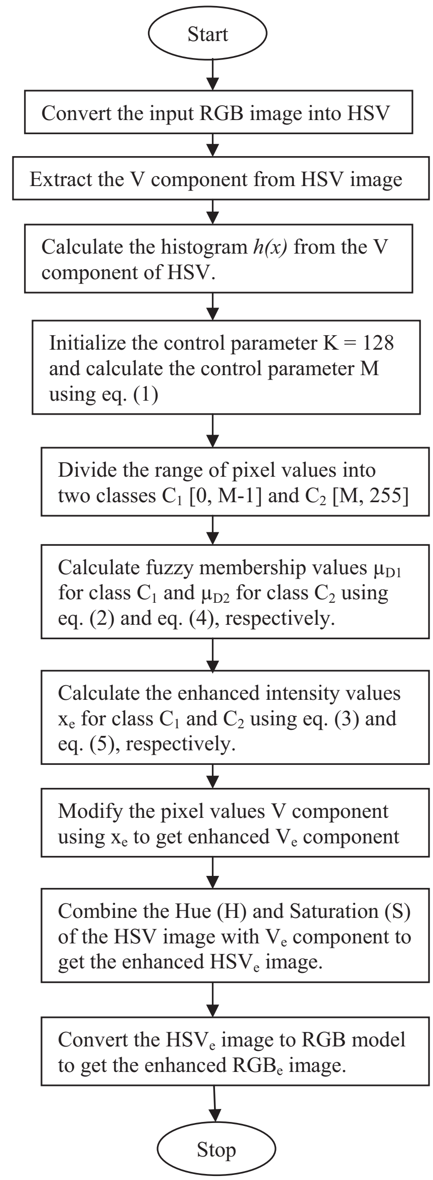

Fig. 1. Flowchart of the proposed method.

4. Performance measures

Quantitative performance measures are very important in comparing different image enhancement algorithms. Besides the visual results and computational time, Contrast Improvement Index (CII) and Tenengrad measure are the two important quantitative measures used here for the performance analysis.

4.1. Contrast improvement index (CII)

In order to evaluate the competitiveness of the proposed fuzzy method against existing contrast enhancement techniques, the most well-known benchmark image enhancement measure, the Contrast Improvement Index (CII) is used to compare the results of contrast enhancement methods. Contrast improvement can be measured using *CII* as a ratio [26]. Contrast Improvement Index is defined as:

$$CII = \frac{C_{\text{proposed}}}{C_{\text{original}}}$$

where C is the average value of the local contrast measured with 3×3 window as:

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

C_{proposed} and C_{original} are the average values of the local contrast in the output and original images, respectively.

4.2. Tenengrad measure

The Tenengrad criterion [11,12] is based on gradient magnitude maximization. It is considered as one of the most robust and functionally accurate image quality measures. The Tenengrad value of an image, I is calculated from the gradient $\Delta I(x, y)$ at each pixel (x, y), where the partial derivatives are obtained by a high-pass filter, *e.g.*, the Sobel operator, with the convolution kernels i_x and i_y. The gradient magnitude is given as

$$S(x, y) = \sqrt{(i_x \otimes I(x, y))^2 + (i_y \otimes I(x, y))^2}$$

and the Tenengrad criterion is formulated as

$$TEN = \sum_x \sum_y S(x, y)^2$$

for $S(x, y) > T$, where T is a threshold. The image quality is usually considered higher if its Tenengrad value is larger. As a performance measure for image enhancement, though Tenengrad measure is less efficient compared to CII, it has been used to analyze whether structural information in the enhanced image has been improved or not.

5. Results and discussion

The performance of the proposed fuzzy-based enhancement algorithm has been tested on various low contrast and low bright

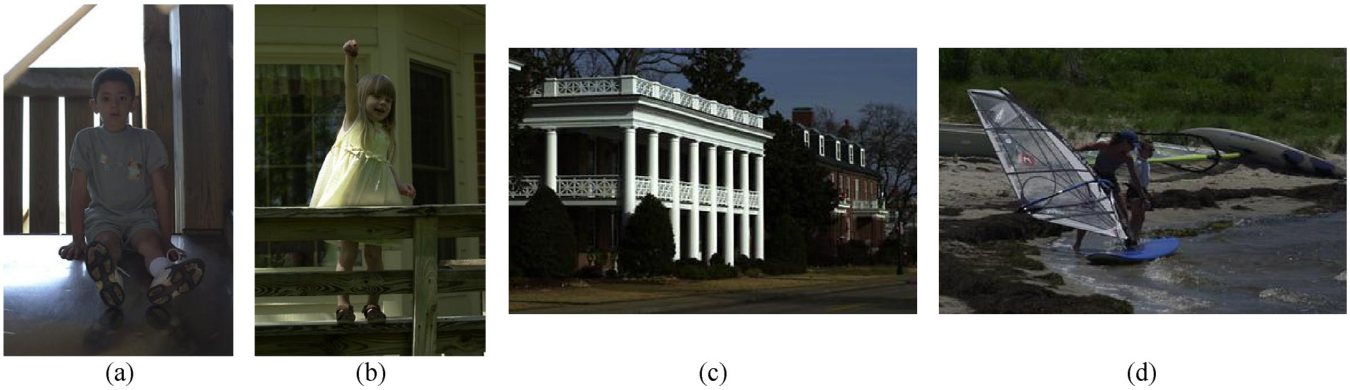

Fig. 2. Original low contrast and low bright images. (a) boy (b) girl (c) building (d) beach.

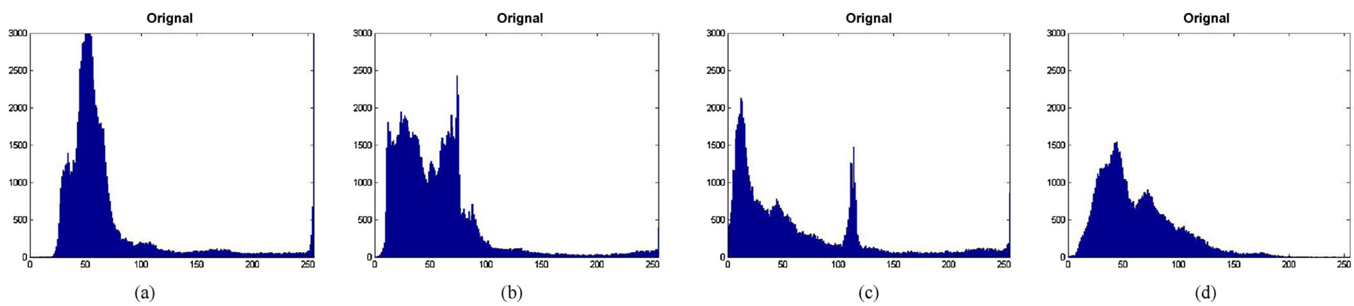

Fig. 3. Histograms of original low contrast and low bright images. (a) Boy (b) girl (c) building (d) beach.

images. In order to prove the superior performance of the proposed method over convention and advanced methods, various quantitative performance measures, discussed in the previous section, has been used. The performance measure values shows that the proposed method gives better results compared to the conventional and advanced enhancement techniques. The proposed method takes less computational time compared to other advanced algorithms which makes it very much suitable for real-time applications. The proposed method is efficient in terms of quality and fast in terms of computation.

Fig. 2(a)–(d) shows the different low contrast and low bright images used in this paper for the performance analysis. The images are *boy.jpg*, *girl.jpg*, *building.jpg* and *beach.jpg* with resolution 283×432, 283×432, 360×236 and 360×236 respectively. Fig. 3(a)–(d) shows the histogram of the *V* component of different test images. The Tenengrad values of *boy*, *girl*, *building* and

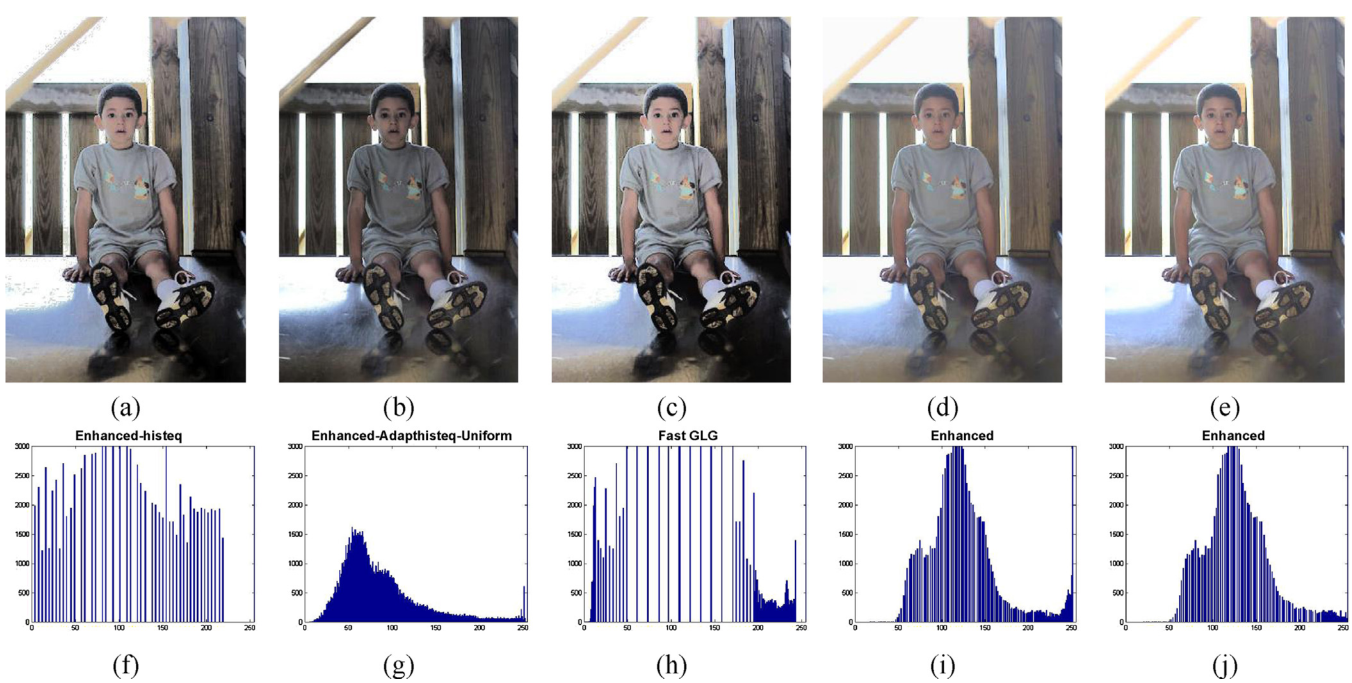

Fig. 4. Contrast enhanced *boy.jpg* images and their histograms after applying (a) (f) histogram equalization (b) (g) adaptive histogram equalization (c) (h) GLG (d) (i) fuzzy method of [13] (e) (j) proposed fuzzy method.

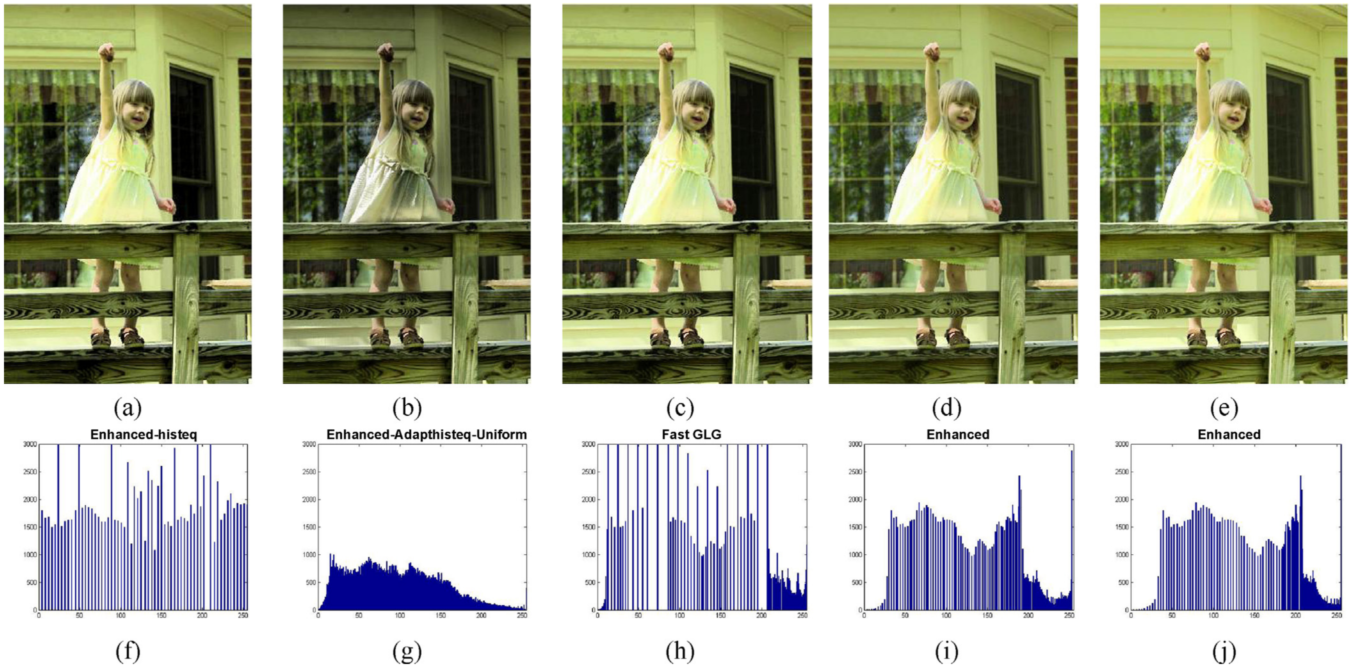

Fig. 5. Contrast enhanced *girl.jpg* images and their histograms after applying (a) (f) histogram equalization (b) (g) adaptive histogram equalization (c) (h) GLG (d) (i) fuzzy method of [13] (e) (j) proposed fuzzy method.

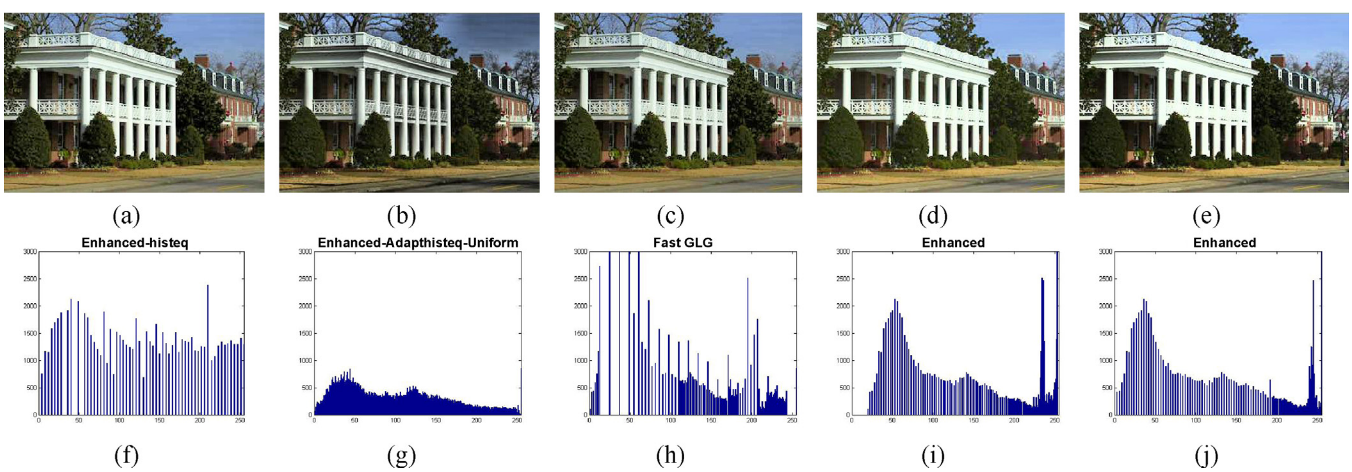

Fig. 6. Contrast enhanced *building.jpg* images and their histograms after applying (a) (f) histogram equalization (b) (g) adaptive histogram equalization (c) (h) GLG (d) (i) fuzzy method of [13] (e) (j) proposed fuzzy method.

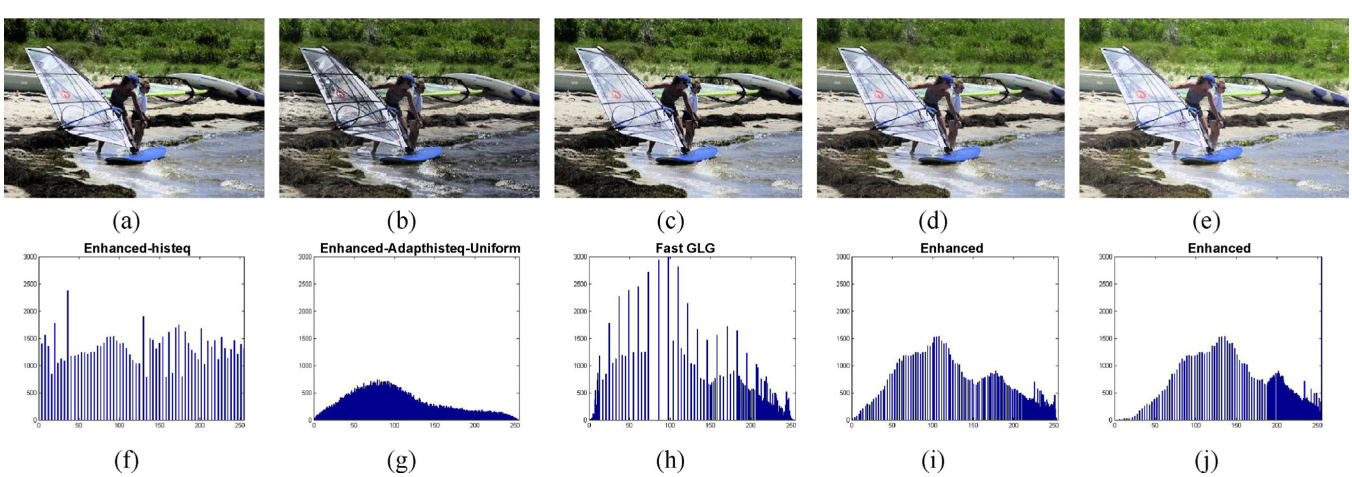

Fig. 7. Contrast enhanced *beach.jpg* images and their histograms after applying (a) (f) histogram equalization (b) (g) adaptive histogram equalization (c) (h) GLG (d) (i) fuzzy method of [13] (e) (j) proposed fuzzy method.

Table 1
Performance measure values obtained after applying different enhancement techniques on the *boy.jpg* image.

Performance measures	Histogram equalization	Adaptive histogram equalization	Gray level grouping (GLG)	Fuzzy method of [13]	Proposed fuzzy method
CII	4.1966	4.2543	4.4132	4.4209	**5.0214**
Tenengrad ($\times 10^4$)	6.7202	5.7502	7.4630	4.4050	**4.7127**
Time (s)	0.272	0.283	0.472	0.551	**0.374**

Table 2
Performance measure values obtained after applying different enhancement techniques on the *girl.jpg* image.

Performance measures	Histogram equalization	Adaptive histogram equalization	Gray level grouping (GLG)	Fuzzy method of [13]	Proposed fuzzy method
CII	4.5556	4.6489	4.8944	4.9311	**5.9933**
Tenengrad ($\times 10^4$)	8.9132	7.8117	8.7948	7.2399	**8.1255**
Time (s)	0.241	0.262	0.466	0.541	**0.368**

Table 3
Performance measure values obtained after applying different enhancement techniques on the *building.jpg* image.

Performance measures	Histogram equalization	Adaptive histogram equalization	Gray level grouping (GLG)	Fuzzy method of [13]	Proposed fuzzy method
CII	2.0875	2.1401	2.2504	2.2613	**2.2875**
Tenengrad ($\times 10^4$)	11.454	12.536	10.640	11.753	**12.973**
Time (s)	0.184	0.204	0.354	0.414	**0.262**

Table 4
Performance measure values obtained after applying different enhancement techniques on the *beach.jpg* image.

Performance measures	Histogram equalization	Adaptive histogram equalization	Gray level grouping (GLG)	Fuzzy method of [13]	Proposed fuzzy method
CII	2.9479	2.9579	3.0817	3.4426	**3.8450**
Tenengrad ($\times 10^4$)	10.409	10.733	9.8088	8.6576	**8.4911**
Time (s)	0.188	0.208	0.348	0.407	**0.239**

beach images are 2.12×10^4, 3.67×10^4, 6.26×10^4 and 4.58×10^4, respectively.

Fig. 4(a)–(e) shows the contrast and brightness enhanced *boy.jpg* images after applying Histogram Equalization, Adaptive Histogram Equalization, GLG, Fuzzy method [13] and Proposed Fuzzy method, respectively. Fig. 4(f)–(j) shows the respective histograms of the *V* component of enhanced *boy.jpg* images. From Fig. 4(j) it is evident that the histogram of the *V* component has been stretched to increase the contrast and brightness by preserving the general shape of the histogram of the original *boy.jpg* image. Figs. 5–7 show similar results for *girl.jpg*, *building.jpg* and *beach.jpg* images, respectively.

Tables 1–4 show performance measure values obtained after applying different enhancement techniques on *boy.jpg*, *girl.jpg*, *building.jpg* and *beach.jpg* images, respectively. From the table values, it is evident that the proposed fuzzy method gives higher *CII* value compared to conventional and advanced image enhancement methods. The higher Tenengrad values for the proposed method shows that it enhances the structural information in the original images. Though GLG and histogram equalization methods give higher Tenengrad values, the visual quality of the resultant images are not comparable with the proposed method. It is also very evident from the table values that the proposed method is computationally fast compared to GLG and the fuzzy method of [13]. The proposed method takes 20–30% and 32–40% less computational time compared to GLG and fuzzy method of [13], respectively.

6. Conclusion

A fast and efficient fuzzy based color image enhancement method has been proposed in this paper. Comparative analysis of proposed method with conventional histogram based contrast enhancement techniques (like histogram equalization, adaptive histogram equalization) along with the recent histogram based Gray Level Grouping method and the Fuzzy Logic method was carried out to ascertain which of these methods is better suited for automatic contrast enhancement of color images. From comparative analysis it is concluded that our proposed Fuzzy Logic method as elucidated in this paper has improved the visual quality as well yielded a higher Tenengrad and CII values. The method is computationally faster compared to existing advanced enhancement techniques. The drawback of this method is that it can be applied only to low contrast and low bright color images. Future work is concentrated on developing a method to adaptively calculate the stretching parameter *K*, to balance the contrast level in both low contrast and over contrast color images.

References

[1] Gonzalez RC, Woods RE. Digital image processing. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall; 2002. ISBN: 0-201-18075-8.
[2] Kim Y-T. Enhancement using brightness preserving bi-histogram equalization. IEEE Trans Consum Electron 1997;43(February (1)):1–8.
[3] Wan Y, Chen Q, Zhang B-M. Image enhancement based on equal area dualistic sub-image histogram equalization method. IEEE Trans Consum Electron 1999;45(February (1)):68–75.
[4] Pizer SM, Amburn SM, Austin JD, Cromartie R, Geselowitz A, Greer T, Romeny BH, Zimmerman JB, Zuiderveld K. Adaptive histogram equalization and its variations. Comput Vis Graph Image Process 1987;39:355–68.
[5] Caselles V, Lisani J-L, Morel J-M, Sapiro G. Shape preserving local histogram modification. IEEE Trans Image Process 1999;8(February (2)):220–30.
[6] Chang D-C, Wu W-R. Image contrast enhancement based on a histogram transformation of local standard deviation. IEEE Trans Med Imaging 1998;17(August (4)):518–31.
[7] Chen S-D, Ramli AR. Contrast enhancement using recursive mean-separate histogram equalization for scalable brightness preservation. IEEE Trans Consum Electron 2003;49(November (4)):1301–9.

[8] Chen S-D, Ramli AR. Minimum mean brightness error bi-histogram equalization in contrast enhancement. IEEE Trans Consum Electron 2003;49(November (4)):1310–9.
[9] Jin Y, Fayad L, Laine A. Contrast enhancement by multi-scale adaptive histogram equalization. In: Proc. SPIE, vol. 4478. 2001. p. 206–13.
[10] Kim J-Y, Kim L-S, Hwang S-H. An advanced contrast enhancement using partially overlapped sub-block histogram equalization. IEEE Trans Circuits Syst Video Technol 2001;11(April (4)):475–84.
[11] ZhiYu C, Abidi BR, Page DL, Abidi MM. Gray-level grouping (GLG): an automatic method for optimized. Image contrast enhancement – part I: the basic method. IEEE Trans Image Process 2006;August (15)(8).
[12] ZhiYu C, Abidi BR, Page DL, Member, Abidi MA. Gray-level grouping (GLG): an automatic method for optimized image contrast enhancement – part II: the variations. Method IEEE Trans Image Process 2006;August (15)(8).
[13] Hanmandlu M, Jha D. An optimal fuzzy system for color image enhancement. IEEE Trans Image Process 2006;15(October (10)):2956–66.
[14] Nair MS, Rekha L, Wilscy M, Tatavarti R. Fuzzy logic based automatic contrast enhancement of satellite images of ocean. Signal Image Video Process, Springer-Verlag 2011;5(March (1)):69–80.
[15] Zadeh LA. Outline of a new approach to the analysis of complex systems and decision processes. IEEE Trans Syst Man Cybern 1973;SMC-3(January (1)):28–44.
[16] Jimmermann HJ. Fuzzy set theory and its applications. 2nd ed. Norwell, MA: Kluwer; 1991.
[17] Russo M, Ramponi G. A fuzzy operator for the enhancement of blurred and noisy images. IEEE Trans Image Process 1995;4(August (8)):1169–74.
[18] Choi YS, Krishnapuram R. A robust approach to image enhancement based on fuzzy logic. IEEE Trans Image Process 1997;6(June (6)):808–25.
[19] Pal SK, King RA. Image enhancement using smoothing with fuzzy sets. IEEE Trans Syst Man Cybern 1981;SMC-11(July (7)):494–501.
[20] Li H, Yang HS. Fast and reliable image enhancement using fuzzy relaxation technique. IEEE Trans Syst Man Cybern 1989;19(May (5)):1276–81.
[21] Hanmandlu M, Tandon SN, Mir AH. A new fuzzy logic based image enhancement. Biomed Sci Instrum 1997;34:590–5.
[22] Lakshmanan R, Nair MS, Wilscy M, Tatavarti R. Automatic contrast enhancement for low contrast images: a comparison of recent histogram based techniques. In: IEEE international conf. on computer science and information technology, ICCSIT 2008. 2008. p. 269–76.
[23] Rekha L, Nair MS, Wilscy M, Tatavarti R. Automatic contrast enhancement using selective gray-level grouping. Int J Signal Imaging Syst Eng (IJSISE), Inderscience Publishers 2010;3(2):126–35.
[26] Zeng P, Dong H, Chi J, Xu X. An approach for wavelet based image enhancement. In: IEEE international conference on robotics and biomimetics, ROBIO 2004. 2004. p. 574–7.