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Controlling Over Enhancement of Images Using Histogram Equalization Technique

Anisha Raheja[1], Rashmi Chawla[2], Shailender Gupta[3], Akshar Vashist[4]
[1,2,3]J. C. Bose University of Science and Technology, YMCA, Faridabad

[4]Indian Institute of Science, Bangalore

rahejaanisha16@gmail.com, rashmichawlaymca@gmail.com, shailender81@gmail.com, akv1792@gmail.com

Abstract. Contrast Enhancement is a powerful technique to procure high quality images with outstanding contrast enrichment and an appreciable improvement in visual quality. A multitude of contrast enhancement schemes based on Histogram Equalization accomplished to improve image perceptibility are available in literature. Although these perform quite well, but image over enhancement is a stumbling block, which cannot be overlooked. This paper is an effort to resolve the above problem by incorporating a novel recursive approach, taking Histogram Equalization (HE) as the base methodology for improving the subjective quality of image. The proposed mechanism searches those portions of image where contrast enhancement is actually required, thus avoiding over enhancement. Furthermore, contrast adjustment is performed on the overall image so as to suppress the excessively enhanced regions. A simulator is designed in MATLAB 2016a to fulfil the defined purpose. The comparison results of proposed technique with already reported ones show that ours is better than others in terms of the performance metrics, Contrast Improvement Index(CII) and Colour Enhancement Factor (CEF).

Keywords: Contrast enhancement, histogram equalization, histogram modification, image processing

1. Introduction

Contrast enhancement[1-5] is an integral part of image processing with extensive use in various application areas such as remote sensing, medical field, microscopic imaging, digital photography etc. A poor-contrast image might be obtained as a result of bad quality processing device or myriad other factors[6]. In order to make the image more suitable for further processing, contrast enhancement is a prerequisite requirement. It plays a pivotal role in improving images for better human perception and visibility. Contrast enhancement makes the details of an image more pronounced and enriches its information content as can be seen in Fig. 1(a) and Fig. 1(b).

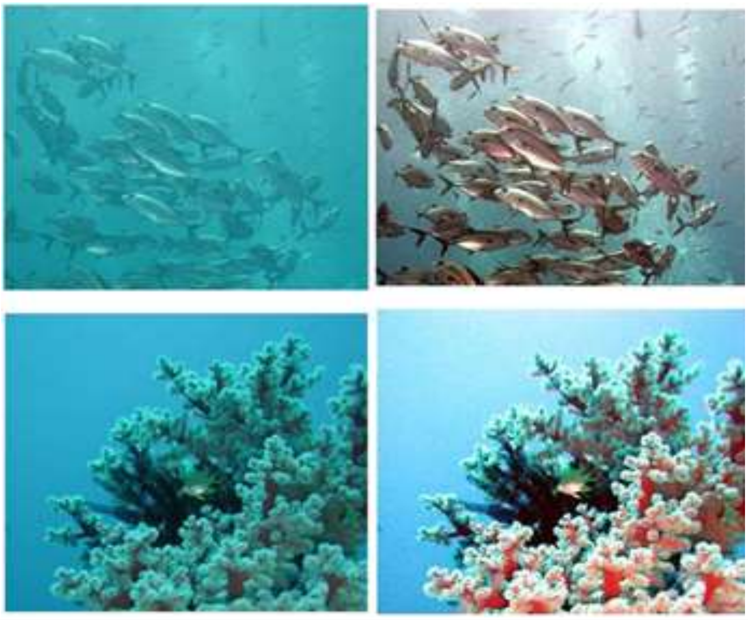

Fig.1 (a): Original Images Fig.1(b): Images after Enhancement

Histogram Equalization (HE) [7-10] is one of the most popular and conventional techniques used for image contrast enhancement. Numerous approaches based on HE have been proposed in literature with the aim to make images clear and visually appealing to the viewer. It is considered as a simple and effective method to improve the image, but also acknowledges many shortcomings such as:

- Applying HE on an image alters the mean brightness of input image and useful details are lost.
- HE results into excessive enhancement of image, addition of unwanted artefacts; yielding an unrealistic look [11]. The result of performing HE to an image is illustrated in Fig.2 and it is noteworthy that the image has been over enhanced as the face of subject is not clear.

Fig.2: Over Enhanced Image by Histogram Equalization

Due to these limitations, HE cannot be employed in consumer electronic applications [12]. To overcome the aforementioned problems of traditional HE, various HE based approaches have been reported in literature. These methods exploit different ways for histogram segmentation of input image and apply traditional HE on sub-histogram afterwards; thereby attempt to preserve image details as well as input luminance. Although some have been quite successful, but it cannot be denied that over-enhancement problem still persists.

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Therefore, this paper proposes a mechanism which strives to outweigh the drawbacks of conventional HE. An algorithm is put forward, which applies HE only on the poor contrast regions of image, leaving rest of the portions untouched. Furthermore, contrast adjustment is performed on the overall image to suppress the over-enhanced portions and provide a natural, pleasant, pleasing look. The rest of the paper is organised as follows: Section 2 presents a comprehensive literature survey of HE-based schemes. Sect.3 is an inclusive description of proposed mechanism. Sect.4 enlists the simulation set up parameters; Sect.5 summarizes the comparison analysis results, Sect. 6 &7 give conclusion and references respectively.Other paragraphs are indented (BodytextIndented style).

2. Literature Survey

A number of contrast enhancement schemes based on histogram equalization with the aim to eliminate the limitations of traditional HE have been reported in the past. A comprehensive review of some of these techniques is illustrated in Table-1 below.

Table 1: Comprehensive Review of HE-Based Schemes in Literature

S No.	Author/ Year	Proposed Technique	Features	Noteworthy Quality Parameter	Comments
1	Kim et al. 1997 [13]	BBHE	Separately equalizes the histograms obtained by decomposition of input image based on mean.	Better AMBE than HE	• No unnecessary artefacts • Brightness of original image is preserved • Can be utilized in consumer electronics
2	Wang et al. 1999 [14]	DSIHE	• Performs HE on two equal area sub images obtained on the basis of PDF and then combines equalised sub parts to achieve complete enhanced image. • Makes use of entropy value for histogram equalization	• AIC more than HE, BBHE • Preserves image brightness, entropy better than BBHE	Overcomes the drawback of HE and can be directly used in video systems
3	Chen & Ramli 2003 [15]	MMBEBHE	Minimizes the difference between mean of input and output image	Low value of AMBE as compared to BBHE, DSIHE	• Optimal mean brightness preservation • Removes noise
4	Chen & Ramli 2003 [15]	RMSHE	Makes use of BBHE iteratively to maintain input image brightness.		• Scalable and full range brightness preservation, hence better

					than MMBEBHE. • Convenient for use in consumer electronics
5	Sim et al. 2007 [16]	RSIHE	• Follows median separation approach for histogram division. • SEM images are used as test images for application of algorithm	Yields high PSNR and SSIM than HE, BBHE, RMSHE	Exhibits better contrast than RMSHE
6	Wadud et al. 2007 [17]	DHE	• Image histogram division is performed on the basis of local minima • Repeatedly ensures absence of dominating portion		• Image information and details are maintained. • No unnecessary side effects.
7	Haidi et al. 2007 [18]	BPDHE	• Extension to MPHEBP and DHE. • Mean intensity of the output image is equal to the mean intensity of input image. • Histogram partitioning is done on the basis of local maxima.	• Lowest AMBE as compared to previous techniques. • Better than MPHEBP in terms of enhancement and better than DHE in mean brightness preservation.	• Mean brightness of input image is preserved • No serious side effects
8	Wang et al. 2007 [19]	FWTHE	• Histogram modification is done using weighting and thresholding		• Controllable extent of enhancement • Flexibility for variety of images • Finds use in enhancement of videos
9	Ooi et al. 2009 [20]	BHEPL	• Bifurcation of input histogram is followed by		• Remarkably high speed

			clipping sub-histograms based on computed plateau value		• Avoids unnecessary enhancement • Mean brightness is maintained
10	Ooi et al. 2010 [21]	DQHEPL	• Extension of RSIHE • Divides input histogram into four sub parts based on median value, then clipping is followed by HE.	• Higher PSNR and AE than HE, BBHE, DSIHE, RMSHE, RSIHE, BHEPL • Lower AMBE than HE, BBHE, DSIHE, MMBEBHE, RMSHE, RSIHE, BPDHE, BHEPL, BHEPL-D	• Avoids over enhancement
11	Ooi et al. 2010 [21]	BHEPL-D	• Extension of BHEPL • Histogram division involves mean value while histogram clipping utilizes median value of intensity	• Higher PSNR and AE than HE, BBHE, DSIHE, RMSHE, RSIHE, BHEPL, DQHEPL • Lower AMBE than HE, BBHE, DSIHE, MMBEBHE, RMSHE, RSIHE, BPDHE, BHEPL	• Better brightness and details preservation than DQHEPL
12	Tan et al. 2012 [22]	BBPHE	Segmentation of input image is performed on basis of background and non-background levels	Higher PSNR than HE, BBHE, DSIHE, MMBEBHE	Preserves background luminance
13	Muniyappan et al. 2013 [23]	CLAHE	Splitting image into tiles is followed by histogram equalization	Better contrast than HE	Avoids over amplification of noise

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Although the aforementioned approaches have improved the enhancement process by brightness and information preservation, there's still a scope to improve the image so as to avoid over-enhancement, washed out appearance and undesirable effects. The next section is a thorough explanation of proposed mechanism which tends to overcome these difficulties.

3. Proposed Mechanism

This section elaborates the methodology adopted for contrast enhancement of image in this paper with the following objectives in mind:

- Over enhancement should be avoided
- Contrast improvement index should be high, i.e. the output image should have increased contrast for high perceptibility.
- CEF should be optimum that is neither too high nor too low; the colour of output image should be increased, but should be kept balanced to provide a natural look and preserve information.
- Contrast enhancement should be applied on the contrast-deprived regions only.

The block diagram of the proposed mechanism in shown in Fig. 3

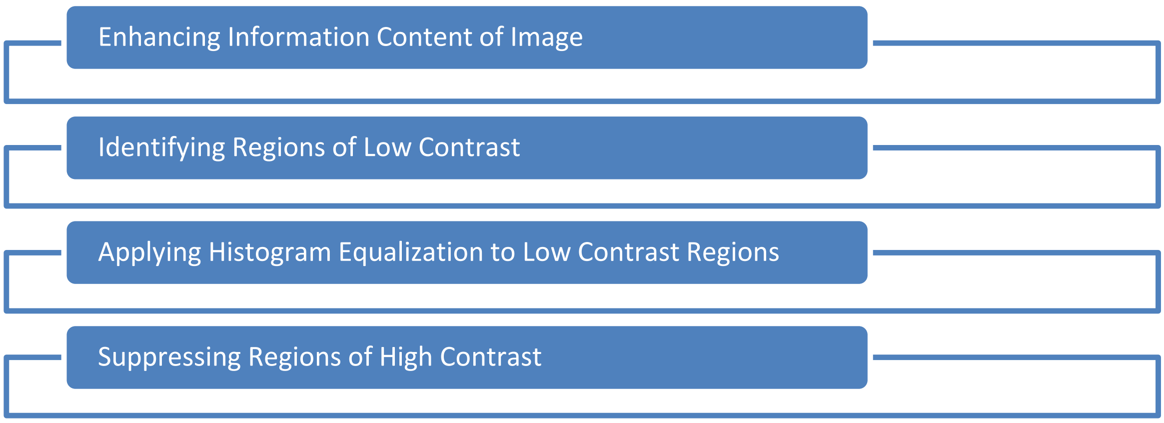

Fig.3: Block Diagram of the Proposed Mechanism

3.1 Enhancing Information Content of Image

1. In the process of improving quality of an image, it is crucial to preserve and enhance its information content. Image sharpening is a method which highlights the edges of an image while boosting the important details and features. This is carried out using unsharp masking method which is illustrated in the Fig. 4 below and explained in detail afterwards.

2.

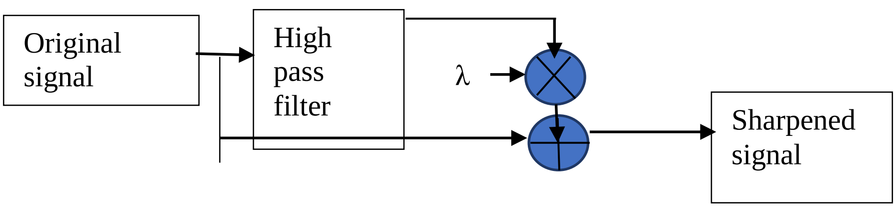

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Fig.4: Image Sharpening Process [24]

- The original signal is passed through a High Pass Filter (HPF) which extracts the high frequency components of input signal. Conventionally, the employed HPF used to be linear filter, but weighted median filter with appropriate weights is used now.

$$W = \frac{1}{3}\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Here, $Filter\ output\ \propto (center\ pixel - smallest\ pixel\ around\ center\ pixel)$
Hence, the filter output takes higher value when prominent edge is detected, whereas small value for smooth regions and zero for constant ones.

- The scaled version of filter output is added to original image and sharpened image is obtained.
- The sharpening operation of an image can be stated as:

$$S_{i,j} = X_{i,j} + \lambda . F(X_{i,j}) \qquad -(1)$$

Where,

$X_{i,j}$ *=Original pixel value at coordinate (i, j)*
F = High pass filter
λ *=Tuning parameter (≥0)*
$S_{i,j}$ *=Sharpened pixel at coordinate (i, j)*
The tuning parameter (λ) depends on the level of sharpness desired. Higher the value of λ, higher is the resultant sharpness. Image sharpening is applicable for both gray scale and colour images. Sharpening of input image is the primary step in our mechanism in order to make the image more detailed and prominent which can be seen in Fig.5(a) and Fig.5(b).

	
Fig.5 (a): Original image	***Fig.5(b): Sharpened image***

3.2 Identifying Regions of Low Contrast
Once the details of an image have been improved, next step is to identify the regions of low contrast. This is achieved by traversing the overall image with the help of windows and then determining which portion require enhancement. For detection of poor contrast portions, we follow the algorithm-1 shown:

Algorithm-1: Identifying Regions of Low Contrast
Step-1: *Make window of size (w X w)*

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Step-2: *Calculate absolute value of (mean(image)-median(image))*
Step-3: *If (x>=threshold), then apply Histogram Equalization; else skip that part of the image*
Step-4: *Repeat until whole image is traversed*

3.3 Applying Histogram Equalization to Low Contrast Regions

After determining the low contrast region in image, we apply the traditional Histogram Equalization technique on it. This is an intensity-level transformation, which works on modifying the pixel values of input image and increasing its contrast [25]. The working is demonstrated below:

- Let the intensity levels of an image be in range[0,1] viz. normalized values,
- Let $p_r(r_j)$ denote the Probability Density Function (PDF) of intensity levels in input image for $r = 0,1,2 \ldots\ldots, L-1$(L=total possible intensity levels),
- Let T(r) be transformation function,
- Let *s* denote the output intensity levels.

The equalization process is carried out as:

$$s = T(r) = \int_0^r p_r(w)dw \qquad -(2)$$

The PDF of output levels is uniform i.e.:

$$p_s(s) = \{1\, for\ 0 \le s \le 1\ ; 0\ otherwise\} \qquad -(3)$$

While working with discrete quantities, the above technique is referred to as histogram equalization. The equalization transformation now becomes:

$$s_k = T(r_k) \qquad -(4)$$

$$s_k = \sum_{j=0}^{k} p_r(r_j) \qquad -(5)$$

$$s_k = \sum_{j=0}^{k} \frac{n_j}{n} \qquad -(6)$$

Where,

$k = 0,1,2, \ldots., L-1$

n *: number of pixels in given image*

$p_r(r_j)$*: histogram of given input image*

s_k*: intensity value in output image*

r_k*: intensity value in input image*

Thus, histogram equalization enhances the contrast through modification of histogram and increasing dynamic range of output histogram. The sharpened image obtained as a result of previous step shown in Fig.6 (a), is then equalised as shown in Fig.6 (b).

	
Fig.6(a): Sharpened Image	***Fig.6(b):Equalised Image***

3.4 Suppressing Regions of High Contrast

After obtaining the equalized image by above steps, it is mandatory to ensure a well-balanced contrast in output image. This is achieved by performing contrast adjustment in the overall image. A good contrast image implies that there exist sharp difference between black and white of image.

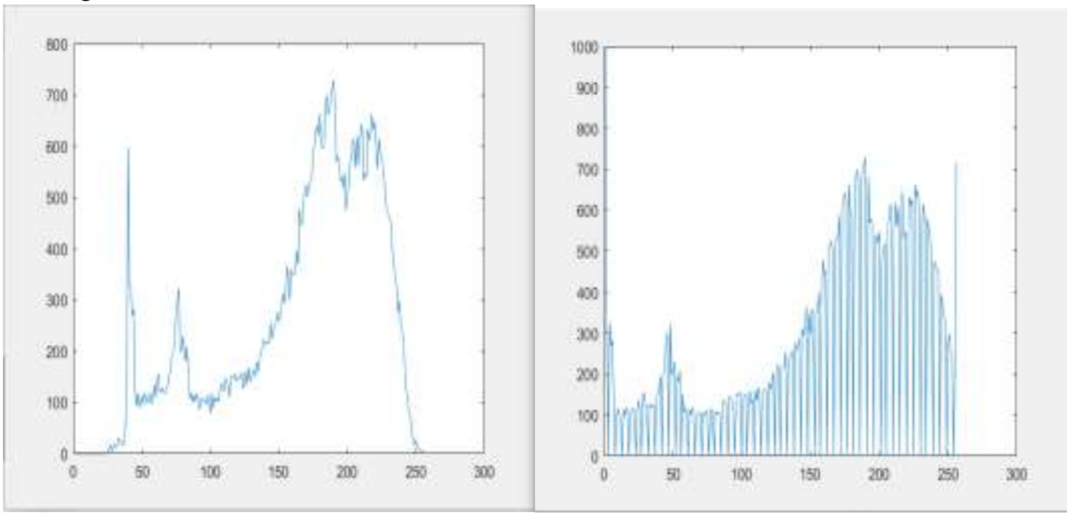

Fig. 7: Histogram Result of Applying Contrast Adjustment on an Image

The histogram of contrast adjusted image represented in fig.7 exhibits intensity values in full range i.e. [0-255] which is evidently better than histogram of original image whose intensity value are concentrated in shorter range. We make use of contrast adjustment in our mechanism to suppress over enhanced regions and provide a natural look to image.

Fig.8(a): Equalized Image

Fig.8(b): Contrast Adjusted Image

As is evident from fig.8 (b), contrast adjusted image has better highlights, sharp edges and detailed features than fig.8 (a).

4. Simulation setup parameters

The parameters utilized for simulation are enlisted in Table-2 below.

Table 2: PC Configuration and Image Specifications

Parameter	Specifications
Processor	Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz
Memory	8 GB RAM
Operating System	Windows 10 Home
Software	MATLAB 2016 a
Image Type	Gray scale, colour images of nature
Image Resolution	256*256
Image Format	Jpeg
Window Size (w)	10 X 10
Threshold	2
Tuning Parameter (λ)	0.8

5. Results

For comparison analysis of proposed scheme with several other HE-based approaches, we took 15 images of same type and applied each technique one by one on these images. The performance metrics namely AMBE, AIC, CII, MSE, PSNR, DEU, CEF and SSIM were evaluated for each of these. Finally, mean of results obtained was taken and comparison was drawn out shown in Table-3 below.

Table 3: Performance Metrics for Various Contrast Enhancement Schemes

Parameter	HE	CLAHE	BBHE	BBPHE	BHEPLD	DSIHE	FWTHE	MMBEBHE	RSIHE	RMSHE	Proposed
AMBE	18.199	17.903	5.864	4.975	18.85	7.345	25.569	18.739	6.261	6.739	16.564
AIC	5.9798	7.6613	7.586	7.55	4.6158	7.612	7.4239	7.6059	7.446	7.359	6
CII	1.0223	0.974	0.982	0.977	0.9747	0.998	1.0067	1.0145	0.963	0.954	1.0552
MSE	106.22	120.87	191.2	148.3	229	188.7	237.64	198.34	117.7	111.3	85.694
PSNR	29.007	27.925	25.79	27.78	24.828	25.75	27.04	26.264	27.8	28.18	29.817
DEU	1.3728	0.3282	0.239	0.198	2.7368	0.265	0.2404	0.2589	0.141	0.141	1.4644
CEF	1.3336	0.8839	1.43	1.166	5.7632	1.409	1.4646	1.273	1.681	1.748	1.7412
SSIM	0.6264	0.6374	0.74	0.88	0.359	0.727	0.6826	0.6429	0.753	0.755	0.647

The proposed scheme outperforms the other approaches in terms of following performance metrics:

5.1 Contrast Improvement Index (CII):

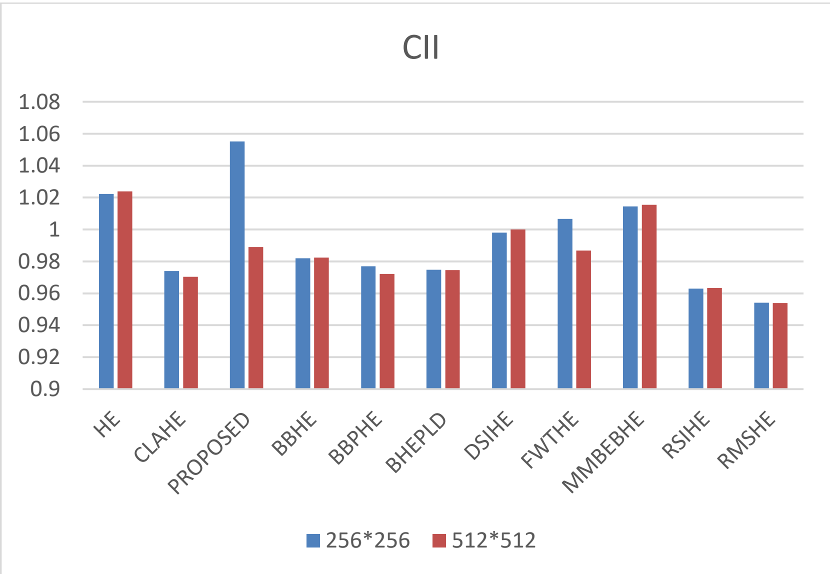

Fig. 9: Comparison Chart of Proposed Scheme with others based on CII for 256*256 and 512*512 Images

The comparison of the proposed scheme with others based on CII is illustrated in fig. 9. Contrast improvement index(CII) signifies how much the contrast has improved after processing or applying an enhancement scheme. CII can be quantitively expressed as the ratio of mean local contrast of processed output image to the mean local contrast of original input image, as given by eq(7):

$$CII = \frac{C_{processed}}{C_{original}} \quad -(7)$$

The local contrast of image(C) can be calculated as:

$$C = \frac{max - min}{max + min} \quad -(8)$$

where, max and min are the maximum intensity value and minimum intensity value respectively in 3*3 window of the image.

CII of proposed scheme is highest as compared to the other techniques, which justifies that contrast has significantly improved.

5.2 Colour Enhancement Factor (CEF)

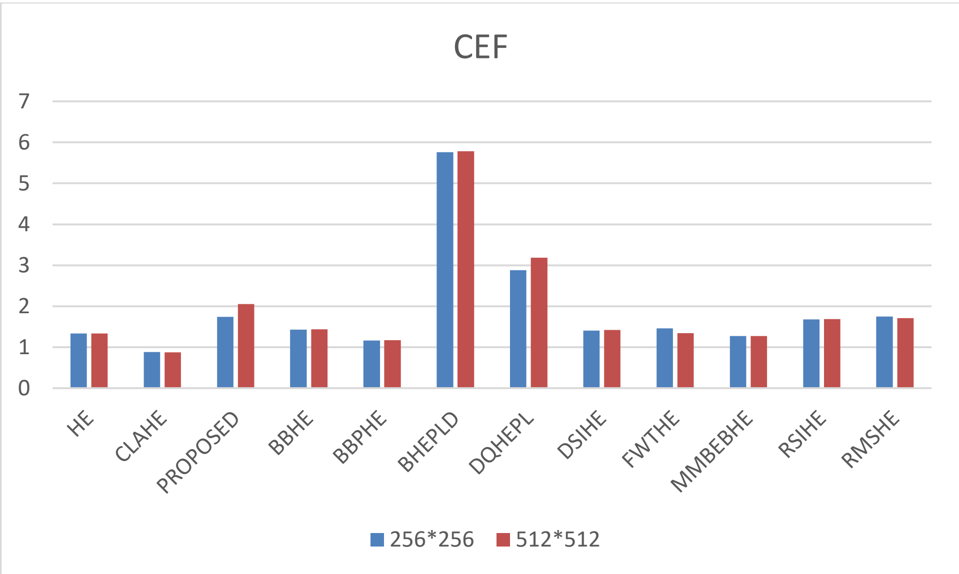

Fig. 10: Comparison Chart of Proposed Scheme with others based on CEF for 256*256 and 512*512 Images

The comparison of the proposed scheme with others based on CEF is illustrated in fig. 10. Colour Enhancement Factor (CEF) signifies how much the colour has improved after processing the image. CEF can be quantitatively expressed as:

$$CEF = \frac{\sqrt{{\sigma_\alpha}^2 + {\sigma_\beta}^2} + 0.3\sqrt{{\mu_\alpha}^2 + {\mu_\beta}^2} \ \ (for\ processed\ image)}{\sqrt{{\sigma_\alpha}^2 + {\sigma_\beta}^2} + 0.3\sqrt{{\mu_\alpha}^2 + {\mu_\beta}^2} \ \ (for\ output\ image)} \quad -(9)$$

where
α=R-G ;
β=(R+G)/2 –(B) ;
σ= standard deviation, β=mean of α and β

The proposed scheme has CEF higher than HE, CLAHE, BBHE, BBPHE, DSIHE, FWTHE, MMBEBHE and RSIHE. This shows that the colour of output processed image has reasonably increased than original input image. While techniques like BHEPLD and DQHEPL have higher CEF than proposed technique, it is to be considered that the output image should possess optimum increase in colour thus giving a well-balanced colour. Table-4 and Table-5 depict the screenshots of various techniques applied on colourful and gray scale image respectively.

Table 4: Snapshots for a Colourful Flower Image

ORIGINAL	**HE**	**CLAHE**	**BBHE**
			
BBPHE	**BHEPLD**	**DSIHE**	**FWTHE**
			
MMBEBHE	**RSIHE**	**RMSHE**	**PROPOSED**
			

The proposed mechanism yields a higher contrast, enriched colour and pleasant image as compared to other techniques.

Table 5 : Snapshots for a Gray Flower Image

Original	**HE**	**CLAHE**	**BBHE**
			
BBPHE	**BHEPLD**	**DSIHE**	**FWTHE**
			
MMBEBHE	**RSIHE**	**RMSHE**	**PROPOSED**
			

As illustrated above, the image obtained after processing with the proposed mechanism, has better highlights of white and black, prominent edges, improved contrast and natural look as compared with other methods.

6 Conclusions

Contrast enhancement in image processing is widely being used to improve the image quality. Although researchers have come up with myriad techniques based on Histogram Equalization, but there persists the problem of excessive enhancement of images, amplification of noise, loss of useful information or washed out appearance. This paper has made an effort to overcome the shortcomings of previously proposed schemes, and provide a natural look to the image. The paper brings forward a novel recursive approach, which applies HE only on the poor contrast portions of image, hence maintains a balance of contrast in overall image. Thereafter, Contrast adjustment helps to supress over enhanced regions and provide a natural look to output image. The comparison analysis shows that the proposed scheme has majorly improved the image contrast and enhanced its colours. It is noteworthy that performance metrics of our technique viz. CII and CEF are found to be better than rest of the techniques, which quite well justifies the capability of proposed scheme to enhance image contrast.

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