Optik - International Journal for Light and Electron Optics 183 (2019) 329–337

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Image contrast and color enhancement using adaptive gamma correction and histogram equalization

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A R T I C L E I N F O

Keywords:
Contrast enhancement
Gamma correction
Image quality assessment
Histogram equalization

A B S T R A C T

Image contrast and color preservations are essential needs for color vision and the processing of digital color images. Histogram Equalization (HE) is mostly used for enhancing the digital images. However, HE results in over-enhancement and intensity saturation effect in most cases. In this paper, an effective image contrast enhancement method called an Adaptive Gamma Correction with Weighted Histogram Distribution (AGCWHD) method is proposed to improve contrast while preserving natural color and richer details in images. In the proposed method, the new adaptive gamma correction method is implemented to enhance the contrast, while a weighted histogram distribution is employed for natural color and detail preservation. Experiments are conducted and tested on 500 TID 2008 benchmark images to evaluate the performance of proposed method. Experiment results show that the proposed technique performs well for a wide variety of low-quality images, and achieves better or comparable objective and subjective comparisons with the state-of-the-art methods. Experimental results demonstrated that the proposed technique produced extremely high-quality images compared with the state-of-the-art existing techniques.

1. Introduction

Image enhancement plays a significant role in the enhancement of visual perception for computer vision, pattern recognition, and the handling of digital images. Low brightness and low contrast color images often get in image acquisition and they are essential to processing for vision-based applications. Histogram Equalization (HE) [1–6] is a simple and effective technique for image contrast enhancement. HE distributes intensity levels of input histogram uniformly over an entire range. However, HE has undesirable effects such as excessive enhancement, intensity saturation effect etc. HE alters the mean brightness of the original image irrespective of image contents. In order to lessen over-enhancement problems, Brightness Preserving Bi-Histogram Equalization (BBHE) [7], Dualistic Sub-Image Histogram Equalization (DSIHE) [8], and Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) [9] have been proposed, which performs a histogram partition before applying the HE. BBHE splits the histogram based on the mean intensity whereas DSIHE uses the median based splitting instead of the mean. MMBEBHE recursively partitions the input histogram into multiple groups based on Absolute Mean Brightness Error (AMBE). In addition to Bi-histogram techniques, the Dynamic Histogram Equalization (DHE) [11] method divides the input histogram using local minima, and a new dynamic range is allocated to each partition based on the original dynamic range and the number of pixels in the corresponding partition. However, under poor lighting conditions, DHE suffers from intensity saturation effect. Recursively Separated and Weighted Histogram Equalization (RSWHE) [10] method employs a weighting process to smooth each sub-histogram for contrast improvement and brightness

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https://doi.org/10.1016/j.ijleo.2019.02.054
Received 4 July 2018; Received in revised form 3 February 2019; Accepted 13 February 2019
0030-4026/

conservation. Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE) [12] uses a theory of fuzzy logic in order to preserve the original brightness. Representation of images in the fuzzy domain handles the inexactness of grey level in a better way. Image contrast can be enhanced by the histogram modification framework (HMF) [13], which incorporates the penalty of histogram deviation from primary to uniform histograms as well as minimizes a cost function to compute a smooth histogram. Although HMF effectively prevents the unnatural look due to over enhancement, its improvement results are quite sensitive to parameter setting. Dynamic histogram specification (DHS) method proposed by Sunet al. [14] that preserves the shape of the input image histogram but image contrast is not significantly enhanced; Edge-based Texture Histogram Equalization (ETHE) [15] technique for improving image contrast; Singh et al. proposed an exposure-based sub-image histogram equalization (ESIHE) [16] for contrast enhancement of under exposure images. In this method, the histogram is clipped based on mean intensity. This clipping process controls the excessive contrast enhancement. ESIHE method control only excessive enhancement, it does not preserve mean brightness.

Gamma correction method is used to improve the image quality through contrast adjustment with the preservation of mean brightness. However, the selection of gamma parameter is manual and time-consuming. An adaptive gamma correction (AGC) method [17] is proposed to improve the contrast of the image where the appropriate gamma value is set automatically based on the statistics extracted from images. Later, Huang et al. introduced the adaptive gamma correction with Weighting Distribution (AGCWD) [18] for image enhancement by choosing gamma value as a function of cumulative density function (CDF) obtained from the input image. However, such AGC methods generally fail to improve the contrast of low light images, the brightness is over-enhanced and some essential details are lost, which generates the resultant images undesirable.

In this paper, to solve the above-mentioned problems, an efficient image enhancement method is proposed to enhance the contrast and preserve the maximum information in the image. In the proposed method, the RGB input image is first stretched to extent the permissible magnitude range and transformed to the Hue Saturation Intensity (HSI) space where the intensity channel is further enhanced. Then it adopts a new optimal adaptive gamma correction and weighting histogram distribution method to improve the contrast considerably by dropping excessive enhancement and intensity saturation effect. Finally, we get the enhanced image after converting new HSI color space into RGB color space. This method is very effective for low illumination images.

The rest of this paper is structured as follows. Section 2 discusses conventional image enhancement method. Proposed work is presented in Section 3. Section 4 shows experimental results. The conclusion is given in Section 5.

2. Conventional image enhancement method

Consider an original input color image in Red Green Blue (RGB) format, sized U × V in width-by-height, having N = U × V pixels. The magnitude of each and every color channel is confined within the range [0 to L-1], where L = 256. An input color image is given as

$$\mathrm{I}(\mathrm{u},\ \mathrm{v}) = \{\mathrm{R},\ \mathrm{G},\ \mathrm{B}\} \tag{1}$$

where (u, v) is the input image's pixel coordinate. The input RGB image is transformed into HSI space using a transformation given in Eq. (2)

$$\mathrm{HSI} = \mathrm{T}(\{R,\ G,\ B\}) \tag{2}$$

Where T is the transformation function for RGB to HSI color conversion. The intensity I-channel is processed for contrast correction and then transformed back to the RGB space. In the conventional HE process, a histogram or a probability density distribution (PDF) is first computed as

$$\mathrm{h}(\mathrm{i}) = \{\mathrm{n}(\mathrm{i})\}\text{and}\, p(\mathrm{i})\frac{h(i)}{N} \tag{3}$$

where i corresponds to the intensity index and n(i) is the number of pixels in an image with i^{th} intensity. Then, the corresponding CDF is computed as

$$\mathrm{C}(\mathrm{i}) = \sum_{\mathrm{j}=0}^{\mathrm{i}} \mathrm{p}(\mathrm{j}) \tag{4}$$

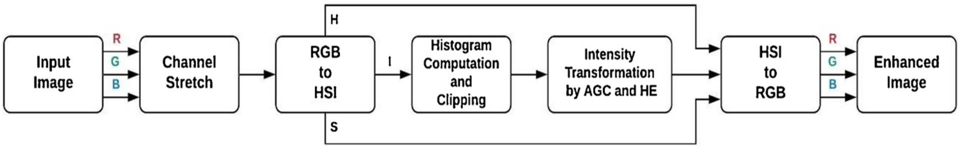
The final step in the HE procedure is as follows

$$\mathrm{I}_E = (\ \mathrm{L}-\ 1) \times \mathrm{C}(\mathrm{i}) \tag{5}$$

Where I_E is the enhanced intensity.

3. Proposed work

An efficient contrast enhancement method is proposed here for improving the contrast of an image in RGB format. The frame work of the proposed model is shown in the flow diagram The proposed approach starts with a color channel stretching in the RGB space and then input RGB color space is transformed into HSI color space for image contrast enhancement. Next, new adaptive gamma correction with weighting histogram distribution scheme is applied on the intensity channel to improve the details in an image. Finally, the improved image is converted back into the RGB format for better display.



Flowchart 1. Frame work of the proposed model.

3.1. Color channel stretching

Consider an input color image $I(u, v) = \{R(u, v), G(u, v), B(u, v)\}$ where $\{R, G, B\}$ are the red, green and blue color spaces, (u, v) is the pixel co-ordinates, $u = 1,\ldots, U$, $v = 1,\ldots, V$ and U, V are the image width and height.

The input image is first stretched on every color channel in order to correct for any color distortion arising from unfavourable capturing environment. A magnitude or channel stretching process stretches the input color channels into their corresponding tolerable maximum range in order to bring the ironic set of color info to the viewer. The stretched red color value is given as,

$$R(u, v) \longleftarrow \frac{R(u, v) - \min\{R(u, v)\}}{\max\{R(u, v)\} - \min\{R(u, v)\}} \tag{6}$$

where min{.} and max{.} are the minimum and the maximum values are gained over all pixels in the image. The green and blue channels are also stretched in the same way. The process of stretching enriches the image color content and serves as pre-processing for contrast enhancement. After magnitude stretching, all color signals are converted to the Hue–saturation–intensity (HSI) space. The I-signal representing the intensity or brightness is processed in the system. The H-channel and S-channel components are not manipulated, as they do not directly affect the human perceived contrast of an image. On the other hand, the human visual system is particularly sensitive to intensity changes and hence, the intensity I-channel is processed in the enhancement process. The stretched RGB input image is then converted into HSI color space using the transformation process given in Eq. (7).

$$[H(u, v), S(u, v), I(u, v)] = T_{RGB}^{HSI}[R(u, v), G(u, v), B(u, v)] \tag{7}$$

where T_{RGB}^{HSI} is the RGB-to-HSI color transformation process. The image can be enhanced by conserving H and S channel components while improving only intensity channel. In the HSI space, the intensity channel is given as

$$I(u, v) \longleftarrow \frac{\{R(u, v) + G(u, v) + B(u, v)\}}{3} \tag{8}$$

3.2. Contrast enhancement with maximum information preservation

In this enhancement stage, the central idea is to enhance the image contrast and to preserve maximum information content close to the input image. In the proposed model, transformed pixel intensity is calculated as

$$T\{I(u, v)\} = \mathrm{round}\left(\frac{\{I(u, v)\}}{I_{max}(u, v)}\right)^{\gamma} \tag{9}$$

Here, the gamma parameter with weighted CDF is computed as,

$$\gamma = 1 - c_w(i) \tag{10}$$

where, the weighted CDF is defined as

$$c_w(i) = \sum_{i=0}^{I_{max}} \left(\frac{p_w(i)}{\sum p_w(i)}\right) \tag{11}$$

Where, I_{max} is the maximum intensity level. Then, the weighted PDF sum is defined as follows

$$\sum p_w(i) = \sum_{i=0}^{I_{max}} (p_w(i)) \tag{12}$$

Then, the corresponding Weighted Histogram Distribution function (WHD) is constructed as

$$p_w(i) = \longleftarrow p_{max}\left(\frac{p(i) - p_{min}}{p_{max} - p_{min}}\right)^{\alpha} \tag{13}$$

where $\alpha = c(i)$, p_{min} and p_{max} are the minimum and maximum PDF of the clipped histogram respectively. Now, the CDF, $c(i)$ is formulated as

$$c(i) = \sum_{i=0}^{L-1} p(i) \tag{14}$$

The proposed method calculated the gamma value automatically via CDF c(i) obtained from the input image by combining the GC and HE methods efficiently. The AGC method can gradually enhance the lower intensity and avoid the loss of the higher intensity. Moreover, the weighting histogram distribution procedure is used to slightly adjust the histogram and shrink the creation of adverse effects. Now, the corresponding PDF (p(i)) is calculated as

$$p(\mathrm{i}) = \frac{h_c(i)}{M} \tag{15}$$

where i = 0, 1, ..., L-1, M is the total intensity levels and $\mathrm{h_c(i)}$ is histogram clipping which is used to control the level of excessive contrast enhancement and it is constructed as,

$$\mathrm{h_c(i)} = \begin{cases} T_c & if\ h(i) \geq T_c \\ h(i) & \text{else} \end{cases} \tag{16}$$

Where h(i) and $\mathrm{h_c(i)}$ are the original and clipped histogram respectively. The clipping limit is computed based on the mean value of the intensity occurrence. The formula for clipping limit $\mathrm{T_c}$ is presented below,

$$\mathrm{T_c} = \frac{1}{\mathrm{L}}\sum_{\mathrm{i=0}}^{\mathrm{L-1}} \mathrm{h(i)} \tag{17}$$

In order to obtain the enhanced image, the processed intensity image (T{I(u, v)}) is first combined with the hue space, and then it is converted back to the RGB color space. It is given as,

$$[\mathrm{R(u, v),\ G(u, v),\ B(u, v)}] = \mathrm{T_{HSI}^{RGB}[H(u, v),\ S(u, v),\ T\{I(u, v)\}]} \tag{18}$$

4. Image quality assessment

The quality of an image, when presented to a computer vision for further processing, can be measured in many aspects. The performance measures used in assessing the enhancement results are mentioned below.

4.1. Entropy

The entropy is defined as the amount of maximum information content present in an image. In general, greater entropy value shows that the image retains richer details and more data content. The entropy [20] is defined as

$$\text{Entropy}= -\sum_{\mathrm{i}} \mathrm{p(i)log(p(i))} \tag{19}$$

Where p(i) = n(i)/N is the probability of intensity occurrence whose magnitude i ranges from 0 to 255 and N is the total number of pixels.

4.2. Contrast

Contrast is a measure of the image quality where local measurements are used to obtain a numerical quantity [1]. A contrast with greater values denote the better contrast. The contrast measure is defined as

$$\text{contrast}= \frac{1}{N}\sum_{\mathrm{u=1}}^{\mathrm{U}}\sum_{\mathrm{v=1}}^{\mathrm{V}} I^2{}_{\mathrm{e}}(u, v) - \left(\frac{1}{N}\sum_{\mathrm{u=1}}^{\mathrm{U}}\sum_{\mathrm{v=1}}^{\mathrm{V}} I_{\mathrm{e}}(u, v)\right)^2 \tag{20}$$

where (u, v) indicate the position of the pixel. An image with a good contrast has evenly distributed histogram.

4.3. Colorfulness

Colorfulness [19] denotes the ironic color contents in an image. A larger value of colorfulness indicates the higher color.

$$\text{Colorfulness}= \sigma_{\mathrm{rgyb}} + (0.3 \times \mu_{\mathrm{rgyb}}) \tag{21}$$

Where

$$\sigma_{\mathrm{rgyb}} = \sqrt{\sigma_{\mathrm{rg}}{}^2 + \sigma_{\mathrm{yb}}{}^2} \text{ and } \mu_{\mathrm{rgyb}} = \sqrt{\mu_{\mathrm{rg}}{}^2 + \mu_{\mathrm{yb}}{}^2} \tag{22}$$

The colorfulness measure is a function of the standard deviation of the intensity-wise color differences rg and yb where

$$\mathrm{rg}= (\mathrm{R} - \mathrm{G}) \tag{23}$$

$$\mathrm{yb}= 0.5 \times (\mathrm{R}+ \mathrm{G}) - \mathrm{B} \tag{24}$$

Similarly, μrg, μyb are the average number of rg and yb respectively.

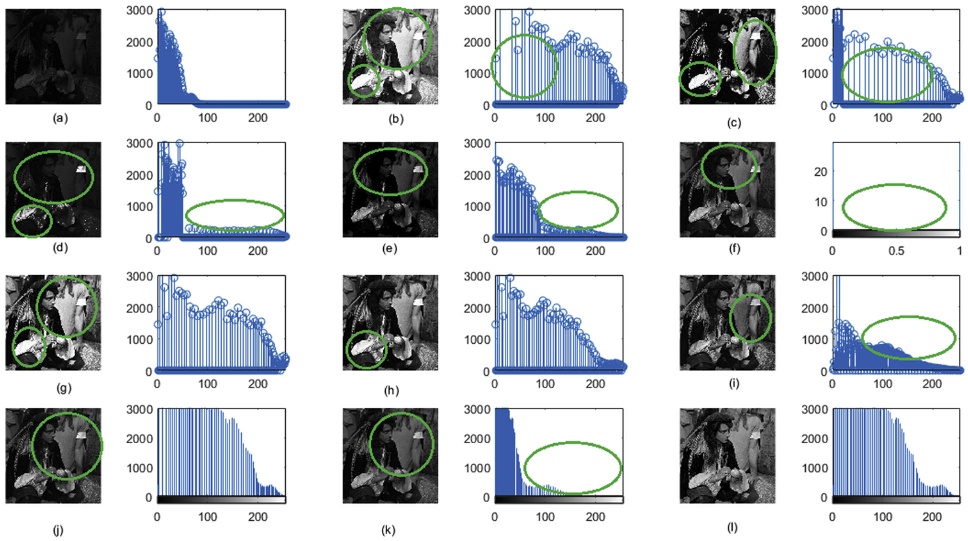


Fig. 1. Contrast Enhancement results of the grey scale Man Image and its histogram. a. Original image; b. HE-ed image; c. BBHE-ed image; d. MMBEBHE-ed image; e. DHE-ed image; f. BPDFHE-ed image; g. RSWHE-ed image; h. ETHE-ed image; i. ESIHE-ed image j. Gamma correction -ed image, k. AGCWD-ed image and j. Proposed- image.

4.4. Saturation

The highness of the object color in an image is denoted by the term called Saturation [4]. More bright colors in an image is being indicated by its highest value. By averaging the saturation of all intensities in an image, saturation is measured. It is defined as,

$$\text{Saturation}=\frac{1}{N}\sum_{u=1}^{U}\sum_{v=1}^{V}1-\frac{3\min\{R(u,v),\ G(u,v),B(u,v)\}}{\sum(R(u,v),\ G(u,v),B(u,v))} \tag{25}$$

5. Experimental results and discussion

In this section, we first compare the results of the proposed method with some HE based methods including HE, BBHE, MMBEBHE, DHE, BPDFHE, RSWHE, ETHE, ESIHE, GC and AGCWD. The comparison is performed in both subjective and objective measurements. Objective evaluation is done with the help of four parameters i.e., entropy, contrast, colorfulness and saturation.

Fig. 1 shows the original grey image along with contrast enhancement results produced by the HE, BBHE, MMBEBHE, DHE, BPDFHE, RSWHE, ETHE, ESIHE, GC, AGCWD and proposed method. On analysing Fig. 1(b), the HE technique is able to effectively enhance the contrast. However, HE results in excessive enhancement where the intensities were driven to extreme bright and dark intensities. Moreover, HE produces very high-intensity saturation problem. This is proven in Fig. 1(b) as the HE-ed pixel intensity values are highly focused on the right side of the histogram plot. Results of MMBEBHE and DHE methods introduce undesired artefacts and the quality of the image gets degraded. Highlighted regions of MMBEBHE and DHE are darker than the original image, which makes an unpleasant view. BPDFHE method offer slightly better image quality. However, the contrast-enhancement is not significantly improved. The enhanced images of RSWHE and ETHE methods presented in Fig. 1(g) and (h) are significantly better than that of HE, but still suffer with the problem of intensity saturation. The results (Fig. 1(i) and (j)) of ESIHE, and GC methods display that they do not enhance the contrast of those images properly and the enhanced images are still a little bit black. The enhanced image of AGCWD method has insignificant contrast enhancement which is highlighted using encircles. By the visual inspection, it is clear that the proposed method can able to produce a natural looking image with better contrast. From the visual assessment of histogram plot, it is seen that a histogram of the proposed method is effectively distributed evenly to its entire dynamic range as compared to other existing enhancement methods. The enhanced image obtained by the proposed technique is visually pleasing and the contrast is significantly improved.

The extensive experimental results obtained for each color image are displayed in Figs. 2–5, respectively. Image (a) displays the original image, while images (b) to (l) denote the corresponding enhanced images after applying HE and other contrast enhancement methods and the proposed method. Fig. 2 displays the ‘tower’ image and contrast enhancement results with histograms produced by the HE, BBHE, MMBEBHE, DHE, BPDFHE, RSWHE, ETHE, ESIHE, GC, AGCWD and proposed method. The original image shown in Fig. 2(a) includes a tower, roofs and fence in a boundary. The HE process equalizes the histogram of the input image to yield an enhanced image in which the statistical histogram lost some intensities, as shown in Fig. 2(b). Since most of the intensities are lesser than the mean brightness and minimum mean brightness error, a better contrast image cannot be generated by either BBHE or MMBEBHE, as displayed in Fig. 2(c) and (d). However, the intensity could not be improved by bi-HE methods. The BPDFHE slightly

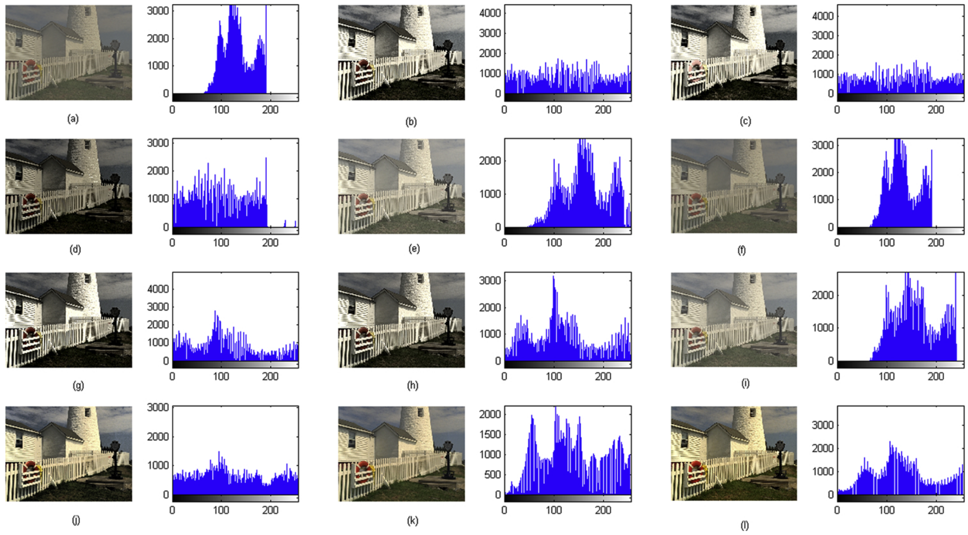


Fig. 2. Contrast Enhancement results of the Tower Image and its histogram. a. Original image; b. HE-ed image; c. BBHE-ed image; d. MMBEBHE-ed image; e. DHE-ed image; f. BPDFHE-ed image; g. RSWHE-ed image; h. ETHE-ed image; i. ESIHE-ed image j. Gamma correction -ed image, k. AGCWD-ed image and j. Proposed- image.

Fig. 3. Contrast Enhancement results of the House Image. a. Original image; b. HE-ed image; c. BBHE-ed image; d. MMBEBHE-ed image; e. DHE-ed image; f. BPDFHE-ed image; g. RSWHE-ed image; h. ETHE -ed image; i. ESIHE -ed image j. Gamma correction -ed image, k. AGCWD-ed image and j. Proposed- image.

Fig. 4. Contrast Enhancement results of the Birds Image. a. Original image; b. HE-ed image; c. BBHE-ed image; d. MMBEBHE-ed image; e. DHE-ed image; f. BPDFHE-ed image; g. RSWHE-ed image; h. ETHE -ed image; i. ESIHE -ed image j. Gamma correction -ed image, k. AGCWD-ed image and j. Proposed- image.

equalized the original histogram to preserve brightness, but the contrast of the resultant image, displayed in Fig. 2(f), was not sufficiently enhanced. The RSWHE technique was an improvement on the HE, but still some minor artefacts exist in the wall and tower regions as shown in Fig. 2(g). The ETHE method improved the contrast, as displayed in Fig. 2(h). Unfortunately, the enriched color seems unnatural when compared to that of the given image. The ESIHE technique did not preserve an adequate brightness of the given image, therefore making result with inadequate contrast, as displayed in Fig. 2(i). The GC and AGCWD techniques uniformly

Fig. 5. Contrast Enhancement results of the Flower Image. a. Original image; b. HE-ed image; c. BBHE-ed image; d. MMBEBHE-ed image; e. DHE-ed image; f. BPDFHE-ed image; g. RSWHE-ed image; h. ETHE -ed image; i. ESIHE -ed image j. Gamma correction -ed image, k. AGCWD-ed image and j. Proposed- image.

enhanced the image. Though, the produced histogram in Fig. 2(l) is more uniform than that in Fig. 2(i). The results from the proposed method, as displayed in Fig. 2(l), is the most colorful among the compared methods.

Fig. 3 shows resultant images obtained by the proposed and existing methods on 'house' image. From Fig. 3, we can see that the outputs based on HE, and BBHE seem to have higher contrast than the ones based on MMBEBHE and BPDFHE. However, the mean brightness of HE and BBHE deviate very much from the original image. Fig. 3(e) and (f) displays like appearances as observed by human viewers and are almost close to the original image. Results in Fig. 3(d) and (h) seem similar where from the perception of a human viewer the images are dusky and details are not clear. For the house image in Fig. 3(a), the result from RSWHE method illustrated in Fig. 3(g) demonstrated improved dim and bright areas where the brightness of the enhanced image does not correspond to that of the original one. From Fig. 3(i), we can see that ESIHE does not enhance the image much. The obtained output from the proposed method is illustrated in Fig. 3(l). It is perceived that image colors are brighter as compared to resultant images in Fig. 3(j) and (k) which are obtained from the gamma correction and AGCWD approaches.

Fig. 4 shows the contrast-enhancement results for the 'bird' image. It is observed that the results of HE (Fig. 4(b)), and BBHE (Fig. 4(c)) have experienced excessive change in brightness and result in the unnatural enhancement and an intensity saturated effect all over the image. This problem can be clearly demonstrated on the body of the 'bird' image in Fig. 4(b), and (c). In Fig. 4(d), MMBEBHE makes the stones around red bird very bright; hence, it has an unnatural look. The results (Fig. 4(e) and (f)) of DHE and BPDFHE show that they do not enhance the contrast significantly. For the RSWHE, and ETHE methods, the contrast of the images is significantly enhanced, but the intensity saturation problem occurs in and around red bird. This problem is also observed with results in Fig. 4(g), and (h). AGCWD technique performs well in contrast improvement than the ESIHE technique but still fails in preservation of mean brightness as displayed in Fig. 4(k). On the other hand, image enhanced by GC and AGCWD (Fig. 4(j)–(k)) displays the better result as compared to Bi-HE and Multi-HE methods but still, the visual artefacts are presented in the enhanced images, whereas proposed method (Fig. 4(l)) yield good quality images without incurring any unwanted visual artefacts.

Figs. 5 and 6 displays the enhancement results of the proposed method with existing algorithms. From the outputs of the proposed method, objects appear clearer and colors are also brighter as compared all other existing methods. Significant improvement is found in the contrast for all tested images. Therefore, it produces images without any loss in its natural appearance.

Fig. 7 displays the enhancement results of the proposed method with existing algorithms such as HE, GC and AGCWD for low illumination images. In Fig. 7, left column displays original images, second column displays HE images, third column displays gamma correction images, fourth column displays AGCWD images and right column displays results of the proposed method. Based on Fig. 7(b), the HE method is able to effectively improve the contrast of those images. However, it also magnifies the noise level of the

Fig. 6. Contrast Enhancement results of the Lady Image. a. Original image; b. HE-ed image; c. BBHE-ed image; d. MMBEBHE-ed image; e. DHE-ed image; f. BPDFHE-ed image; g. RSWHE-ed image; h. ETHE -ed image; i. ESIHE -ed image j. Gamma correction -ed image, k. AGCWD-ed image and j. Proposed- image.

Fig. 7. shows result of the proposed method with existing algorithms such as HE, Gamma correction and AGCWD for five different images. (First column: original images; enhanced image using: second column: HE; third column: Gamma correction; fourth column: AGCWD; fifth column: Proposed).

images. In Figs. 7(c) and (d), images seem brighter and are more attractive to human perception. The output from the proposed method is displayed in Fig. 7(e). Objects appear clearer and colors are also brighter as compared to GC and AGCWD results displayed in Fig. 7(c) and (d). The contrast for all tested images is significantly improved; therefore, producing result without losing their natural appearance.

The performance of the proposed technique is further assessed by collecting measurements in entropy, contrast, colourfulness and saturation as specified in expressions (19), (20), (21) and (25). The performance measures are summarized in Table 1. From the proposed method, 7.193 is the average entropy obtained and is found to be the maximum among all existing methods. While comparing the other existing techniques entropy of the proposed method is almost closer to the original image's entropy. Hence information content is preserved more. In our experiment 500 TID 2008 database images are tested and the average entropy of the proposed method is close to the input image when compared with other existing methods. Hence the proposed method preserves the maximum information content as compared to the existing methods. The HE and RSWHE techniques provide the maximum contrast measure while the proposed technique is the third highest. The proposed method yields highest colorfulness measure at 0.320 and hence the proposed algorithm grabs more natural color contents from the input image. The resultant image also shows adequate performance in viewing. AGCWD method produces best saturation and 0.560 is the amount of metric obtained from this method. The saturation of the proposed technique is at 0.545 falling in the above mid-range of the performance measures. The enhanced images from the proposed system are restricted in the abrupt modification of intensity levels, saturation values are almost retained closed to the original values.

To evaluate the computational complexity, all the enhancement algorithms are run on a personal computer with spec Intel i5 processor @ 2 GHz with 8 GB RAM. MATLAB R2013a software platform is used for evaluating the algorithms. An average of 500 TID 2008 database images are taken for measuring the computation time. For computational time shown in Table 2, HE, BBHE and

Table 1
illustrates average value of performance measures for 500 TID 2008 database images.

Methods	Performance Measures			
	Entropy	Contrast	Colorfulness	Saturation
Input	7.190	0.691	0.249	0.548
HE	6.991	**0.773**	0.167	0.521
BBHE	7.210	0.712	0.221	0.523
MMBEBHE	7.122	0.711	0.287	0.529
RSWHE	6.181	0.771	0.255	0.525
DHE	6.211	0.739	0.296	0.501
BPDFHE	7.121	0.721	0.189	0.481
ETHE	7.061	0.738	0.223	0.485
ESIHE	7.089	0.721	0.259	0.509
AGC	6.912	0.731	0.288	0.557
AGCWD	7.197	0.747	0.317	**0.560**
Proposed	**7.193**	0.749	**0.320**	0.545

Table 2
Quantitative comparison in computational time (sec) of various enhancement algorithms for an average of 500 TID 2008 database images.

Algorithms	HE	BBHE	MMBEBHE	DHE	BPDFHE	RSWHE	ETHE	ESIHE	GC	AGCWD	Proposed
Average Computational time (sec)	0.151	0.252	0.263	0.291	0.277	0.312	0.391	0.364	0.302	0.351	0.275

MMBEBHE algorithms attain best values due to its low complexity. However, these methods yield the results that are excessively enhanced and has insignificant contrast improvement. BPDFHE has the computational time as close when compared with the proposed method but, the output image results with undesired artefacts and also hue of the original image is not preserved. Nevertheless, the average computational time of our proposed method is 0.275 s, this value indicates that our proposed method can effectively improve the valuable information and the quality of the image gets improved.

6. Conclusion

An efficient and effective image enhancement method is proposed based on an improved adaptive gamma correction and Histogram Equalization. The experiments were conducted on benchmark test images with subjective and objective measures to demonstrate the significance of proposed approach. Extensive subjective experiments demonstrate that proposed method preserve natural colors more accurately than other histogram-based methods. Proposed method outperformed the other existing enhancement methods in terms of entropy, colorfulness and Histogram Utilization Efficiency. The low contrast color images are enhanced effectively and efficiently without incurring annoying artefacts. Experimental results have proved that the proposed method outshine the state of art methods with regard to colorfulness, information content, and contrast enhancement.

Declarations of interest

The authors declare that there is no conflict of interest for publication of this manuscript.

References

[1] M. Kanmani, V. Narsimhan, An image contrast enhancement algorithm for grayscale images using particle swarm optimization, Multimed. Tools Appl. (2018), https://doi.org/10.1007/s11042-018-5650-0.
[2] C. Akila, R. Varatharajan, Color fidelity and visibility enhancement of underwater image de-hazing by enhanced fuzzy intensification operator, Multimed. Tools Appl. 77 (2018) 4309, https://doi.org/10.1007/s11042-017-5187-7.
[3] Shubhi Kansal, Shikha Purwar, Rajiv Kumar Tripathi, Image contrast enhancement using unsharp masking and histogram equalization, Multimed. Tools Appl. 77 (2018) 1–20.
[4] ChinYeow Wong, Guannan Jiang, ArifurRahman Md, Histogram equalization and optimal profile compression based approach for color image enhancement, J. Vis. Commun. Image R. 38 (2016) 802–813.
[5] M. Shakeri, M.H. Dezfoulian, H. Khotanlou, A.H. Barati, Y. Masoumi, Image contrast enhancement using fuzzy clustering with adaptive cluster parameter and sub-histogram equalization, Digit. Signal Process. 62 (2017) 224–237.
[6] Mohammad Farhan Khan, Ekram Khan, Z.A. Abbasi, Segment dependent dynamic multi-histogram equalization for image contrast enhancement, Digit. Signal Process. 25 (2014) 198–223.
[7] Y.T. Kim, Contrast enhancement using brightness preserving bi-histogram equalization, IEEE Trans. Consum. Electron. 43 (1) (1997) 1–8.
[8] Yu Wang, Q. Chen, B. Zhang, Image enhancement based on equal area dualistic sub-image histogram equalization method, IEEE Trans. Consum. Electron. 45 (1) (1999) 68–75.
[9] S.D. Chen, A. Ramli, Minimum mean brightness error Bi-Histogram equalization in contrast enhancement, IEEE Trans. Consum. Electron. 49 (4) (2003) 1310–1319.
[10] M. Kim, M.G. Chung, Recursively separated and weighted histogram equalization for brightness preservation and contrast enhancement, IEEE Trans. Consum. Electron. 54 (3) (2008) 1389–1397.
[11] M. Abdullah-Al-Wadud, M. Ali AkberDewan, M. HasanulKabir, O. Chae, A dynamic histogram equalization for image contrast enhancement, IEEE Trans. Consum. Electron. 53 (2) (2007) 593–600.
[12] Debdoot Sheet, Hrushikesh Garud, Amit Suveer, Brightness preserving dynamic fuzzy histogram equalization, Ieee Trans. Consum. Electron. 56 (4) (2010) 2475–2480.
[13] Tarik Arici, Salih Dikbas, Yucel Altunbasak, A histogram modification framework and its application for image contrast enhancement, IEEE Trans. Image Process. 18 (9) (2009) 1921–1935.
[14] Chi-Chia Sun, Shanq-Jang Ruan, Mon Chau Shie, Dynamic contrast enhancement based on histogram specification, IEEE Trans. Consum. Electron. 51 (4) (2005) 1300–1305.
[15] Kuldeep Singh, Rajiv Kapoor, Image enhancement using exposure based sub image histogram equalization, Pattern Recognit. Lett. 36 (15) (2014) 10–14.
[16] K. Singh, R. Kapoor, S. Sinha, Enhancement of low exposure images via recursive histogram equalization algorithms, Optik 126 (20) (2015) 2619–2625.
[17] Zhenghua Huang, Tianxu Zhang, Qian Li, Adaptive gamma correction based on cumulative histogram for enhancing near-infrared images, Infrared Phys. Technol. 79 (2016) 205–215.
[18] S.-C. Huang, F.-C. Cheng, Y.-S. Chiu, Efficient contrast enhancement using adaptive gamma correction with weighting distribution, IEEE Trans. Image Process. 22 (4) (2013) 1032–1041.
[19] D. Hasler, S.E. Suesstrunk, Measuring colorfulness in natural images, Electronic Imaging 2003, Int. Soc. Opt. Photon. (2003) 87–95.
[20] G. Jiang, C.Y. Wong, S.C.F. Lin, Image contrast enhancement with brightness preservation using an optimal gamma correction and weighted sum approach, J. Mod. Opt. (2015), https://doi.org/10.1080/09500340.2014.991358.