A new image enhancement method considering both dynamic range and color constancy

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A new image enhancement method considering both dynamic range and color constancy

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Abstract: This paper proposes an approach to improve color images suffering from low dynamic range, by employing both histogram matching and histogram stretching techniques. Firstly, the color image is transformed from RGB into HSV color space, in which the color information is separated from intensity. Then, an appropriate reference image is selected by comparing component V of the enhancing image with component V of the database images using a similarity measure. This selected image is used as the target image in histogram matching algorithm to enhance image. Secondly, components V and S are linearly stretched in order to recover the image color information. Finally, using the treated V and S components and untreated component of H, the enhanced image is obtained in RGB color space by inverse transform. The qualitative and quantitative results show that the contrast and color of resultant images are greatly improved using the proposed method, which outperforms the current state-of-the-art methods.

Key words: image enhancement, histogram matching, similarity measure, histogram stretching.

1. Introduction

Images are captured using various photography tools that may not necessarily be in high-quality. The color shifting problem causes the captured image appears in low contrast and low color dynamic range, resulting in the images with important information lost. Therefore, image enhancement plays a vital role in various applications such as satellite imaging [1], medicine [2], and geography image acquisition [3]. It is the process of enhancing the visual information within the image. Existing image enhancement methods can be classified in three main categories [4]: histogram equalization techniques, Retinex-based algorithms [5-6], and unsharp masking techniques [7-8].

Contrast enhancement may be considered as a front-end solution in image enhancement to elicit important information from a low quality image taken in unsuitable conditions. Among various functions affecting on contrast improvement, histogram equalization and histogram matching are the most common methods due to the simplicity and high efficiency [9-10]. Since image histogram is a useful description to display the information in an image, different histogram-based methods have been introduced to enhance image contrast. Celik proposed a two-dimensional histogram equalization method which employs the contextual information around each pixel to improve the contrast of an input image [11]. In another study, the contrast of an image is enhanced using spatial information of pixels [12]. This technique uses spatial distribution of pixel gray levels, i.e. the distribution of spatial locations of gray levels of an image instead of gray-level distribution, to compute the spatial entropy of pixels. Kwak and Park introduced a contrast enhancement technique using multi-local histogram transformations for supervisory systems [13]. Recently, Wang et al. have proposed a novel histogram modification scheme which improves image contrast [14]. The modified histogram is generated by Gamma correction, and the mapping function is obtained by applying histogram equalization on modified histogram. Finally, the image is enhanced uniformly while retaining the mean illumination. Although an acceptable image is obtained from these enhancement methods but the details of image cannot promote well [15]. Therefore, other methods have been developed that enhance the image contrast using other techniques such as bionic algorithms like bee colony algorithm [16] and genetic algorithm [17] or by wavelet transform and entropy [18]. This study scales the high-frequency coefficients of the image in wavelet domain due to magnified entropy which can enhance the contrast.

Different techniques have also been introduced for improving color of images, based upon the models of subjective human color vision. An iterative histogram matching algorithm was presented for color image enhancement based on statistical moments [19]. A texture based color image enhancement methodology was proposed by Raji et al. that focuses on an automated way for target image generation [20]. An adaptive enhancement algorithm based on HSV color space was proposed for enhancement of low illumination color images [21]. A method was proposed for low contrast color images enhancement using histogram and fuzzy logic [22]. The method operates based on two important parameters, illumination and contrast level in HSV color space. A kind of contrast resolution compensation algorithm has been presented that operates based on human visual perception model [23]. In this approach, the image is transferred from RGB to HSV color space, then components of V and S are processed to enhance image brightness and to recover the image color information. Recently, authors of [24] have proposed a fusion-based method to enhance the weakly illumination images. After estimating the illumination by a morphological algorithm, a strategy based on weighting and fusion is used to improve the illumination. Sun et al. have presented a novel image enhancement approach based on illumination-reflection model [25]. This study applies nonlinear functions to extract the reflection component which preserves the important features of edges of image and improves the image. An image enhancement method has been proposed by Guo et al. that enhances the visibility of image by changing the R, G, and B channels and building new illumination map [26]. A trainable convolutional neural network has been presented that is able to obtain the illumination map from input image and then improves the image based on Retinex model [27].

As mentioned, although there are various image enhancement methods, it sounds necessary to develop the more efficient one than the existing methods; since the majority of existing methods have two main problems: first, some of these methods enhance image which the resultant does not seem natural [28]. Second, some techniques can just improve the outdoor images [29].

A two-stage technique is proposed in this paper to enhance both the contrast and color of an image. In the first stage, after converting RGB images to HSV color space, the contrast of image is enhanced using automatic histogram matching. The color shifting effect would be more obvious in the contrast enhanced image compared to the original one. Hence, another method is applied to improve image color. The histograms of the V and S components of the image are stretched which its contrast was improved in the first stage.

The rest of the paper is organized as follows: Section 2 introduces the reference images database; the used similarity measure is presented in Section 3; Section 4 describes the proposed method and its algorithm. The results of applying the proposed method on several images and conclusion are respectively provided in Sections 5 and 6.

2. Material and methods

2.1. Reference images database

For automatic selection of the target image in histogram matching, well-contrast images from various scenes are required to enable the system to choose the most proper image. There is no general suitable database which we can use in our work. Hence, we have provided a database of 85 images. The database includes images of forest landscapes, waterfall and rivers in different seasons, human faces and people with proper contrast. Some of the images (74 images) were collected from the internet by querying several image search engines. The database has diversity and was constructed with different objects in various appearances, positions, viewpoints, poses as well as background clutter and occlusions. The rest are images taken from NASA [30]. Some of database images are shown in Figure 1. Our experiments will show that our collected database is suitable to enhance images via histogram matching.

2.2. Similarity Measure

In order to measure the similarity between two histograms, a similarity measure can be used. There are many similarity measures, each of which is appropriate for a certain application [31-32]. In this study, Jensen similarity measure is used to measure the similarity between histograms of the original and the target images [33-34]. This measure is a useful tool for assessing the similarity of time series with the same length but various amplitudes, which is the case in measuring the similarity between histograms.

For two verctors $\boldsymbol{P} = \{\boldsymbol{p_1}\ \boldsymbol{p_2}\ \ldots\ \boldsymbol{p_k}\}$ and Q= $\{\boldsymbol{q_1}\ \boldsymbol{q_2}\ \ldots \boldsymbol{q_k}\}$ associated with the histograms of two images, the Jensen function is defined as below:

$$\boldsymbol{J} = \frac{1}{2}\sum_{i=1}^{k}\left\{\boldsymbol{p}_i' \boldsymbol{log_2 p}_i' + \boldsymbol{q}_i' \boldsymbol{log_2 q}_i' - (\boldsymbol{p}_i' + \boldsymbol{q}_i')\boldsymbol{log_2}\left(\frac{\boldsymbol{p}_i' + \boldsymbol{q}_i'}{2}\right)\right\} \quad , \qquad (1)$$

$$\boldsymbol{where} \quad \boldsymbol{p}_i' = \boldsymbol{p}_i / \sum_{i=1}^{k} \boldsymbol{p}_i \ , \quad \boldsymbol{q}_i' = \boldsymbol{q}_i / \sum_{i=1}^{k} \boldsymbol{q}_i$$

The output of the Jensen function is between 0 and 1. If the two sequences P and Q are identical or very similar, the output of the Jensen function will be equal to 0.

Figure 2 shows three histograms associated with three different images. Similarity of the three histograms has been measured using the Jensen function. As seen, the calculated similarity value is a smaller number for the histograms which are more similar to each other.

2.3. The proposed method

Images suffering from low contrast are often accompanied with color shifting effect. Therefore, for improving the images, it is needed to enhance both the color and contrast. We propose to enhance the low dynamic range images in a two-stage approach.

In the first stage, for improving contrast, we use a histogram matching technique in which the reference image is automatically chosen from the database. In this approach, the images are considered in HSV color space. HSV contains three components: H (hue) refers to color wavelengths, S (saturation) indicates the ratio of the dominant wavelength to other wavelengths in the color, and V (value) determines lightness or darkness of a color. In enhancing the contrast of an image, the lightness (i.e. component V) of the images should be taken into account. Hence, by comparing the V component of the input image and the images in the database using Jensen, an image which has more similar brightness to the original image is selected as the target image for histogram matching. Finally, the image contrast is enhanced by applying the histogram matching technique to the V component of the image.

As the brightness of the image after applying the first stage is improved, the existence of color shifting effect would be more obvious in the contrast enhanced image. Hence, it may also be required to improve the color information of the image, where the second image enhancement stage is applied.

In the second stage, we use the histogram stretching technique, min-max based sub-image-clipped introduced in [35]. We obtain the histograms of components S and V of the image resulted from the first step. Then, we find the maximum and minimum points in each histogram. The minimum intensity point, i_{min} refers to the lowest intensity value in the image histogram, whereas the maximum intensity value, i_{max} refers to the highest intensity value in the image histogram. The mid-point of the intensity level, i_{mid} of a histogram is calculated using equation (2). Figure 3 illustrates an example of these points in a histogram.

$$i_{mid} = \frac{i_{max} - i_{min}}{2} + i_{min} \qquad (2)$$

Since brightness of image is shown in component V, we then process the V component to overcome under or over-enhanced areas possibly resulted in the first step. The S component is also processed for improving the color information of the image. Hence, each histogram is divided into two regions, lower and upper regions. Each region is then stretched as follow:

a) The lower region, from i_{min} to the mid-point, i_{mid}, is stretched towards the higher intensity-level with the minimum output value of 1% from the minimum intensity value of the dynamic range.
b) The upper region, from i_{mid} to the maximum intensity-value, i_{max}, is stretched towards the lower intensity-level with the maximum output value of 1% from the maximum intensity value of the dynamic range.

The above limits are set in order to avoid the S and V components exceed from their minimum and maximum values which could lead to under- and over-brightness of the image. The stretching (1%) is done to decrease the effect of dominant color channels. This limiting is empirically chosen. The resultant images with a bigger limiting value are very over-enhanced. Figure 4 illustrates this stretching process for a given histogram.

The stretching process produces two stretched histograms, associated with the S and V components. The lower- and upper-stretched histograms of S are integrated by means of average value, as shown in equation (3).

$$\boldsymbol{average} = \frac{(\boldsymbol{lower\_stretched\ histogram})+(\boldsymbol{upper\_\ stretched\ histogram})}{\mathbf{2}} \qquad (3)$$

The same integration process is applied to component V where the lower- and upper-stretched histograms are integrated. Then, H, S, and V components are composed to produce an image in HSV color model. Finally, the enhanced image is converted to RGB by inverse transform. Figure 5 shows resultant images after applying each step to the image. The effect of stretching 1% on the histograms is clear in this figure.

As mentioned, in the first stage, image contrast is enhanced based on the chosen target image, and as a result, this process probably interferes the color purity in some regions. Therefore, in the second stage, we simultaneously change the histogram of both components S and V of the image produced from the first stage; in order to solve this possible problem. Indeed, the process in the second stage resolves the problem of under- and over-enhanced regions.

The execution time of the proposed method is reasonable. The average of execution time per different images in average size 838*627 is 10 seconds in a system characterized 4GB RAM, Intel core i2, 2.10 GHz CPU. Also, if we save the histograms of the database images, the average of execution time decreases nearly 2.06 seconds.

3. Results

We have considered several images in RGB color space to examine the capability of the proposed method in image enhancing. Figure 6 shows the results of applying the proposed method on a number of images. As seen, all of the processed images have considerably a better contrast with a more pleasant color.

To compare the results of the proposed method with the results of other existing methods, we choose the methods introduced in [18], [21-22] and [25-27] which are used to enhance color images. In addition to these techniques, the proposed method is also compared with CLAHE* [36] method that is widely used by other researches in their comparison.

We evaluate the proposed method based on qualitative observation and quantitative measurements. Through the quantitative analysis, the proposed method is evaluated in terms of entropy, MSE, PSNR, SSIM and Sobel edge detection. Entropy can be considered as corresponding states of gray-level which individual pixels can acquire [37]. Entropy represents the abundance of image information. MSE and PSNR are two error metrics used in order to compare the quality of resultant images. The SSIM considers image degradation in structural information. To evaluate the capability and performance of the proposed method, several researchers used edge detection on the basis of the number of edges found in an image [38-39]. This is carried out by counting the number of edges detected using Sobel edge detector. A high number of edges is desired as it shows that the image has a high feature content. However, the number of counted edge should be balanced with the value of MSE or PSNR. Therefore, the high number of Sobel edge should be balanced with the low value of MSE (or high value of PSNR).

To indicate the contribution of the first stage, we show the results of only performing the second stage, both qualitatively and quantitatively in Figure 7. Both of the results show that the first step has a positive effect. Besides good contrast and color, PSNR, SSIM and Entropy show the resultant images after applying two stages keep structure and information of original image well.

4. Discussion

* Contrast-limited adaptive histogram equalization (CLAHE)

Figures 8 and 9 show three images which are enhanced by the introduced methods. These figures show that the details are seen in high resolution. Also, details of the enhanced images by the proposed method are more obvious. Quantitative results of the sample images in Figures 8 and 9 are provided in Table 1 and 2. Table 3 shows the quantitative average results obtained from comparing the proposed method with other studies by applying them on 200 images from MIT-Adobe FiveK Dataset [40]. The high values of entropy, PSNR, SSIM and Sobel edge detection are desired as they show that the images contain more information features. On the other hand, the low value of MSE is desired as it shows that the resultant image contains less noise. In Tables 1, 2 and 3, the bold typeface values indicate the best results obtained in the comparison.

As the second image in Figure 8 shows, the outcome image of the method in [21] is very bright that looks unnatural while the sun is shining at the time the photo is taken. The entropy of results obtained using the method in [21] shows that it is not as successful in providing information as other methods. It has the lowest value after CLAHE. The images produced by CLAHE have a good contrast as the resultant image is clearly seen. However, from the observation, the quality of image color is reduced.

For the CLAHE method, the over-enhanced problem could be observed in the resultant image of Figure 8, first image. The tree areas on the left of house become darker and the tower is over-saturated as the pixels are too bright. This effect causes the image to lose its details. The quantitative result agrees with the observation as the entropy value of the resultant image produced by CLAHE is the lowest. The highest Sobel count shown by CLAHE may result from the noise produced in the process as the resultant image has the highest MSE value. The proposed method is observed enhancing the image better as the resultant image contrast is balanced, where the areas are not too dark or too bright. The proposed method significantly increases the image contrast at the fore- and background since both areas are significantly enhanced. This observation is supported by quantitative result due to the fact that the resultant image produced by the proposed method has the highest entropy value. In addition to the highest entropy value, the proposed method almost has the lowest MSE and the highest PSNR and SSIM. As seen in Figure 9, the resultant image from the proposed method seems natural and details of images are obvious. For instance, in the third image the signs and lights besides of road are shown clearly. Moreover, it is clear that the resultant images by applying [26] in Figure 9, first and second are just enhanced contrast and the brightness and quality of images are not proper. In fact, they do not seem natural. By looking at average results in Table 3, the superiority of proposed method is noticeable due to having highest values in measurements compared to other techniques. As said before, the proposed method has a reasonable processing time. Table 4 shows a comparison of execution time between the proposed method and other state-of-the-art techniques. All methods are applied in a computer with Intel core i2, 2.10 GHz CPU and 4 GB RAM and the processing time of images with size of 838*627 is measured. It is noticeable that the proposed method is the least time-consuming method compared to other techniques due to using uncomplicated algorithms for enhancing images rather than evolutionary algorithms or neural networks.

5. Conclusion

We proposed a method which can enhance both contrast and color of images suffering from low contrast or low color dynamic range. In a two-stage method, after converting the RGB images to HSV, an automatic method for selecting target image in histogram matching was suggested and the contrast of input image is enhanced. The target image is automatically selected from the database containing 85 reference images using a similarity measure. In the second stage, the histogram stretching is then employed to correct the color of the contrast enhanced image. We have shown the success of this method for contrast and color enhancement by comparing the results of the proposed method with eight other existing methods. Likewise, it can enhance improper contrast and color images.

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Figure 1: Sample images from our database.

Figure 2. (a) Histogram of the original image, (b) Histogram with less similarity (J=0.24) to histogram (a), (c) Histogram with more similarity (J=0.019) to histogram (a).

Figure 3. Illustration of the maximum, minimum, and mid-points of an image histogram.

Figure 4. Illustration of division and stretching of histogram to produce lower- and upper-stretched regions.

Figure 5. The illustration of applying the second stage of the proposed method to an image.

Figure 6. Result of applying the proposed method on images, the top row contains the original images and the second row shows enhanced images by the proposed method.

Figure 7. The top row shows resultant images using only the second stage of the proposed method, and the second row shows results of the proposed method (applying both the first and second stages).

Figure 8. (b)- (h): result of applying the methods introduced in [21], [22], CLAHE [36], [18], [25] and the proposed method to image (a), respectively.

Figure 9. (b)- (e): result of applying the methods introduced in [24], [26], [27], and the proposed method to image (a), respectively.

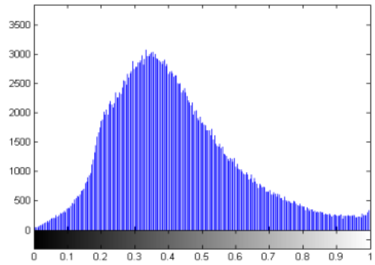
Table 1. Quantitative results of the sample images in Figure 8. (High values of PSNR, SSIM, and entropy show more successful methods.)

Table 2. Quantitative results of the sample images in Figure 9. (High values of PSNR, SSIM, and entropy show more successful methods.)

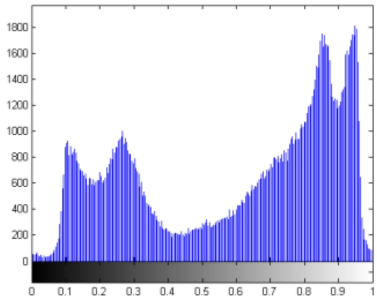
Table 3. Average quantitative results of 200 images in MIT-Adobe FiveK Dataset [40] in comparison to other researches.

Table 4. Processing time in (s) for various image enhancement methods.

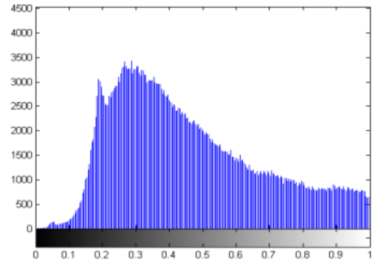
Fig 1



(a)



(b)



(c)

Fig 2

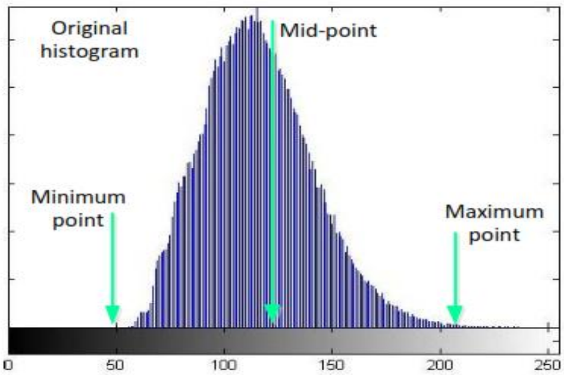


Fig 3

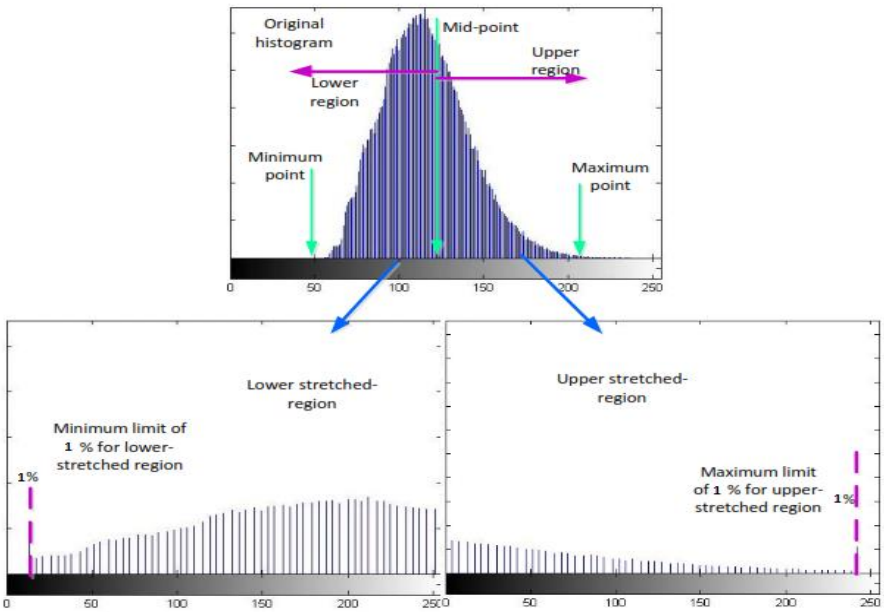
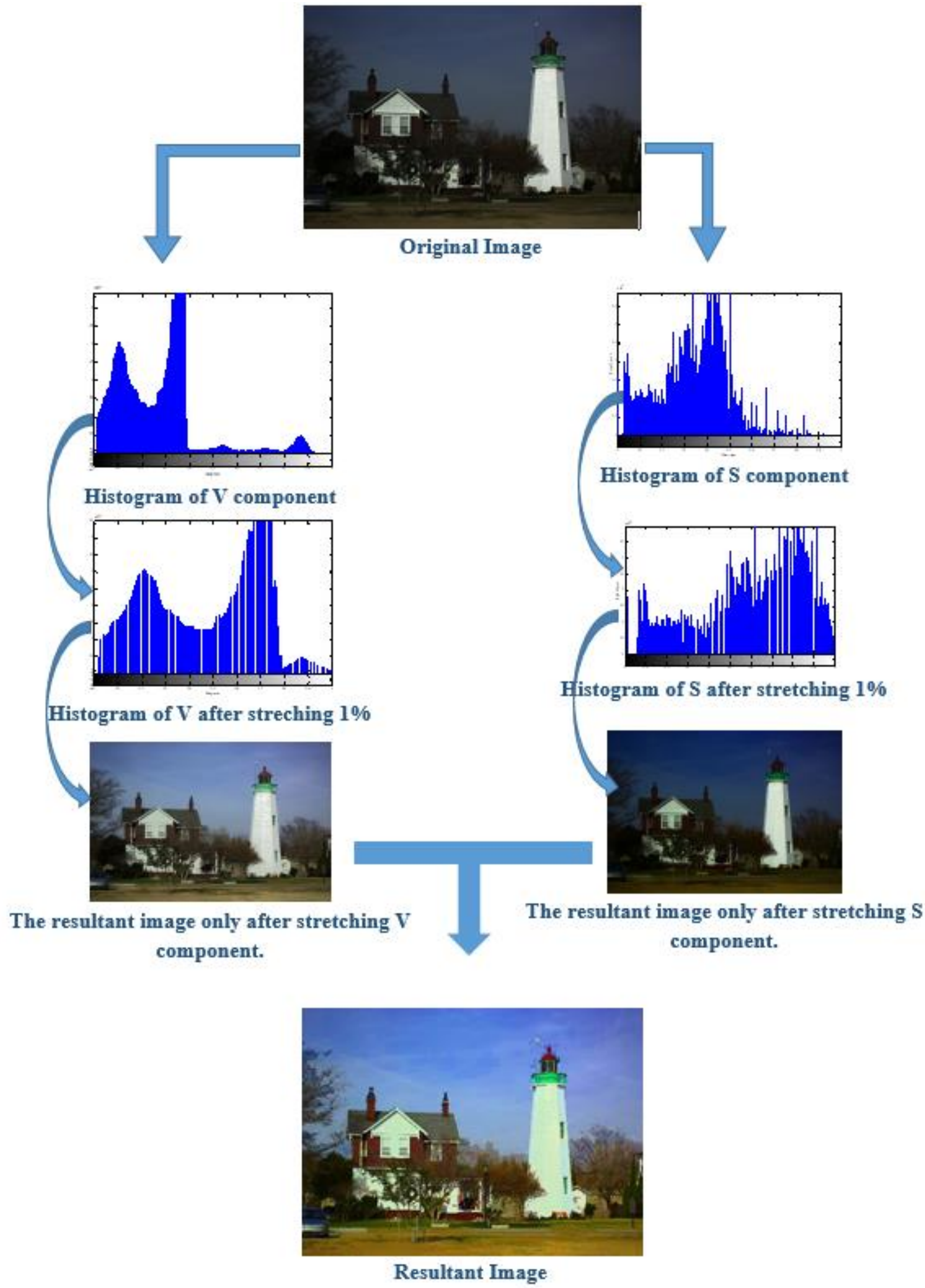

Original histogram
Mid-point
Upper region
Lower region
Minimum point
Maximum point
0
50
100
150
200
250
Lower stretched-region
Minimum limit of 1 % for lower-stretched region
1%
Upper stretched-region
Maximum limit of 1 % for upper-stretched region
1%

Fig 4


Original Image
Histogram of V component
Histogram of V after streching 1%
The resultant image only after stretching V component.
Histogram of S component
Histogram of S after stretching 1%
The resultant image only after stretching S component.
Resultant Image

1

2 Fig 5

Fig 6

Psnr=63.12
Entropy= 7.45
Mse=0.0311
SSIM= 0.85
Edge Count=5295

Psnr=62.20
Entropy=7.57
Mse=0.0371
SSIM= 0.87
Edge Count=4589

Psnr=72.80
Entropy=7.25
Mse=0.0040
SSIM=0.78
Edge Count=13370

Psnr=72.11
Entropy=7.02
Mse=0.0050
SSIM=0.81
Edge Count=1476

Psnr=68.34
Entropy=7.76
Mse=0.0095
SSIM= 0.91
Edge Count=5257

Psnr=69.94
Entropy=7.77
Mse=0.0072
SSIM= 0.93
Edge Count=3818

Psnr=74.78
Entropy=7.44
Mse=0.0024
SSIM=0.81
Edge Count=14217

Psnr=74.36
Entropy=7.43
Mse=0.0026
SSIM=0.84
Edge Count=2441

Fig 7

(a) (b) (c) (d) (e) (f) (h)

Fig 8

(a) (b) (c) (d) (e)

Fig 9

	Method	Entropy	MSE	PSNR	SSIM	Sobel Count
Figure 8- first image	Original Image	7.1455	-	-	-	3314
	[18]	7.7265	6852.4	13.845	0.93	4145
	[21]	4.9553	9189.9	8.4982	0.92	7233
	[22]	7.7529	7325.3	14.459	0.87	2071
	[25]	6.8885	3017.2	16.5804	0.84	5033
	CLAHE [36]	3.9345	9597.1	8.3096	0.72	6673
	Proposed method	**7.8516**	**2330.2**	**19.487**	**0.98**	**3818**
Figure 8- second image	Original Image	6.9816	-	-	-	2567
	[18]	7.5821	3295.6	13.105	0.91	2754
	[21]	4.9185	8862.5	8.6553	0.89	6126
	[22]	7.7342	3476.0	12.725	0.82	1864
	[25]	6.8817	4602.2	12.7849	0.88	4624
	CLAHE [36]	3.9417	9376.7	8.4106	0.68	6135
	Proposed method	**7.8438**	**2788.3**	**13.706**	**0.94**	**3858**
Figure 8- third image	Original Image	6.9312	-	-	-	3796
	[18]	6.9541	2045.1	16.485	0.92	2415
	[21]	4.9185	8174.0	9.0075	0.89	6126
	[22]	7.7342	2175.5	17.083	0.87	1864
	[25]	6.8817	7901.9	16.1554	0.84	6624
	CLAHE [36]	3.9417	8680.7	8.7466	0.72	6135
	Proposed method	**7.8438**	**1276.3**	**17.758**	**0.96**	**3858**

Table 1

	Method	Entropy	MSE	PSNR	SSIM	Sobel Count
Figure 9- first image	Original Image	7.2965	-	-	-	3241
	[24]	7.5295	3484.6	15.8145	0.89	4885
	[26]	7.3573	3125.9	16.4582	0.93	2233
	[27]	7.7249	2825.7	16.9939	0.91	2151
	Proposed method	**7.8974**	**1904.0**	**18.487**	**0.97**	**3584**
Figure 9- second image	Original Image	7.4152	-	-	-	3574
	[24]	7.4225	3425.7	11.454	0.85	2755
	[26]	7.3685	3162.4	11.783	0.87	3961
	[27]	7.4745	3067.0	12.051	0.88	3445
	Proposed method	**7.7148**	**2888.4**	**12.460**	**0.92**	**3682**
Figure 9- third image	Original Image	6.8974	-	-	-	2748
	[24]	6.4511	1842.7	16.845	0.81	1847
	[26]	6.9815	1674.9	17.425	0.88	3050
	[27]	6.8432	1552.8	17.934	0.92	2185
	Proposed method	**7.1348**	**1347.4**	**18.382**	**0.98**	**2876**

Table 2

Method	Entropy	MSE	PSNR	SSIM	Sobel Count
Original Image	7.2533	-	-	-	3238
[18]	7.7304	4525.7	14.7466	0.85	1936
[21]	7.0645	3515.4	16.1452	0.89	4201
[22]	4.9407	8741.13	8.7303	0.87	6495
[25]	6.8839	4507.1	17.4504	0.90	4565
CLAHE [36]	3.7693	9216.4	8.8448	0.68	6214
Proposed method	**7.8564**	**2031.6**	**17.9863**	**0.94**	**3849**

Table 3

[14]	[16]	[18]	[24]	[25]	The proposed method
3.875	885.73	4.7	3.17	4.36	2.06

Table 4

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