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Color Retinal Image Enhancement by Rayleigh Contrast-Limited Adaptive Histogram Equalization

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Abstract: Retinal fundus image is important for ophthalmologist to identify and detect many vision-related diseases, such as diabetes and hypertension. From an acquisition process, retinal images often have low gray level contrast and low dynamic range. This paper proposes a method using improved nonlinear hue-saturation-intensity color model(iNHSI) to preserve color information of the retinal images. The intensity component is enhanced by Rayleigh transformation in contrast-limited adaptive histogram equalization (Rayleigh CLAHE) algorithm. This algorithm help to increase the contrast and improve the overall appearance. The proposed algorithm was tested by using standard public database for benchmarking diabetic retinopathy detection from digital image. The proposed method can preserve the original hue component unchanged; because, the hue information of the input images is important to ophthalmologist in diagnosis process.

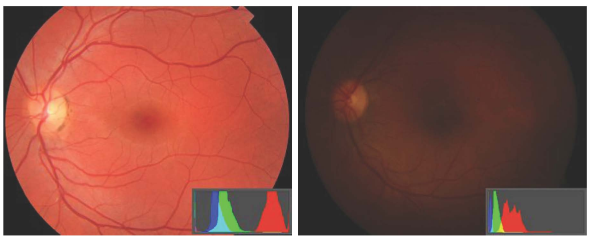
Keywords: Gamut problem, improved nonlinear HSI color model (iNHSI), Rayleigh Contrast-limited Adaptive Histogram Equalization (Rayleigh CLAHE).

1. INTRODUCTION

Digital color fundus imaging in ophthalmology plays an important role in medical diagnosis of several pathologies, for example, hypertension, diabetes, and cardiovascular disease [1]. Computer-aided image analysis of the fundus image or retinal image is widely used as a diagnostic tool for gathering important information from patient with retinopathy. The retinal image is very important for the doctors to be able to clearly detect and recognize the lesions among the numerous capillary vessels and optic nerve presented in the images. However, some retinal images acquired from a fundus camera often have low grey level contrast and low dynamic range as shown in Fig. 1.

Contrast enhancement is a technique applied to a digital image to qualitatively improve the contrast of image. This technique allows modified manipulation of the dynamic range such that the results are more informative for human eye. The classical contrast enhancement is Histogram Equalization (HE) [2] which has good performance in ordinary images, such as human portraits or natural images. However, HE is not a good choice for the retinal images due to its amplification of the noise and the absence of some brightness levels after enhancement [3]. HE has been generalized to a local histogram equalization which is known as adaptive histogram equalization (AHE) [2]. AHE is based on HE that the adaptive method formulates each histogram of sub-image to redistribute the brightness values of the images. AHE is therefore suitable for improving the local contrast of an image and bringing out more details. However, The problem remain the same with the global histogram equalization because of amplifying noise in relatively homogeneous regions. In order to overcome this problem, contrast limited adaptive histogram equalization (CLAHE) was proposed [4].

CLAHE based enhancement was used to improve a retinal image. Shome and Vadali [5] engaged CLAHE to enhance the diabetic retinopathy image; however, their methods had to remove noise by median filter. Setiawan et al. [6] proposed a method to improve the contrast of color retinal image by enhancing green channel in red-green-blue(RGB) color model by using CLAHE. The effect of enhancing only the green band made the results more greenness and destroyed the chromatic information.



(a) Normal eye (b) Poor quality

Fig. 1 Retinal images.

Considering a diagnosis of a color retinal image, chromatic information provides a major factor to identify the lesions of the retinopathy images. This paper proposes a method to preserve the chromatic information and to improve contrast of color retinal image. The proposed method keeps the chromatic data by operating the images in improved nonlinear hue-saturation-intensity (iNHSI) color model [7]. The intensity component was selected to enhance by Rayleigh transformation [8] based on CLAHE method to increase the contrast and to improve the overall appearance. In our algorithm, the input image was analysed the exposure status to declare some parameters of CLAHE. On the other hand, the noise in the background image was suppressed by a linear contrast stretch of the transfer function of Rayleigh-CLAHE.

The organization of this paper is as follows. Section 2 describes the proposed algorithm to enhance the color retinal image. The experimental results are presented in Section 3. The conclusions are discussed in Section 4.

2. PROPOSED ALGORITHM

An algorithm to enhance a color medical image has to preserve the chromatic information to support the correct decision of a doctor in the image diagnosis step. In our algorithm, color model no gamut problem, iNHSI, is provided to keep the chromatic information. To improve the contrast of the color retinal image, the intensity component is employed to enhance by using Rayleigh CLAHE.

The proposed algorithm is illustrated in Fig. 2. In the algorithm, a color retinal image is transformed from RGB to iNHSI color model. The chromatic data(hue and saturation) are preserved and the intensity component, I, is employed to enhance the contrast of the color retinal images. The intensity, I, is the analysed brightness levels which are classified into two categories of exposure levels: under-exposure, and over-exposure. The exposure levels are used to declare a set of paraments of CLAHE that consist of clip-limit value and α value in Rayleigh distribution. Finally, new intensity, I', which was enhanced, is provided to combine with the hue and saturation components to invert the transformation to RGB color model.

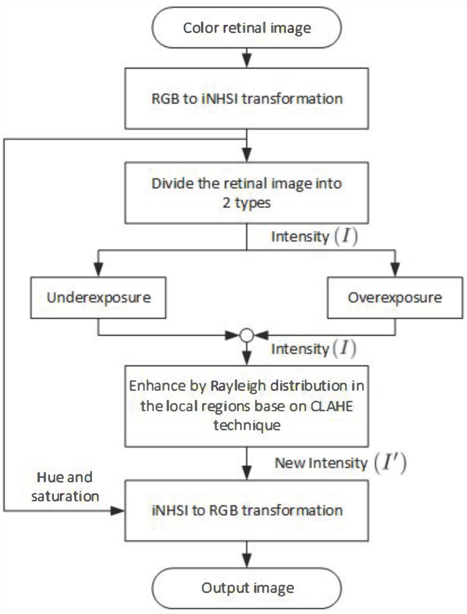


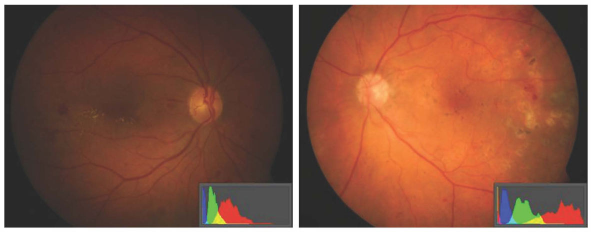
Fig. 2 Flow Chart of the proposed algorithm.

2.1 Nonlinear HSI color model

A perceptual color model, HSI(Hue, Saturation, Intensity), is widely used in color image processing [9]. In our color image enhancement, the intensity values are modified. When HSI is transformed back to RGB color model for displaying, out-of-gamut problem is usually occurred because some color pixel values are out-of-range of the RGB color space. To avoid this problem, iNHSI color model [7] is provided to preserve the color information of the retinal images.

2.2 Color Retinal Image Exposure

An image capturing device is sensitive to light. If the light is less than necessary, the image will be under-exposure; vice versa, if the light is more than necessary, the image will be over-exposure. Fig. 3 illustrates two color retinal images, which represent the under and over exposure as shown in the figures (a) and (b), respectively. As seen in the histograms of the images, the red band of the color retinal images usually has higher intensity levels than the others. The under-exposure image does not have an effect of out-of-gamut. However, the over-exposure has this effect by the red band.



(a) Under-exposure (b) Over-exposure

Fig. 3 Color retinal images.

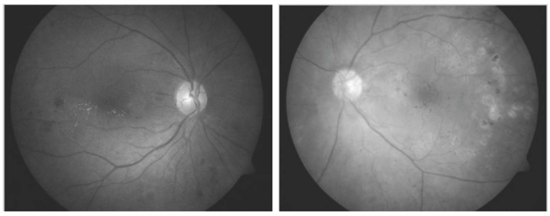
According to both the cases of over and under exposure, an image will have low contrast. In the color retinal images, the intensity component is provided to measure the exposure situation by analysing skewness of the intensity histogram. The skewness is calculated in the region of interest(ROI), which consists of the retinal area. Thus, the retinal image is identified by the exposure status as the following steps.

Step 1: Select the ROI from the intensity component by using a threshold value of Otsu method [10]. Fig. 4 shows ROI of the intensity component of Fig. 3.

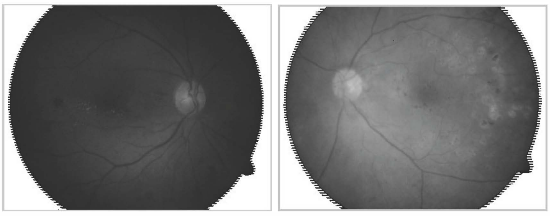
Step 2: Calculate mean of the ROI data in set $A = \{a_1, a_2, a_3, ..., a_n\}$ of n elements that is given by

$$\mu_A = \frac{1}{n}\sum_{i=1}^{n} a_i \qquad (1)$$

Step 3: Identify the skewness of ROI to define the exposure stage of each input image. The identification method is provided by calculating two regions of set A. The region, $Area_L$, consists of the intensity values less than μ_A. Otherwise, $Area_R$ region has intensity values



(a) Under-exposure (b) Over-exposure



(c) ROI of under-exposure (d) ROI of over-exposure

Fig. 4 ROI of the intensity components.

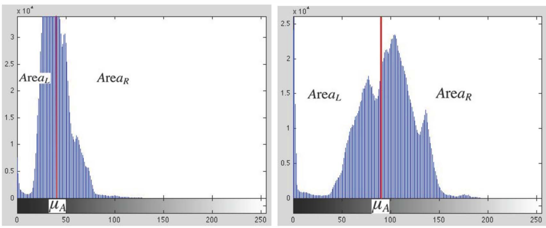
more than μ_A.

$$Area_L = \sum_{k=0}^{\mu_A} \frac{n_k}{n} \tag{2}$$

$$Area_R = \sum_{k=\mu_A+1}^{L-1} \frac{n_k}{n} \tag{3}$$

where n_k is a number of pixels in set A having gray level k in the range $[0, L-1]$ and L is total number of gray levels.

The skewness of ROI is evaluated by comparing the parameters, $Area_L$, and $Area_R$. If $Area_L$ is more than $Area_R$, it means that the input image has majority of under-exposure; vice vera, if $Area_R$ is more than $Area_L$, then input image has majority of over-exposure. Fig. 5 (a) and (b) show histogram of ROI from Fig. 4(c), 4(d) which are defined as under-exposure and over-exposure, respectively.



(a) Skewness measurement of Fig. 4(a), $Area_L > Area_R$, which obtains under-exposure (b) Skewness measurement of Fig. 4(b), $Area_L < Area_R$, which obtains over-exposure

Fig. 5 Exposure measurement.

2.3 Rayleigh CLAHE

In our algorithm, two parameters of Rayleigh CLAHE: $clip-limit$ and α value are declared depending on an input data. Clip-limit value is used to protect the over-enhancement. CLAHE method restricts the amplification by clipping the histogram at a user-defined value called clip-limit. The clipping level determines how much noise in the histogram. It should be smoothed and hence how much the contrast should be enhanced.

α parameter in Rayleigh distribution is provided to control the designation of the transfer functions in each region. Generally, the parameter α endows to control a shape Rayleigh distribution [11]. The parameter value will result in more significant contrast enhancement in the image while increasing saturation and noise levels. Although the proposed parameter may generate continuous local transformation under the proper conditions by assigning carefully the parameter to an individual image, the continuity cannot be proved and is not guaranteed. If there are big changes between nearby local histograms, the local intensity level transformation will be changed abruptly. To reduce this effect, the output from transfer function of Rayleigh transform is re-scaled using linear contrast stretch.

In CLAHE technique, an input image is divided into non-overlapping contextual regions called $tiles$. A number of $tiles$ depend on the other parameters of CLAHE. If the number of $tiles$ is small, the clip-limit should be quite small [12]. From our studies on the retinal images, 8×8 is a good value to preserve the chromatic data.

The Rayleigh CLAHE to enhance the color retinal images consists of the following by step:

Step 1: Dividing the intensity image into non-overlapping contextual regions. In Fig. 6, intensity components of Fig. 4(a) and 4(b) are partitioned into 8×8 non-overlapping contextual regions.

Step 2: Calculating the histogram of each region.

Step 3: Clipping the histogram of each region by the clip-limit value. The clipping rule is given by the following statements:

if $H_{region}(i) > N_{clip}$ ***then***

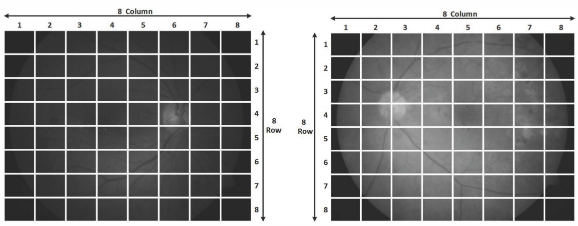
$$H_{region\_clip}(i) = N_{clip} \tag{4}$$

Else if $(H_{region}(i) + N_{avgbin}) > N_{clip}$ ***then***

$$H_{region\_clip}(i) = N_{clip} \tag{5}$$

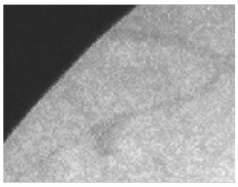
Else $H_{region\_clip}(i) = (H_{region}(i) + N_{avgbin})$ (6)

where $H_{region}(i)$ is a local histogram of each region at i-th gray level. $H_{region\_clip}(i)$ represents clipped histogram of the region, N_{clip} denotes the actual clip-limit which is defined by

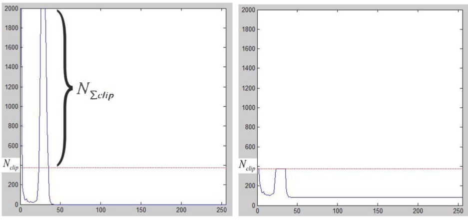


(a) Under-exposure (b) Over-exposure

Fig. 6 Non-overlapping contextual regions.



(a) Sub-image at index row 1, column 2 of Fig. 6(a)



(b) Histogram of the region (c) Clipped histogram

Fig. 7 Histogram clipping process.

$$N_{clip} = Min_{clip} + round(V_{clip} * (N_{pix} - Min_{clip})) \quad (7)$$

where V_{clip} is clip-limit value in the range [0, 1] defined by the user. N_{pix} denotes the total number of pixels in the region. Min_{clip} is the minimum average of total pixels, N_{pix}, per total bins, N_{bin}, in the local histogram. Min_{clip} is defined by:

$$Min_{clip} = round(\frac{N_{pix}}{N_{bin}}). \quad (8)$$

From eq. (4) and (5), N_{clip} is provided to threshold each of the local histogram. Thus, the total number of pixels, $N_{\Sigma clip}$, denotes the remain pixels from the clipped histogram as illustrated in Fig. 7(b). The average of the remain pixels to redistribute to each bin is calculated by

$$N_{avgbin} = \frac{N_{\Sigma clip}}{N_{bin}} \quad (9)$$

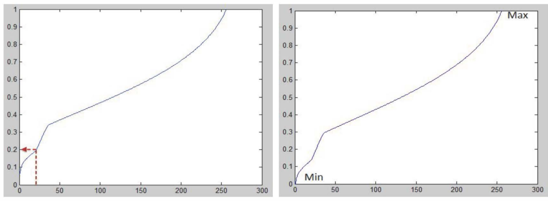
The clipped local histogram at 1st row and 2nd column has been demonstrated in Fig. 7.

Step 4: Enhancing intensity values in each region by Rayleigh transform. The clipped histogram, H_{region_clip}, is transformed to cumulative probability, $P_{input}(x)$, which is provided to create transfer function. Rayleigh forward transform is given by

$$y = y_{\min} + \sqrt{2\alpha^2 \ln\left(\frac{1}{1 - P_{input}(x)}\right)} \quad (10)$$

where $y_{\min}$ is the lower bound of the intensity value. α is a scaling parameter of Rayleigh distribution that is defined depending on each input image. The output probability density of each intensity value, y, can be derived as

$$p(y) = \frac{y - y_{\min}}{\alpha^2} \exp\left(-\frac{(y - y_{\min})^2}{2\alpha^2}\right) for\ y \geq y_{\min}. \quad (11)$$



(a) Transfer function of eq. (11) (b) Modify transfer function of eq. (12)

Fig. 8 Transfer function set parameter $\alpha = 0.4$ and $V_{clip} = 0.01$.

A higher α value will result in more significant contrast enhancement in the image meanwhile increasing saturation value and amplify noise levels. Fig. 8(a) shows the Rayleigh transfer function from the clipped histogram of Fig. 7(c).

Eq. (11) is used as a transfer function of CLAHE based on Rayleigh distribution as shown in Fig. 8(a). This equation will modify a gray-level value. If it abruptly changes in the low values, it will amplify a noise background of the retinal image as shown in the Fig. 8(a) when the gray-level range of 0 to 0.2 approximately.

Step 5: Reducing abruptly changing effect, the output from the transfer function in eq. (11) is re-scaled using linear contrast stretch. The re-scale function still keeps the original shape of the transfer function to compress noise background and to design the color of output continuously. The linear contrast stretch is calculated by

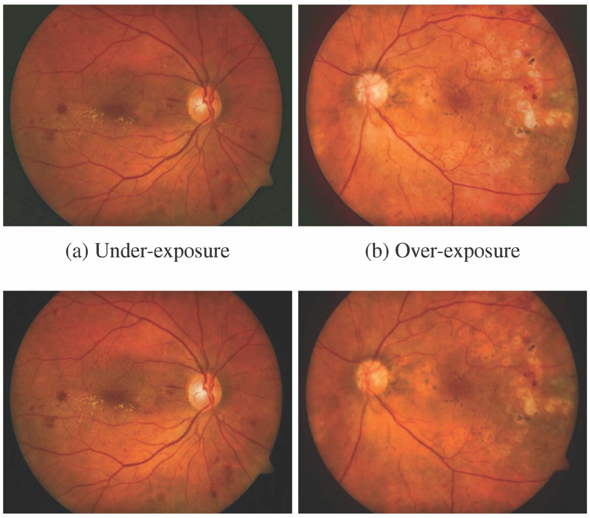
$$y = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \quad (12)$$

where x is the input value from the transfer function, $x_{\min}$ and $x_{\max}$ denotes the minimum and maximum value of the transfer function.

Step 6: Interpolating by using bilinear of the neighboring sample points from the center pixel of contextual regions to form the enhanced in each region for the whole image as the new intensity, I'. New intensity image, I', from the output of Rayleigh CLAHE is combined with the hue and saturation components becoming to HSI model. Finally, HSI is transformed to RGB color model by iNHSI algorithm [7]. Fig. 9 shows the enhanced results from our algorithm by the input images from Fig. 3(a) and (b). In Fig. 9, we compare the efficiency of eq. (11) as observed from the figure (a) and (b), for the figure (c) and (d) are the results from eq. (12).

3. EXPERIMENTAL RESULTS

Our algorithm is tested by using the public retinal image datasets which are DIARETDB (Standard Diabetic Retinopathy Database) [13]. This database was provided for benchmarking diabetic retinopathy detection from digital images. The proposed method is compared with the global and local histogram equalization techniques that consist of HE method [2] and color retinal image en-



(a) Under-exposure (b) Over-exposure

(c) Under-exposure (d) Over-exposure

Fig. 9 Color retinal image enhancement of the proposed algorithm by parameters $\alpha = 0.4$ and $V_{clip} = 0.01$.

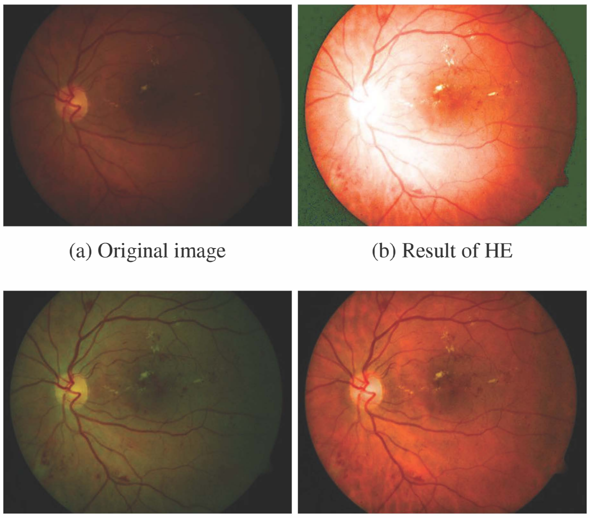
hancement using CLAHE in green channel in RGB color model [6], respectively.

3.1 Visual Analysis

The experimental results in Fig. 10 and 11 which are illustrated for visual comparison to the proposed method. The results from the proposed method give better visual quality of the enhanced image. It keeps a good contrast of retinal structures and preserved chromatic information of the input images. HE results are amplified background noises and cannot preserve the overall appearance of retinal structures. For example, in the optic disk and retinopathy, it degrades the information detail by having gamut problem of the red band of image as shown in Fig. 10(b) and 11(b). Fig. 10(c) and 11(c) show the results in the local image enhancement from CLAHE method by using green channel of RGB color model [6]. The results have a good contrast of blood vessels; however, this method does not preserve the chromatic information. As seen from the results, they have much of greenness. Our proposed algorithm could preserve the color data and improve overall contrast in the output images as shown in Fig. 10(d) and 11(d). The parameter values are $\alpha = 0.5$, $V_{clip} = 0.01$, and 8×8 blocks for Fig. 10(d) and for Fig. 11(d) consisting of $\alpha = 0.37$, $V_{clip} = 0.0075$, and 8×8 blocks.

3.2 Quantitative comparison

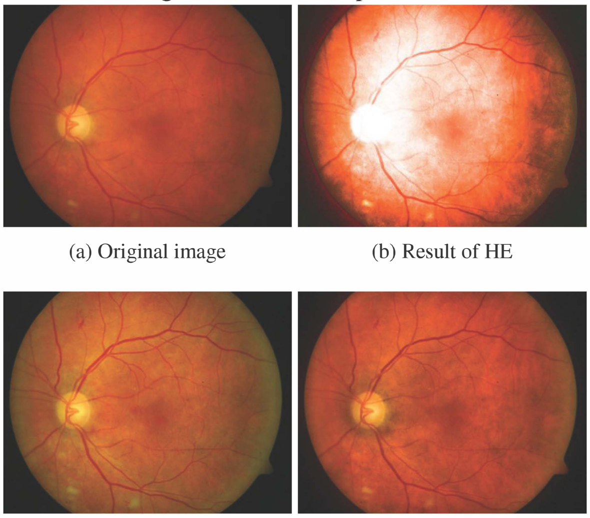
In quantitative comparison, correlation coefficient(CC) is used to measure the chromatic information, and entropy is provided to inspect the contrast properties. CC measures the strength of the linear association between two images A and B. CC value ranges between -1 to 1 depending on the similarity of A and B. If they similar and go in the same directions, CC will approach to 1. If



(a) Original image (b) Result of HE

(c) CLAHE of the green band (d) Proposed method

Fig. 10 Visual comparisons.



(a) Original image (b) Result of HE

(c) CLAHE of the green band (d) Proposed method

Fig. 11 Visual comparisons.

CC approaches to -1, it indicates that A and B are having similarity, but they are in an opposite direction. On the other hand, if they are not the same, CC will go to zero. CC is given as:

$$CC_{A,B} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(A_{i,j} - \bar{A})(B_{i,j} - \bar{B})}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(A_{i,j} - \bar{A})^2 \sum_{i=1}^{M}\sum_{j=1}^{N}(B_{i,j} - \bar{B})^2}} \quad (13)$$

where M and N denote image size, $\bar{A}$ and $\bar{B}$ are mean values of A and B, respectively.

Entropy measures the content of an image, with higher values indicating more detailed in the images. With the image, I, the entropy is defined by

$$H(I) = -\sum_{i=1}^{m} P(x_i) log_2 P(x_i) \quad (14)$$

where x_i is an intensity value of I. m denotes the total number of the intensity values. $P(x_i)$ is the probability function of x_i.

The Quantitative comparisons are illustrated in Table 1 and 2, which formulate from the under and over exposure image of Fig. 10 and 11.

Table 1 CC values between the original input images and the enhanced results.

Fig	Method	R	G	B	Avg
10(b)	HE	0.8855	0.8693	0.4398	0.7315
10(c)	CLAHE	1.0000	0.9535	1.0000	0.9845
10(d)	Proposed	0.9450	0.9641	0.9227	0.9439
11(b)	HE	0.9458	0.8895	0.5854	0.8069
11(c)	CLAHE	1.0000	0.9687	1.0000	0.9895
11(d)	Proposed	0.9591	0.9678	0.9569	0.9646

Table 2 Entropy values of the enhanced results from Fig. 10 and 11.

	Original	HE	CLAHE	Proposed
Fig.10	5.5161	5.4455	5.798	5.9846
Fig.11	6.1775	5.9750	6.1516	6.1790

4. CONCLUSIONS AND DISCUSSION

This paper was presented the color retinal enhancement method in the iNHSI color model to preserve the color information for visual diagnosis. The intensity component was enhanced by using the Rayleigh Contrast-Limited Adaptive Histogram Equalization. In our algorithm, the intensity component was analysed to classify the exposure levels: under- and over-exposure. The exposure levels were used to declare the set of paraments of CLAHE that consists of $clip-limit$ and α value in Rayleigh transform. The enhanced results has a good property for visual inspection in diagnosis process. It results provide a good contrast and improve the overall appearance of the color retinal images. From the quantitative comparison, the proposed algorithm offers high values of CC that is the enhancement method can preserve the chromatic information; however, CC values of our method are lower than CLAHE. Because the green band of CLAHE causes the red and blue band to be unmodified. On the other hand, enhancing only one band of RGB causes degradation of the color information. The proposed method gives the better visual quality of the enhanced images which represent a good contrast of retinal structures when considering the entropy values as shown in Table 2.

5. ACKNOWLEDGMENT

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