Performance of Image Enhancement Methods for Diabetic Retinopathy based on Retinal Fundus Image

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***Abstarct*—In Malaysia, Non-mydriatic fundus camera become a primary tool for Diabetic Retinopathy screening protocols due to user friendly and cost effective procedure. However, the quality of fundus image produces often suffer from uneven illumination, color distortion, blur, and low contrast. Therefore, the need for image enhancement become crucial to be implemented as a pre-processing technique in image processing funnel. This paper presents six general basic methods that commonly applied for image enhancement which includes histogram equalization, contrast stretching, image negative, brightness enhances, low light image and gray level slicing. The performance evaluation of each method compared based on human interpretations and quantitative measurement using MSE, PSNR and entropy. Retinal fundus images collected from Ophthalmology Clinic, Hospital Universiti Sains Malaysia were used as the input images. Quantitative and qualitative result shows that CS method become the preferred method to be used for image enhancement of retinal fundus image in Diabetic Retinopathy.**

Keywords—image enhancement, diabetic retinopathy

I. Introduction

Diabetic Retinopathy is a microvascular disease that become the most common cause of vison deterioration among people with diabetes and working-age adult. Approximately, one third of people with diabetics have Diabetic Retinopathy and it is reported that in 2015, 2.6 million people were visually impaired because of Diabetic Retinopathy and being projected to rise to 3.2 million in 2020 [1], [2]. In United States, almost 24,000 people losing vision from Diabetic Retinopathy each year [3]. Even though, there is a serial epidemiological evidence shows blindness due to DR has declined in high-income countries but it is overcome with the rising number of diabetic and Diabetic Retinopathy patients in low- and middle-income countries [4]. The duration of diabetes, hyperglycemia and hypertension were considered to be higher risk factors in progression of vision loss as well as the Diabetic Retinopathy cases increase with age, hence, middle-aged and elderly patients with diabetes are susceptible to diabetic retinopathy [5], [6].

Attainment in reducing the worsening of Diabetic Retinopathy prognosis in developed country were due to increased awareness through public health education efforts, early detection by Diabetic Retinopathy screening, sustained with the controlled of the systemic risk factor, and the availability of effective tertiary level treatment [4]. In India, it is reported that an early stages treatment interventions of diabetic retinopathy help decrease the burden of blindness resulted from Diabetic Retinopathy [7]. While in Malaysia, screening guideline for Diabetic Retinopathy have been set for a patient which at time the patient being diagnosed with diabetes mellitus, they must also undergo screening for Diabetic Retinopathy and plan for annually screening [8]. Early detection and appropriate follow-up care of diabetic eye disease can protect against vision loss.

Non-mydriatic fundus camera become a primary tools for Diabetic Retinopathy screening protocols due to user and patient friendly and cost effective procedure [8]. Non-mydriatic fundus camera has high sensitivity and specificity as compare to others screening tools with its capabilities to eliminate the need for pupillary dilatation, promoting compliance, efficiency and safety [8], [9]. Non-mydriatic fundus camera accounted 92.0% sensitivity and 97.0% of specificity, meet the standard of screening tools modalities issued by The UK National Institute for Clinical Excellence (NICE) [10]. However, quality of fundus images produce often suffer from uneven illumination, colour distortion, blur, and low contrast since there were varies medical assistant/ophthalmologist skills and experiences, camera limitations and patient's problem effecting the quality and consistency of retinal images [1], [11].

There are different ways for imaging the retina which the most common method applied in non-mydriatic fundus camera is by adopting an infrared light. White light quickly flash into the eye without constricting the pupil and capture the color of fundus photograph before the pupil can constrict [10]. Fig. 1 shows the working principle of the fundus camera. Features of retinal image which are used to determine the severity of Diabetic Retinopathy shows in Fig. 2. Formation of microaneurysms, hemorrhages, hard exudate, and soft exudates (cotton wool spots) as clinical features for retinopathy staging. The early stage name as non-proliferative diabetic retinopathy (NPDR) and advanced stage is proliferative diabetic retinopathy (PDR) [12].

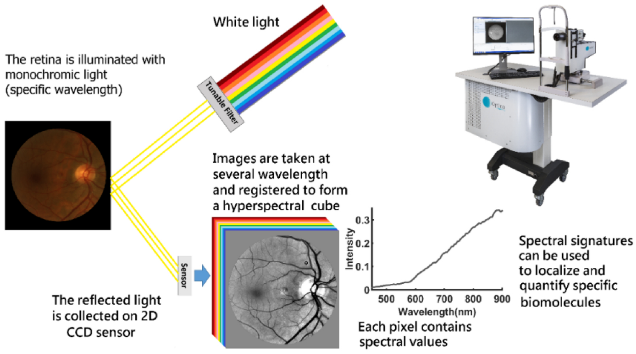


Fig. 1. Working principle of the fundus camera [13].

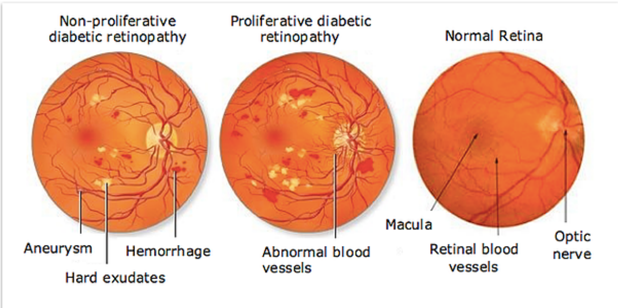


Fig. 2. Features of retinal image.

Looking forward of the world digitalized era, emerging of artificial intelligent in assisting medical screening and diagnosis evolved since the first discovery of medical imaging for x-ray by W. C. Roentgen in 1895 [14]. Throughout the year, numerous niche in medical had implements image processing techniques includes in eye disease. Application of this technology in ophthalmology is currently focused mainly on the diseases with a high incidence, such as Diabetic Retinopathy [15]. With the promising of artificial intelligent in Diabetic Retinopathy, the blurred and illumination variations issues over the retinal fundus image captured can be resolved using image enhancement techniques. It is become a mandatory step in pre-processing before the image being used for classification. After all, recognizing a method is very important which is able to regulate the amplification according to the illumination variation [16].

From the rising problem, this study comes with these three main objectives: (1) to review and understand the basic image enhancement technique practiced in medical domain, (2) to perform a test using retinal fundus image on different technique in image enhancement and determine the suitable image enhancement technique for Diabetic Retinopathy image processing. (3) to improve the quality of the retinal fundus image to be processed on the next stages.

In achieving the objectives of this study, this paper is present as follows; Section I discusses the background and overview of research domain, Section II reviews on work proposed by the previous researcher related to image enhancement in Diabetic Retinopathy, Section III presents the pre-processing of image processing by comparing basic image enhancement methods, Section V addresses the result with discussion, and last Section VI summarized the objectives achievement and provides recommendation for future study.

II. Previous Work

The aim of image pre-processing is the output images would be enhanced on the brightness, contrast and resolution to gain a better visual quality. Several methods can be applied to improve the quality of retinal images. Histogram equalization (HE) is the most popular basic equalizing method of an image by mapping a narrow range of intensity level to a wider available intensity level. Even though this method greatly improves the image radiance, but instead it over-enhanced in the image and causes missing of the key information [17]. As HE adopting a neighbourhood-based approach on the pixels, it has contributed to the overall background performance as well as the noise had presence into an artefact and negatively effects on further processing step. [18]. Furthermore, this technique causes decreasing of the grey levels, produces uneven background image that resulted in changes of illumination distribution from original image, unwell improvement at the low-contrast region and may loss of image details. [19].

Image Negative (IN) is the most basic and simple operation that compute the negative of an image [20]. It is useful and suited for enhancing white or grey details embedded in dark regions [21], [22]. IN has been applied in medical imaging and become an immerse advantage in medicine field. One of the best example of IN application is in early detection and screening of mammogram. [23].

Low contrast images often occurred due to several reasons such as poor or non-uniform lighting condition, nonlinearity or small dynamic range of the imaging sensor. Therefore, it is necessary to deepen the contrast of these images in order to provide a better transformation for subsequent image analysis steps [31]. Contrast Stretching (CS) transformations increase the contrast between the darks and the lights [24]. CS is a conventional methods based upon global histogram techniques for enhancing or normalizing image contrast. The mechanism used in CS is by expending the range of intensity values of an image that enable to cover a full dynamic range of an image suited with low contrast images [25], [26]. By performing and specifying lower and upper limits during CS procedure, the image obtained can be low saturated and high image intensity [25].

In improving main component of retinal fundus image such as optic disc, fovea, and tissues, CS is one of common pre-processing technique used to extract the component for easier segmentation process [26]. Ability of CS to maintain the shapes of image by spreading the details of an image from small range of pixel values to various degree of gray levels allow this technique to increase the contrast between vessels and background of the retinal fundus image [27]. Most common CS techniques are based on local and global contrast, partial contrast and bright and dark contrast [28].

Intensity or grey slicing also among per-processing technique frequently used to achieve a better image quality [31]. The gray slicing method can function either by highlighting a group of gray levels and diminish all others or emphasize a group of gray levels and leave the rest alone. For example, in determine the masses of water in satellite image and the flaws of X-ray image, gray slicing technique used to highlight a specific range of gray level and enhance the subject image [32]. Gray-slicing is a simple intensity transformation that involves two basic methods; (1) give high value for all grey levels in the specified range and very low value for the rest of gray levels and (2) give high value to all gray level with specific specified range and preserve the background and tonalities of the image gray level [33].

III. Pre-processing of Image Processing

Pre-processing method is an earlier stage in order to enhance the original retinal fundus image directly taken from the fundus camera. Image enhancement is a part of image pre-processing. We proposed a computerized prototype model that enable the first-hand image directly being enhanced within the same computer where the original image stored after captured. A simple model prototype built to process the image. App Designer and MATLAB software being utilized to develop the model prototype. Fig. 3 shows the model prototype main interface built purposely to analyze the image easily.

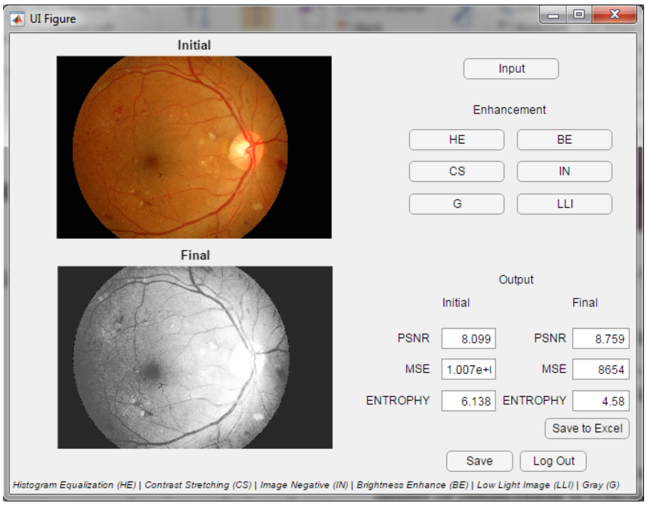


Fig. 3. Model prototype main interface.

In general, currently there is no general image enhancement technique can be used as a standard design to obtain a standard image [34]. Based on the previous studies, here, we only discusses six (6) general basic image enhancement techniques commonly used for pre-processing and analyses the performance of the image qualities specifically for retinal fundus image. Fig. 4 presents the flow of pre-processing for retinal fundus image operated in this study.

A. *Image Acquisition*

The retinal fundus images used in this study obtained from Ophthalmology Clinic, Hospital Universiti Sains Malaysia (HUSM). The retina fundus image captured by the medical assistant using non-mydriatic fundus camera allocated in a special room and connected with a computer. Retina fundus image captured stored in the computer. 90 retina fundus images being verify by the ophthalmologist specialist based on the features and classified into Non-proliferate Diabetic Retinopathy (NPDR) and Proliferate Diabetic Retinopathy (PDR). 65 pictures of NPDR retinal fundus images and 25 of PDR retinal fundus images is selected for image enhancement performance analysis.

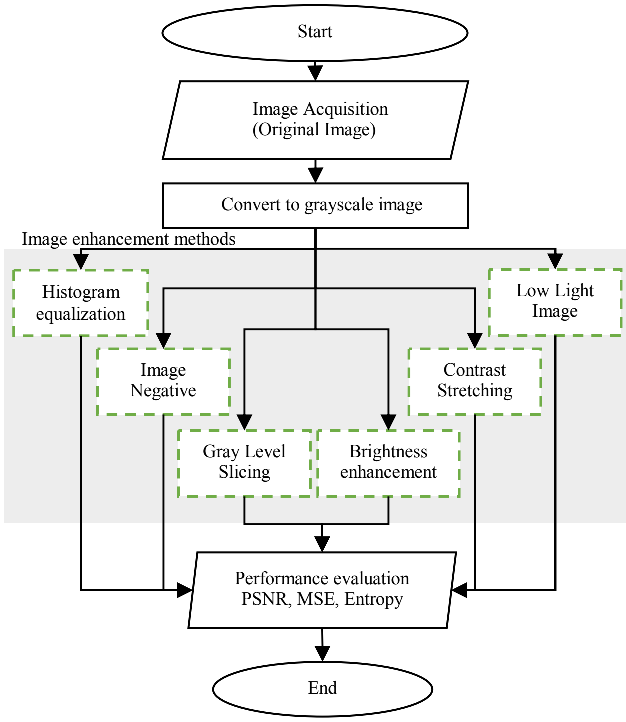


Fig. 4. Pre-processing flow of the retinal fundus image operation.

B. *Convertion to grayscale image*

The original image of retinal fundus image is based on the three color channels named RGB defined as Red, Green, and Blue channel. Before the image use for image enhancement process, retinal fundus image is converted into Grayscale RGB to reduce the computation time during the image enhancement process [35]. Following code used to convert the RGB color channel into grayscale level.

```
b =rgb2gray(a);
```

where, a, indicates the original image and b, is the converted grayscale image.

C. *Application of Basic Image Enhancement Methods*

The image enhancement process includes a series of techniques designed to improve the visual appearance of the image or to transform the image into a form more suitable for human or machine analysis. Six basic image enhancement used are histogram equalization (HE), contrast stretching (CS), image negative (IN), brightness enhancement (BE), gray-level slicing (GL) and low light image (LLI). Below shows the list of codes used in developing the model prototype.

Histogram Equalization,

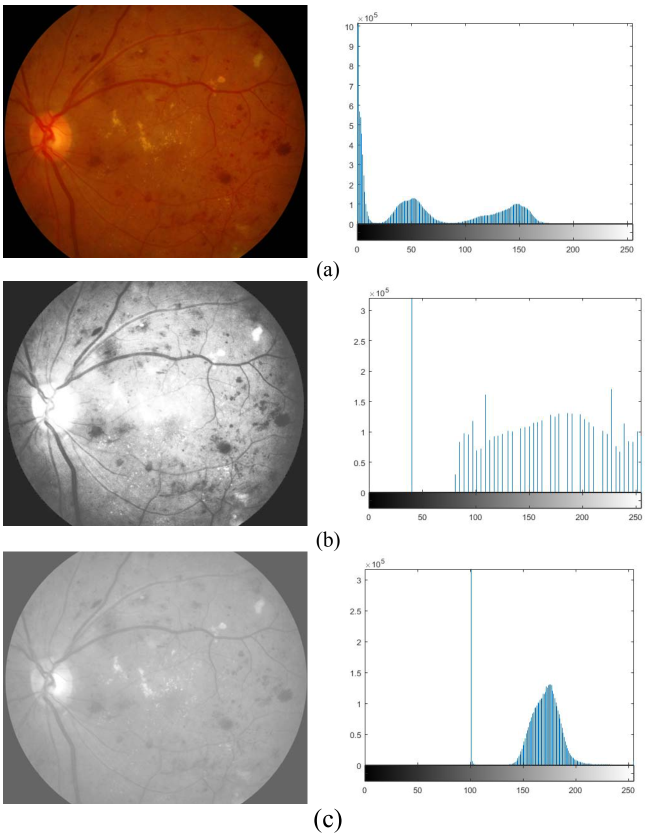
```
c=histeq(b);
```

Contrast Stretching,
c=imadjust(b);
Image Negative,
c=imcomplement(b);
Low Light Image,
c = imcomplement(b);
c2=imcomplement(c);
Gray Level Slicing,
c = imcomplement(b);
c2=imadjust(b,[135/255 200/255],[0.5 1]);
Brightness Enhance,
c = imcomplement(b);
c2=a+100;

IV. Result and Discussion

This study is implemented in MATLAB R2017a. The algorithm is applied on the database of 90 images with abnormal criteria of retinal fundus image. Performance of six algorithms namely HE, CS, IN, BE, GL and LLI are analysed in the preliminary study for enhancement of Diabetic Retinopathy before progressing to the next stage that deals with segmentation and classification of Diabetic Retinopathy . A comparison was made and focused on the qualitative (human interpretations) and quantitative measurement which include histogram, mean squared error (MSE), peak signals to noise (PSNR) and entropy of the enhanced images upon implementation of the six algorithms.

Fig. 5 shows the original image of retinal fundus with the six image upon implementation of the six image enhancement methods and its histogram.



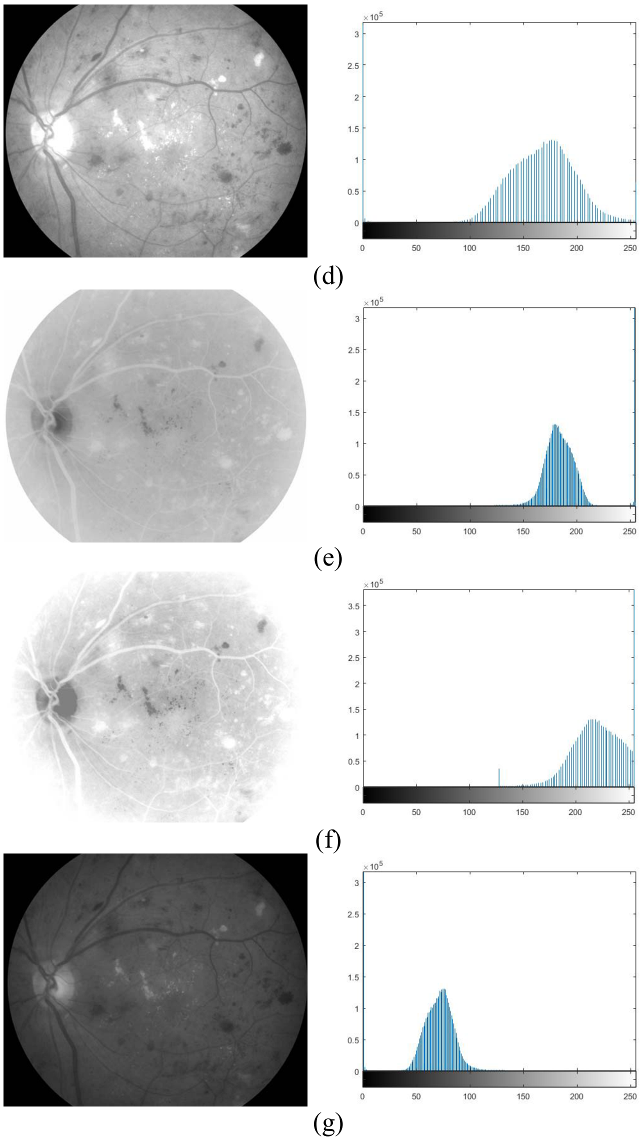
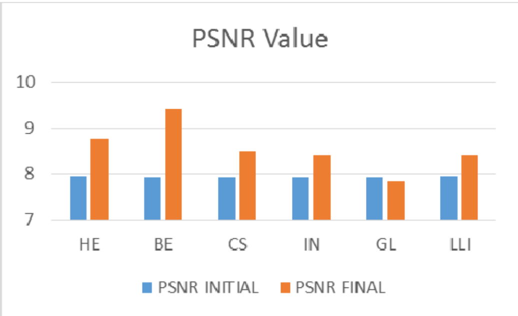


Fig. 5. (a) Original retinal fundus image and its histogram (b) HE retinal fundus image and its histogram (c) BE retinal fundus image and its histogram (d) CS retinal fundus image and its histogram (e) IN retinal fundus image and its histogram (f) GL retinal fundus image and its histogram (g) LLI retinal fundus image and its histogram.

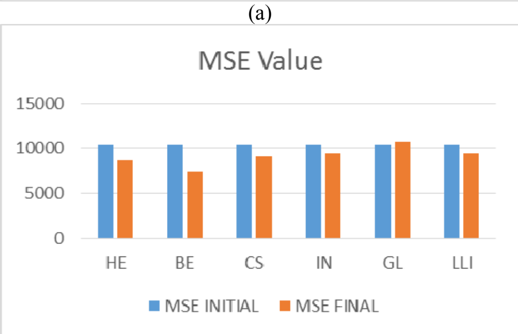
From Fig. 5, based on ophthalmologist specialist review as an expert human interpretation, HE produce a very bright image especially in the central part. These result in some details in the middle are not available for analysis and missing details for optic nerve. BE method is quite good which can detect the abnormalities but the differentiation of the abnormalities with background are not so prominent. For CS method, the retinal fundus image received a very good assessment due to ability to detect and recognized the abnormalities clearly. Form CS- retinal fundus image, the blood and heamorrhage is black on color, hard exudate defined with the white color and blood vessel determined with blood in color.

While retinal fundus image performed IN and GL is a reverse of CS-retinal fundus image where the blood determined with white in color, hard exudate – black in color, and blood vessel – white in color. But, the images attained a bit difficult to detect the abnormalities as the brain need to reverse the information from yellow in original images become black in color in reversed retinal fundus image. LLI-retinal fundus image gives the same image as CS methods but darker. Therefore, based on this qualitative measurement, the ophthalmologist preferred CS methods for further analysis as the image produce can easily interpreted.

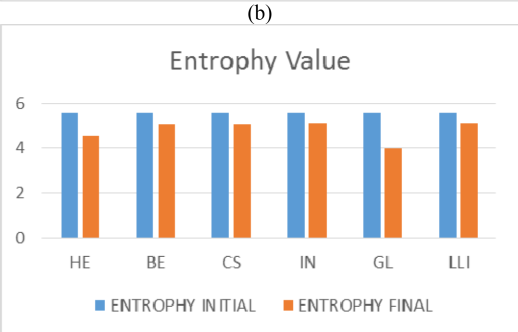
Quantitatively, referring to the histogram of each method applied, CS histogram give the best distribution as an ideal histogram interpreted with evenly distributed, edge to edge and not up at the sides. The performance matrix of each method was analyzed using PSNR, MSE and entropy. The mean value of the quantitative measurement (PSNR, MSE, and entropy) for 90 retinal fundus images presented in Fig. 6.



(a)



(b)



(c)

Fig. 6. (a) Comparison of the mean PSNR value for original image and six image enhancement techniques (b) Comparison of the mean MSE value for original image and six image enhancement techniques (c) Comparison of the mean entropy value for original image and six image enhancement techniques

The comparison of the mean value calculated for each quantitative measurement shows in Table 1.

TABLE I. COMPARISON OF THE MEAN VALUE FOR EACH QUANTITATIVE MEASUREMENT (QM) AMONG ENHANCEMENT TECHNIQUE (ET)

QM / ET	PSNR		MSE		Entropy	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**
HE	7.96	8.75	10409.16	8697.73	5.60	4.55
BE	7.93	9.40	10409.16	7488.94	5.60	5.06
CS	7.93	8.48	10409.16	9229.13	5.60	5.04
IN	7.93	8.40	10409.16	9401.14	5.60	5.11
GL	7.93	7.83	10409.16	10758.57	5.60	4.01
LLI	7.96	8.39	10409.16	9421.52	5.60	5.10

PSNR represents the ratio between the maximum possible value (power) of the signal and the distorted noise power that affects its quality. Because many signals have a very wide dynamic range (the ratio between the maximum and minimum possible values of the variable), the PSNR is usually expressed in a logarithmic decibel scale. MSE is a single value that provides information about the goodness of regression of the regression line. The smaller the MSE value, the better the fit, because a smaller value means a smaller amount of error. Entropy is the average information content called entropy is used to measure image quality. It is a statistical measure of randomness that can be used to characterize the texture of an input image.

Theoretically, a good quality image can be referred when the PSNR value is infinity, zero MSE value and higher entropy value [36]. In relation, the PSNR value will increase when MSE value is decreased or vice versa. The resulting image is visualized smoothly as the PSNR value increase. High value of MSE, less PSNR value and entropy value indicate with highly distorted image.

Based on table, BE method shows the highest value of PSNR (9.40) and lowest MSE value (7488.94). While GL give the lowest entropy value which is 4.01.

V. CONCLUSION AND FUTURE WORK

Understanding, analyzing and applying the general image enhancement techniques is a crucial key to determine the best methods suitable to be used for the next process. In realized that there are many advance techniques have been used which the root of technique mainly comes from the basic methods evaluated in this study. From this study, quantitative result shown contradict with the qualitative outcome which prefer the CS methods. CS method become the preferred method by the ophthalmologist to be used for image enhancement of retinal fundus image in Diabetic Retinopathy. Hence, further experiments and analysis must be done to obtain a better output and can synchronize within quantitative and qualitative output. In addition, further discussion need to be done focusing on advance image enhancement and optimization to obtain a high quality images.

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