Enhancement of Diabetic Retinopathy Imagery Using Contrast Limited Adaptive Histogram Equalization

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***Abstract*—Diabetic Retinopathy (DR), a common micro vascular disease observed in diabetics, is also a major cause of adult blindness across the globe. It results in observable changes in retina which may be cured, provided, if it is detected in the preliminary stage. However, the ocular images produced by fluorescent oscilloscope are often noisy and low in contrast making it seriously difficult for doctors to precisely detect the inherent abnormalities. In the present paper, we propose to use a regional contrast enhancement scheme, popularly known as Contrast Limited Adaptive Histogram Equalization (CLAHE) to aid the detection of retinal changes in DR imagery. CLAHE is an adaptive extension of Histogram Equalization followed by thresholding, which helps in dynamic preservation of the local contrast characteristics of an image. Following CLAHE, median filtering of DR images is carried in order to smoothen the background noise. Results of the proposed algorithm show a considerable improvement in the enhancement of DR image.**

Keywords—**Diabetic retinopathy, contrast enhancement, histogram equalisation, clahe, smoothening.**

I. Introduction

Diabetes is known for its dreaded complications and Diabetic Retinopathy (DR) is one such serious complication which invariably requires attention at a very preliminary stage [1]. DR is a progressive eye disease that aggravates with time causing irreversible damage to retina, and ultimately resulting in blindness. The global epidemic of DR is, hence, unignorable. According to World Health Organisation, since 20 years, more than 75% of patients throughout the world with high blood glucose suffer from retinopathy [2]. A survey in U. S. reveals the cause of 25% of new onset blindness in adults for over 40 years, is retinopathy. Further, the risk of blindness in patients with diabetes is 25% more than those without. India also has the highest number of diabetics in world with DR steering it to the 6th biggest cause of vision impairment in the country, a disease which may be cured upon precise detection.

Although digital imaging has proven to improve the diagnostic accuracy in ophthalmology, abnormal pathologies of retina diagnosed with lot of difficulty [3]. For doctors, it is very important to clearly detect and distinguish the blood leakages, haemorrhages and lesions from amongst the numerous blood vessels present in an eye. An important feature of this serious blinding disease is that, detectable changes takes place in the retina, as shown in Fig. 1, which can be cured using laser treatment, if detected at an early stage. Detection of DR at a very initial stage helps to reduce its severity and consequently, it's far reaching consequences. Usually, retinal images captured from fluorescence oscilloscope are of low gray level contrast and are of poor in contrast as a result of the acquisition process.

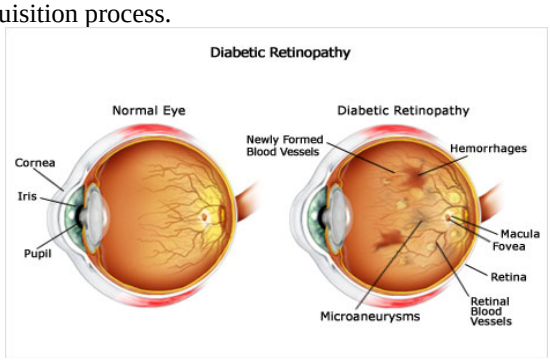

Fig.1: Observable changes in diabetic retinopathy effected eye as compared to that of normal eye.

A well known fact is that image enhancement techniques improve the quality of retinal images. Enhancement, in the present context, refers to bring out the finer details of the image-under-test while emphasizing the features of interest. The goal of image enhancement is to extract the important characteristics from which a detailed description of the target is henceforth possible. Such an image can serve either for improved human perception or as an input to further automated image processing techniques.

Several methods for detection and classification of abnormalities in ocular images appear in literature. Kumari et al [4] propose to extract features to detect DR by through appropriately ordered morphological operations. Using principal component analysis, Li H in [5] locate the centre of the optic disk by finding the minimum distance between the original image and its projection onto the disk space. Hsu et al [6] present a domain knowledge base approach for detecting exudates using median filter and dynamic clusters while Dua et al [7] devised an algorithm based on hierarchical decomposition and quadtrees. The work discussed so far focussed on detection and classification of ocular problems. Poor image contrast, however, is one of the most significant problems encountered in all the above studies. The acquisition process often leads to a low quality and noisy image with reduced dynamic range. A few studies have been published regarding the

enhancement of retinal images. Retinal image enhancement using curvelet transform, a geometrical transformation using anisotropic scaling and directionality is proposed by Candes et al [8]. Miri et al [9] used multi-resolution tools using a non linear function to modify the curvelet coefficients. Techniques based on matched filtering are ideal in enhancing low contrast blood vessels over a limited area but the computation becomes complex with image size [10, 11]. This process is attractive in enhancing the global contrast of an image, but not readily, when features of interest occupy a relatively narrow range of gray scale, especially as those noticed in Non Proliferative Diabetic Retinopathy (NPDR) imagery.

As cited above, a wide range of image processing techniques have been suggested for solving issues in ocular abnormalities which focus on diagnosis and classification of retinopathic diseases. However, very few studies have examined the impact of image enhancement on retinal images. J.A. Stark [12], using Adaptive Histogram Equalisation (AHE) overcame the drawbacks of Histogram Equalisation, especially for images with varying contrast characteristics. Noor et al described the diagnostic capability of AHE for fish bone impaction from radiograph images [13]. Benefits of CLAHE have also been successfully used in biomedical image analysis. Pisano et al [14] proposed CLAHE'd image processing to improve the detection of simulated spiculations in dense mammograms. With CLAHE based enhancement, a spot adaptive segmentation technique shows improved gene quantification in microarray images [15]. The idea behind the present work is to exploit the effectiveness of CLAHE in early detection of retinopathy in diabetic patients with suspected Proliferative, Non Proliferative DR and Macular Edema. In the present work, we propose to contrast enhance ophthalmic images using Contrast Limited Adaptive Histogram Equalisation. In the last stage median filtering of the CLAHE'd images is carried out to smoothen the noisy image.

The rest of the sections in the paper are organized as follows: Section-II provides a medical research background on retinopathy; Section-III presents a detailed explanation of the proposed scheme and preliminary results of the same; Section-IV presents and analyses the results in detail. Section-V concludes the paper.

II. Research Background

In the present section we discuss issues that are in close relation to Diabetic Retinopathy with an emphasis on the medical research background. Towards the end, we provide the limitations with present contrast enhancement solutions for retinopathic imagery.

Diabetes Mellitus, widely known as Diabetes, is a metabolic disease, due to the inability of blood cells to utilize glucose resulting in hyperglycemia (high blood glucose level). It is either a consequence of absolute deficiency of insulin due to destruction of pancreatic beta cells (Type I or Juvenile Onset Diabetes) or characterised by insulin resistance of body cells (Type II), affecting 95% of diabetics. Although all people suffering from diabetics are at risk, Type II victims are more prone to visual handicaps with 90% of them developing DR after 20 years of diagnosis. In U.S., diabetes is the leading cause of blindness in 20-54 year age group. Diabetic Retinopathy, a serious manifestation of diabetes on the retina is - a slow, silent, debilitating and progressive disease causing permanent damage to the eye. DR is actually a micro-angiopathy affecting retinal pre-capillary arterioles and venules producing detectable changes in the retina. Usually DR may be classified into three major stages [1]. Initially starting with Non Proliferative Diabetic Retinopathy (NPDR), it proceeds onto Macular Edema before finally resulting in Proliferative Diabetic Retinopathy (PDR).

The first stage can be further divided into mild, moderate and severe NPDR. NPDR, also known as Background Diabetic Retinopathy (BDR), as shown in Fig. 2, is highly asymptomatic in its early stage. However, better screening and enhanced imaging techniques can help in delaying the progression of the complicacies. Mild NPDR is identified by little outpunchings, called microaneurysms, which appear as minute, sharp, circumscribed, small dark red dotted areas. They are generally located far from the blood vessels with an approximate average diameter of 100 microns. Bleeding from damaged retinal blood vessels is seen as 'dot' and 'blot' haemorrhages. They occur within the inner nuclear layer of the retina mainly near the venous end of the capillaries with size much lesser than microaneurysms. These structures allow leakage and consequent accumulation of lipids and proteins within the retina, known as Hard Exudates which are small, sharp edged, shiny yellowish-white deposits.

Severe NPDR reveals cottonwool spots which are opaque, white puffy, circular patches caused mainly due to ischemia, which in-turn represent swelling and infarction on the retinal surface as a result of damaged nerve fibres due to reduced axonal transport. Abnormalities in the retinal veins, mainly venous segmental dilation, named as 'sausage sign' or venous loop, are also seen. This stage is identified with more than 20 intra-retinal haemorrhages in each of the four quadrants accompanied by venous beads in 2+ quadrants. Intra-retinal micro-vascular abnormalities (IRMA) represent dilated capillaries and abnormal branching of blood vessels. Venous beads with an onlooker of a string of beads is the localized growth of venous calibre. DR is distinctly identified from other retinal diseases by the simultaneous occurrence of venous beads and microaneurysms. Clinically Significant Macular Edema or CSME, results in leakage of fluid into the macula, the central 5% of the retina most crucial for sharp and straight-ahead vision.

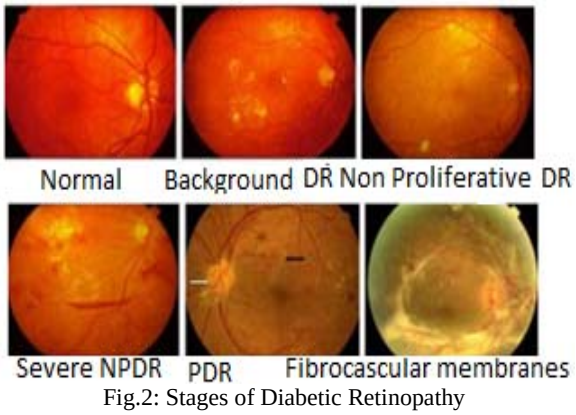

Fig.2: Stages of Diabetic Retinopathy

It effects in swelling or thickening of the macula and is the most common cause of permanent vision loss in diabetes. PDR, defined by neovascularisation, is the growth of new blood vessels. These new vessels themselves do not cause much problem. However, due to absence of pericytes, they tend to be of poor quality and consequently, a leak or rupture easily occurs, causing blindness. Neovascularisation at or near the optic disc(nerve) is known as Neovascularisation of the Disk (NVD) while those not near the nerve are referred to as Neovascularisation Elsewhere(NVE).

A. Contrast Enhancement of DR Imagery

By and large, all image enhancement techniques increase the quality of image under test and ensure improved comprehendability. Contrast Enhancement (CE) is a major component of enhancement techniques, particularly in dark images which contain information that is not readily visible to the naked eye. Histogram equalization is one such methodology adopted for CE that expands the pixel intensity distribution in order to utilize the entire dynamic range. In the following we provide a brief note on generic histogram equalization procedure.

B. Standard Histogram Equalisation (SHE)

The goal of standard histogram equalisation scheme is to optimize the overall contrast of the image by obtaining a uniform histogrammed version of the gray image. It attempts to equalize the probability of occurrence of all the gray values of the image. SHE employs a monotonic, non-linear mapping that assigns a new intensity value to each of the pixels based on following computation: The probability density function of a digital image of 'n' pixels with gray level range [0, L-1] is given by equation (1):

$$P(r_k) = \frac{nk}{n} \quad (1)$$

where $0 \leq rk \leq 1 \; and \; k = 0,1, \dots, L-1$, and r_k stands for the k^{th} gray level, n_k represents the number of pixels in the k^{th} level and n is the total pixel count. The transformation mapping of the gray level r_k to a new level s_k based on a cumulative distribution function is obtained using equation (2), which may be expressed as:

$$S_k = T(r_k) = \sum_{j=0}^{k} \frac{nj}{n} = \sum_{j=0}^{k} P(rj) \;\; k = 0,1, \dots, L-1 \quad (2)$$

where 'T' stands for the transformation function. This method is particularly useful, where, both background and foreground are dark and represented by a set of narrow gray values. As discussed in earlier sections, images acquired from fluorescence oscilloscope are often very low in contrast, which is evident from their histograms that are narrow and concentrated only to certain gray level values. However, retinopathic images contain minute details of the lesions and intra-retinal occlusions that get obscured due to limited contrast, and hence, are not easily presented before doctors. This may lead to delayed diagnosis and even wrong treatment. Histogram equalization plays an important role in several such cases, however, while leaving local changes in contrast, unconsidered. Recently, CLAHE algorithm has been successfully proposed for biomedical imaging; however, it increases background in-homogeneities and hence calls for some post processing. In the next section, we present a method for enhancement of DR imagery using CLAHE.

III. Proposed Method

In view of the difficulties that arise due to direct application of standard enhancement techniques to Diabetic Retinopathy, in the following we propose to apply CLAHE based image enhancement. The proposed algorithm is divided into two stages. In that order, we first discuss the methodology adopted to apply CLAHE over DR images, and consequences thereafter. Following this, we carry out median filtering of CLAHE'd images to smoothen the noise.

A. Application of CLAHE to DR imagery

In this stage, we first emphasize on local contrast rather than global contrast of the image. Global histogram equalization does not focus on local contrast improvements and consequently minor contrast differences which are very common in NPDR imagery are entirely missed if the number of pixels falling in a particular gray range is small. To solve this problem, the proposed algorithm is defined to function adaptively on the image to be enhanced, unlike standard histogram equalization. It optimizes the contrast enhancement on local image data in a divide and conquer manner and hence efficiently tackles the global noise. In other words, the basic idea of the algorithm is to divide the image into a number of small, non-overlapping contextual regions, called "Tiles".

As a next step, the standard histogram equalization is then applied to each of these regions. Thus, each tile is contrast enhanced locally which is followed by clipping. Fig. 3 is a pictorial representation of the proposed compound CLAHE algorithm. As explained above, the figure depicts the process of tiling, followed by application of standard histogram equalization and subsequently median filtering. A comparison of the contrast enhancement capability of the proposed scheme with that of SHE, is also provided in the figure.

A stage wise explanation of the proposed CLAHE application to DR imagery is explained below:

Step-1: Decimate the DR image into 2x2 sized contextual regions (Tiles)

Step-2: Apply local histogram equalization (Application of SHE to each of the tiles)

Step-3: Place a threshold limit to avoid oversaturation of the image (in homogenous regions) These areas are characterized by a high peak in the histogram due to a lot of pixels falling in the same gray level range

Step-4: Modification of histogram by calculating the slope of the cumulative distribution function obtained by summing the histogram counts (as shown in Fig. 4). A larger bin count corresponds to a greater slope. Thresholding ensures a limit on the maximum allowable pixel count in such a way that the height of each bin does not exceed the clip limit. The clipped pixels are then equally redistributed over the entire histogram, keeping the total pixel count constant.

Step-5: Conjoin local histograms of the neighbouring tiles through bilinear interpolation (To eliminate the discontinuities at the region boundaries)

In step-3, the clip value sets a predetermined threshold on the allowable number of pixels corresponding to each gray value. This feature, in-turn, provides scope to control the overall contrast of the image. Further, pixel values exceeding the clip or cut-off value are redistributed uniformly among gray values, thus, preserving the overall pixel count. In other words, the threshold limit (ranging from 0 to 1) is a parameter which averages selective histogram contents. As indicated in Fig. 5, a higher threshold prevents the desired clipping and results in an output, which may be poor in contrast than the input. Hence, a lower threshold value is often desirable.

B. Median Filtering of CLAHE'd DR Imagery

As a last step (depicted in Fig. 3), the CLAHE'd DR image is median filtered to smoothen the background inhomogenities that are resultant from the enhancement algorithm. A median filter is often chosen as it is proved to be effective in smoothening of the image due to its-

- Capability to reduce impulse noise.
- Ability to preserve edge information of resultant image
- Ability to not create any new unrealistic pixel intensity as the median value is one of the elements present in the neighbourhood.

The median filter used in the proposed algorithm works by computing a running median of the input values available to the filter using a mask of size 3x3. It works by replacing the central elements of a moving window of size M (where M is odd) with the median of the pixels located within the window. In the next section we provide a few results and their analysis from the proposed algorithm.

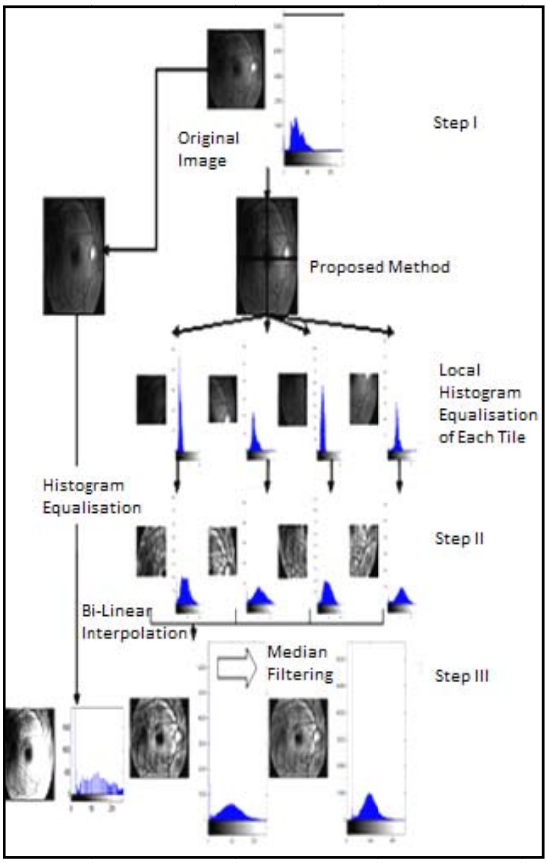

Fig.3: A schematic of proposed CLAHE based enhancement of DR imagery

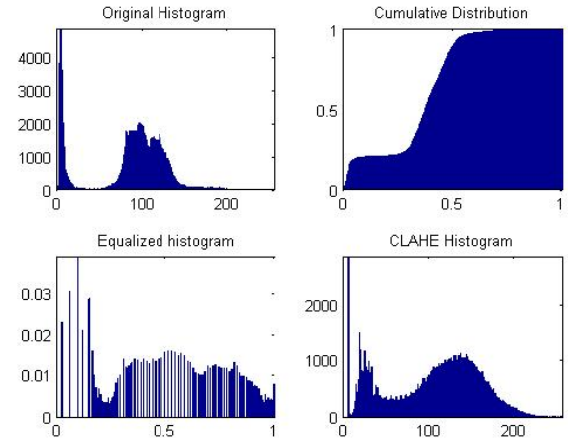

Fig.4: Comparison of histograms of CLAHE (bottom right) with that of the original image histogram (top left) and standard HE (bottom left).

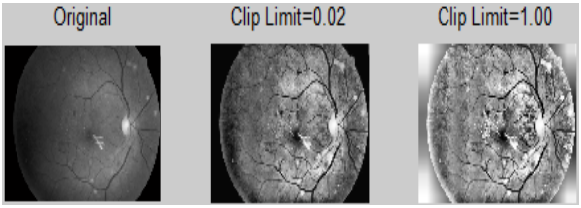

Fig.5: Comparison of the effect of threshold variation on a DR image

IV. RESULTS AND ANALYSIS

The proposed algorithm has been applied on images from Southern California College of Optometry and a standard retinal image source, DRIVE database [16]. Around 30 image data sets have been tested with the proposed algorithm. A few enhanced images are shown in the following figures (Fig. 6 to Fig. 14). In these figures, the results obtained from the proposed algorithm are compared with those obtained from standard histogram equalization (SHE) techniques. The black arrow marks in these figures indicate the visible differences that have been brought out by the proposed algorithm.

A. Enhancement of some common diabetic retinal pathologies along with their stages.

Fig 6: Microaneurysms appearing as bright, red dots in the vicinity of occluded capillaries, signify mild NPDR.

Fig 7: Dot and Blot Haemorrhages occurring as smaller spots in the posterior pole of eye (mild NPDR).

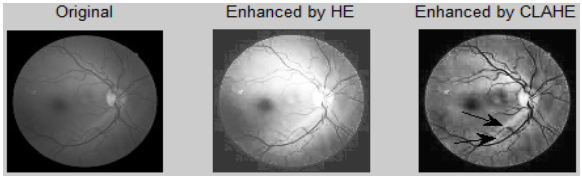

Fig 8: Hard Exudates seen as shiny, irregularly shaped spots.

Fig 9: Opaque white puffy patches, called cotton wools spots indicative of moderate NPDR.

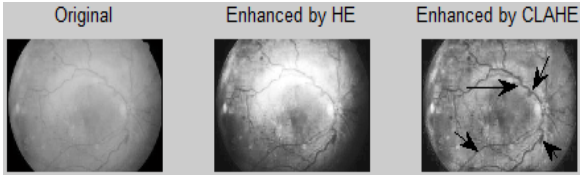

Fig 10: Venous Beading appearing like a string of beads in moderate-severe NPDR.

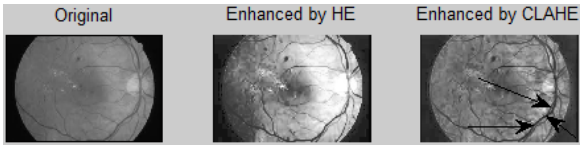

Fig 11: IRMA recognised by dilated capillaries in severe NPDR.

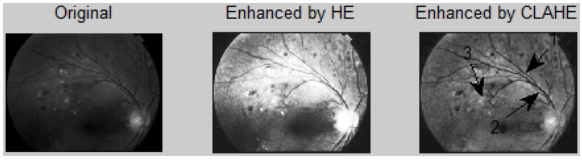

Fig 12: Very Severe NPDR.

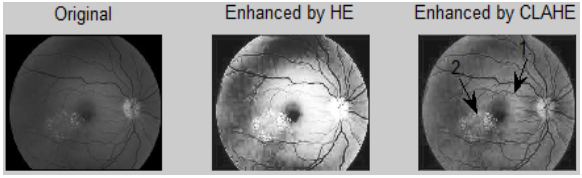

Fig 13: Clinically Significant Macular Edema (CSME) is detected above by the presence of Intra-Retinal fluid in the macular area along Hard Exudates.

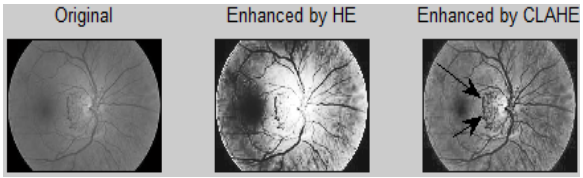

Fig 14. Neovascularisation depicting PDR.

B. Analysis of Enhancement

From the above figures it is evident that standard histogram equalization (SHE) schemes suffer from noise amplification and intensity saturation which is resolved by the proposed algorithm. As a last step, to advocate the efficiency of the proposed DR image contrast enhancement scheme, Normalised Power Spectral Distribution (NPSD) and Cumulative Power Spectra (CPS) of the resultant images are plotted. The case of Neovascularisation in PDR, which is a major cause of diabetic related blindness, is considered for this purpose.

Spatial frequency, usually, refers to the periodicity with which the image intensity values change. This means, an increased spatial frequency corresponds to a greater change in contrast over a shorter image distance. As shown in figures 15 & 16, the greater the power in a certain frequency, the higher is the change in the contrast. Hence, an increase in the power of the high frequency components of an image, which in turn stands for an enhanced contrast and sharpened image details. The steepness of the red curve in the later half of the figures, along with an increased rate of cumulative power corresponds to enhanced contrast of the CLAHE'd images.

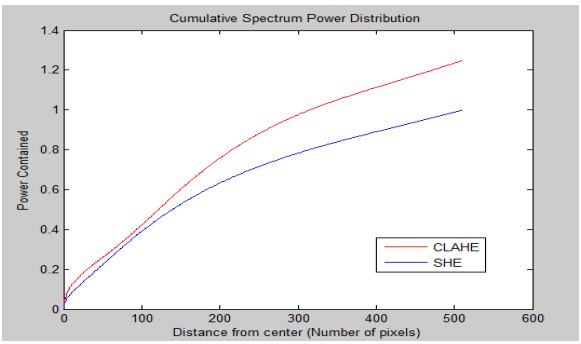

Fig. 15: A comparison of Cumulative Power Spectrum (CPS) of proposed algorithm with that of standard histogram equalization technique.

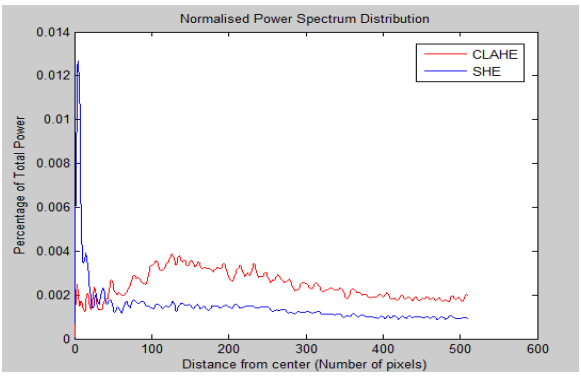

Fig. 16: The NPDS plot reveals that the higher frequencies contain a greater percentage of power (in this case from the 125th pixel onwards)

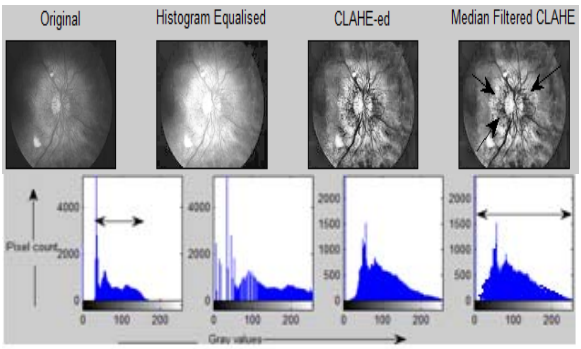

Fig. 17: Comparison of histogram of Original, HE & CLAHE processed images

In Fig. 17, histogram of the proposed algorithm shows a more evenly distributed dynamic spread of gray levels with the clipped amplitude, indicating a higher degree of contrast owing to increased spatial frequency components.

V. CONCLUSIONS

The present work considers application of a compound CLAHE algorithm to enhancement DR images. The proposed approach simultaneously addresses intensity saturation and noise amplification issues that are commonly encountered in enhancement algorithms. While the work started as a research, progressive work lead to the success of the study the characteristics of histogram equalization and its effect on each of the local contextual regions and not the whole image at one go. The proposed method uses a non-mean based approach and enhances the quality of the DR image while preserving the sharpness and minutest of the details. Qualitative analysis of the proposed method clearly indicates a considerable enhancement of diabetic retinopathy image. In view of its modest computational requirements and simplicity, the proposed scheme may be directly implemented in any image processing engine both for large and / or high resolution DR imagery.

ACKNOWLEDGMENT

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