Automated Optical Disc Segmentation and Blood Vessel Extraction for Fundus Images Using Ophthalmic Image Processing

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Abstract. Diabetic Retinopathy that is characterised by the progressive deterioration in retinal blood vessels is considered the root cause of severe vision loss in diabetic patients. This situation can be reduced upto much extent by regular screening and diagnosis. Precise automatic segmentation of optical disc and automated blood vessel extraction results in effective diagnosis of diabetic retinopathy reducing the chances of vision loss. A considerable progress has been made by various researchers towards automating the ophthalmic image processing via computer aided screening but maintaining the image quality as that of the original fundus image is still a challenge. In this paper, authors have evaluated Optical Disc Segmentation methods based on thresholding, region growing algorithm and mathematical morphology for effective removal of optical disc to facilitate blood vessel extraction. A new blood vessel extraction technique using Mathematical Morphology and Fuzzy Algorithm is proposed for precise blood vessel extraction. Two open access standard fundus image databases, DRIVE and STARE were exploited for performance evaluation of the proposed approach. This approach is effective in identifying optical disc to extract the blood vessels near the optical disc area which plays an important role in early diagnosis of diabetic retinopathy.

Keywords: Diabetic retinopathy · Ophthalmic image processing
Computer aided screening · Optical disc segmentation · Blood vessel extraction

1 Introduction

Diabetic Retinopathy (DR) is characterised by long term accumulated damage to the retina occurring due to diabetes mellitus which are marked by the appearance of different lesions like microaneurysms, exudates, haemorrhages, neovascularisation, etc. DR is considered as the major cause of vision loss in most of the diabetic patients and it occurs due to the change in retinal blood vessels which may swell and leak out fluid into the retinal area. These blood vessels may close off completely arresting the oxygen supply to the retina. The other major cause of DR is blood vessel overgrowth leading to bifurcated blood vessel pattern. The newly grown blood vessels are weak and fragile and may leak out blood and fluid into the retinal areas [1]. Broad classification of DR

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falls into two categories Non-Proliferative Diabetic Retinopathy (NPDR) and Proliferative Diabetic Retinopathy (PDR) [2]. The two main structures used for fundus image analysis are optical disc and blood vessels. Optical disc (OD) is the brightest part and it usually appears bright yellowish circular or oval shaped region appearing in the fundus photography. Blood vessels originate from the centre of the optical disc and they are responsible for supplying nutrition to the eye [3]. Segmentation and removal of OD is essential step in image processing for automated detection of DR lesions as inaccurate removal of OD may hamper the detection of bright lesions like EXs leading to misclassification. Since blood vessels appear as dark elongated structures in fundus photography, imprecise detection of blood vessels may impede the detection of dark lesions like MAs and HEMs [4].

Various researchers have contributed to the remarkable improvement in the screening and diagnosis methods by automated optical disc segmentation and blood vessel extraction. In [5], a novel approach based on histogram matching for optical disc segmentation was proposed. In this method, some of the fundus images from the dataset were used to create the template and then the average of histograms for each color component was calculated to localize the centre of the optical disc. Correlation between each of the R, G, B components of the original image and template is also computed and the point which has the maximum correlation value is selected as the centre of optic disc. Authors in [6] proposed an Automated Diabetic Retinopathy Detection System to process the fundus images so that they have similar quality as that of angiogram to obtain better clarity of lesions. Segmentation of optical disc is done employing speed up robust features and blood vessel extraction is done using morphological image processing operations. Authors in [7] employed clustering approach with a novel correction procedure and vessel transform for automatic optical disc detection. To detect the boundaries of the optical disc, the proposed algorithm is integrated with scale space analysis. The work presented in [8] employed High Resolution Fundus image database (HRF database) and for the enhancement of optical disc, histogram equalization function is applied on green channel of fundus image. For OD segmentation speed up robust features function is exploited and the evaluation of results is done using Receiver Operating Characteristics curve (ROC curve). The method proposed in [9] is a modification of vessel transform by using vessel vector-based phase portrait analysis (VVPPA) and a hybrid between VVPPA and a clustering method used in vessel transform. Exceptional performance was achieved in [10] for blood vessels and optic disc segmentation in retinal images by employing the extraction of the retina vascular tree using graph cut technique. Markov random field (MRF) image reconstruction method is utilised for optic disc segmentation by removing vessels from optical disc region. In [11] extraction of retinal vascular tree is done using graph cut method and this blood vessel information is utilized to identify the approximate position of optical disc which is further fed to ANN classifier. Authors in [12] used various image processing techniques like adaptive histogram equalization and image filtering. Optical disc and the blood vessels are detected and removed using morphological operations and employing Otsu thresholding algorithm for better results. Study implemented in [13] utilises adaptive histogram equalization based preprocessing technique and robust distance transform is used for blood vessel segmentation. After reviewing all these articles it was revealed that inadequate illumination of fundus images and their poor quality leads to inability to analyse them after applying image processing techniques. Therefore, image pre-processing methods plays a major role to improve contrast and illumination for further image analysis steps for OD segmentation, OD removal and extraction of blood vessels. The color and intensity properties of MAs are similar to those of blood vessels due to which most of the methods listed in the literature misses the MAs adjacent to blood vessels and some MAs that are too small or blurred to be seen with the naked eyes. Thus the authors in this research work came up with a solution for optical disc segmentation and blood vessel extraction to facilitate the ophthalmologists for effective diagnosis of eye related diseases using fundus image analysis. In this paper, authors have implemented and critically analysed different OD segmentation methods and proposed a Mathematical Morphology based Fuzzy Algorithm for efficient extraction of blood vessels. Fundus images are obtained from standard publically available DRIVE and STARE databases. The RGB images are converted to green channel as only this channel has maximum intensity out of all the R, G and B channels. Further, histogram equalization is performed to enhance image quality followed by optical disc segmentation of equalized image and blood vessel extraction is done using the proposed approach. Various performance metrics were evaluated to validate the proposed method. Rest of this article is organized as: Sect. 2 comprises of Materials and methods presenting the proposed algorithms for optical disc segmentation. Experimental results comparing different OD detection methods are discussed in Sect. 3 followed by conclusion and future work in Sect. 4.

2 Materials and Methods

2.1 Fundus Image Databases

This research work utilizes two of the publically available standard databases for fundus image analysis. Some of the fundus image databases referred in the literature are as follows; DRIVE [14], STARE [15], DIARETDB0 [16], DIARETDB1 [17], MESSIDOR [18]. The detailed explanation of different databases is given Table 1. These databases are beneficial for image testing, blood vessels extraction, segmentation [19], feature extraction [20] and classification [21] for DR screening and detection.

Out of all the databases discussed in the table above, DRIVE and STARE databases are commonly used databases for fundus image analysis. To generalize our research work, the proposed algorithm was implemented on images obtained from DRIVE and STARE databases and experiments are performed on these databases.

2.2 Different OD Segmentation Techniques

Thresholding: Thresholding is the most common segmentation method and it is used in many of the applications due to its simplicity of implementation and computation speed. Thresholding is used in such applications where the image can be divided into two groups; the main object and the background depending upon the pixel intensity values. Let us consider an image $f(x, y)$, which is composed of a light object on a dark

Table 1. Description of publically available databases for fundus images

Sr. no.	Fundus image database	Field of view (FOV)	Image resolution	Database description
1.	DRIVE [14]	45°	768 × 584	20 color testing images and 20 color training images with extracted blood vessels.
2.	STARE [15]	35°	605 × 700	400 images with masked and extracted blood vessels.
3.	DIARETDB0 [16]	50° FOV with varying imaging settings	1500 × 1152, 1936 × 1296	130 color fundus images of which 20 are normal and 110 contain signs of the diabetic retinopathy.
4.	DIARETDB1 [17]	50° FOV with varying imaging settings	1500 × 1152, 1936 × 1296	89 color images out of which 84 images contains the sign of non-proliferative DR and remaining 5 are normal fundus images containing no sign of DR.
5.	MESSIDOR [18]	45° FOV	1440 × 960, 2240 × 1488, 2304 × 1536	1200 colored fundus images, out of which 800 images are acquired with pupil dilation and 400 without dilation.

background such that all of the image pixels are distributed into two dominant modes of the dynamic range of pixels. Then select a threshold value based on the intensity variation of foreground and background objects to exactly separate these two modes and extract the object from the background [22, 23]. The algorithm used for thresholding is explained in the following section.

Algorithm 1

Input: Image f (x,y)
Output: Segmented image after extracting the optical disc

BEGIN
Step 1: Take the input image and convert the RGB image into gray scale image.
Step 2: As OD is the brightest part in the fundus image, select a threshold value to extract the brightest object from the image and rest is considered as the background.
Step 3: At any point *(x,y)* in the image at which $f(x,y) > T$ is considered an object point and otherwise the point is considered as background.
Step 4: The optical disc segmented part *g (x,y)* is given by

$$g(x,y) = \begin{cases} 255\ (White) & if\ f(x,y) > T \\ 0\ (Black) & if\ f(x,y) \leq T \end{cases}$$

Step 5: Fundus image after extracting the optical disc is obtained by subtracting the segmented part from the original gray scale image.
END

Region Growing: This procedure groups pixels or small sub-regions into larger regions based on some predefined criteria for growth. It involves the selection of initial seed point and then growing the regions by appending those neighbouring pixels to the seed point having similar properties to those of the seed point. The properties upon which the similarity is calculated may be a specific range of intensity or color. The region growing in this technique depends upon the homogeneous neighbouring pixels around the seed. The selection of similarity criteria depends upon the image type of the data available and also on the problem under consideration.

Algorithm 2

Input: Original Image f (x,y)

Output: Segmented image after extracting the optical disc

BEGIN

Step 1: input image and convert the RGB image into grayscale image.
Step 2: Calculate the centre of the optical disc and take that point as the initial seed point *S (x,y)* array containing 1's at the location of the seed point and 0's elsewhere.
Step 3: All the connecting pixels in the neighbourhood of *S (x,y)* fulfilling the similarity criteria are eroded to one pixel and labelled as 1 and all other pixels in S are labelled as 0.
Step 4: Set a threshold value as the absolute difference between the seed and the pixels at *(x,y)*. This threshold is considered as the stopping criteria that give the difference in the intensity values differentiating a darker and a brighter region.
END

Mathematical Morphology (MM): Morphology is an image processing tool that is particularly suitable for extracting and analyzing region shapes like boundaries, skeletons, etc. in images. For morphological operations, a structuring element is used that is a small subset or a sub image used to investigate the image under study to determine the properties of interest. Green channel image is complemented followed by adaptive histogram equalization to apply morphological operations. Morphological opening function is used and the morphologically opened image is subtracted from the histogram equalized image to obtain optical disc segmented image.

2.3 Proposed Methodology

This research work anticipates the importance of OD segmentation and blood vessel extraction in the diagnosis and computer aided screening of fundus images. The fundus images obtained from the databases lack clarity due to poor contrast as they are under illuminated and these images also have larger dimensions which increase the system complexity. These artefacts are removed from the image by using image pre-processing techniques.

Figure 1. gives the block diagram of proposed approach for this research work. Fundus images are collected from fundus image databases [14, 15] and are pre-processed utilizing steps like intensity conversion, image denoising and image contrast

enhancement. The various Optical disc segmentation algorithms were implemented on fundus images taken from DRIVE and STARE databases. The centroid of the image is determined followed by detection of optical disc boundaries using morphological operations for optical disc segmentation and removal. After critical analysis of all these OD segmentation techniques, authors proposed a Mathematical Morphology based Fuzzy Algorithm approach for optical disc removal. Various performance metrics are evaluated to validate the proposed method. The algorithm for the proposed approach is depicted in the flowchart shown in Fig. 2.

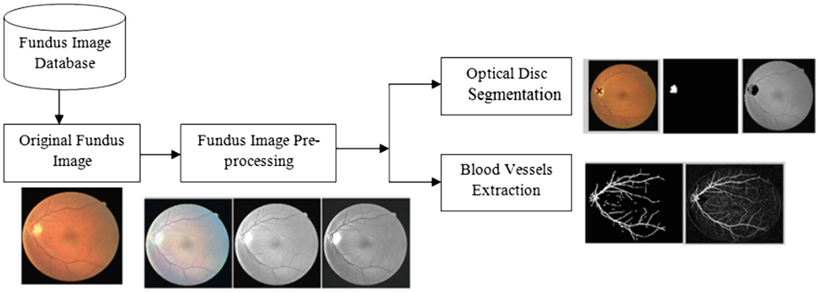

Fig. 1. Block diagram for the proposed approach

2.4 Performance Evaluation Metrics

For this research work various performance metrics are also incorporates to validate the result of the proposed approach and it was found that fuzzy approach when combined with MM approach gives better results in terms of Structural Similarity Index (SSIM), Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR) and run time elapsed when the extracted blood vessels are compared with the ground truth images.

3 Results and Discussion

3.1 Experiment 1

DRIVE database [14] is considered for this experiment to investigate and analyze the effectiveness of all the algorithms explained in the Sect. 2.2. All the experiments are performed using MATLAB2013 software and a tabular comparison is also presented to investigate parameters of ground truth blood vessel images and extracted blood vessels for better quality assessment. In this experiment the OD segmentation using thresholding function is investigated and is shown in Fig. 3. The figure depicts the original image, grayscale converted image, segmented part of optical disc along with the output fundus image after removing the OD. The drawback of this approach lies in setting a new threshold value every time for a new fundus image to be processed. A constant threshold value does not work for this segmentation approach as the intensity of OD is not same for all the fundus images.

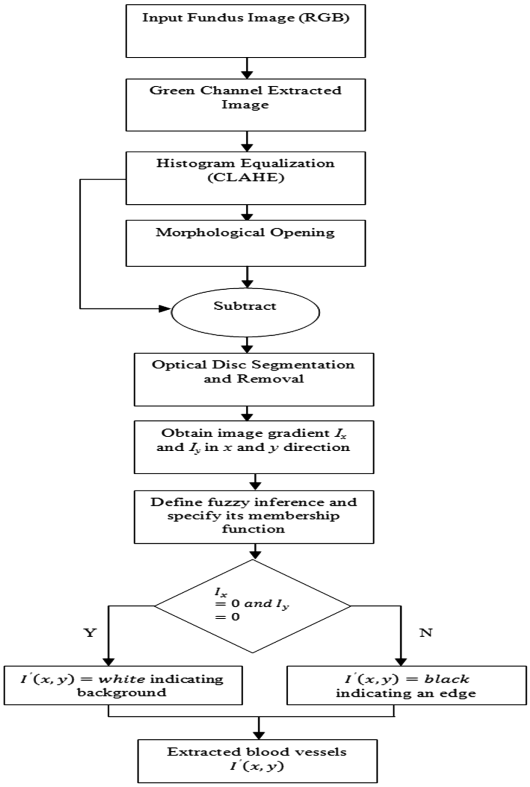

Fig. 2. Flowchart of proposed approach for OD segmentation and blood vessel extraction

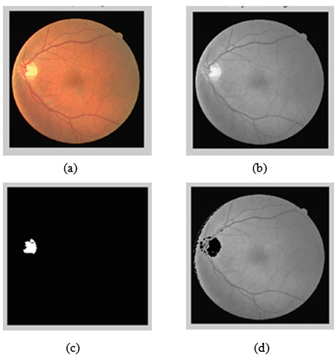

Fig. 3. Optical disc segmentation using thresholding function (a) Input fundus image from DRIVE database, (b) grayscale converted image, (c) segmented part using thresholding and (d) output fundus image after OD segmentation

Region growing process is initiated through a seed point. Selection of seed point is the important criteria for region growing process and is an open challenge. Centre of optical disc is obtained and this point is considered as the seed point for region growing process. After selecting an initial seed point, regions are grown by appending to each seed those neighboring pixels those having the properties similar to the seed point. The absolute intensity difference between the seed point and pixel at point *(x, y)* to stop growing the region is set as stopping criterion. Figure 4. depicts the results obtained by OD Removal using Region Growing algorithm. Segmentation is done using Region growing process and the segmented part is shown along with the output fundus image.

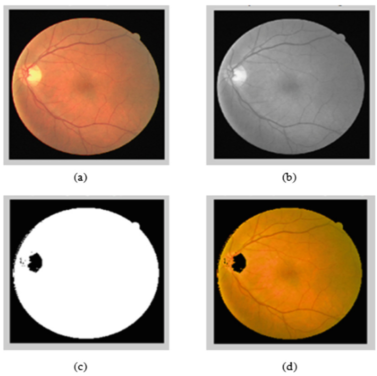

Fig. 4. optical disc removal using region growing approach (a) Input fundus image from DRIVE database, (b) grayscale converted image, (c) segmentation using region growing process and (d) output fundus image after OD segmentation using region growing

The results of Optical Disc elimination done using the MM approach are given in Fig. 5. Figure consists of the original fundus image depicted in Fig. 5(a), green channel is extracted as it is the maximum intensity channel and shown in Fig. 5(b). Segmented part of OD is shown in Fig. 5(c) and the output fundus image after OD segmentation is shown in Fig. 5(d).

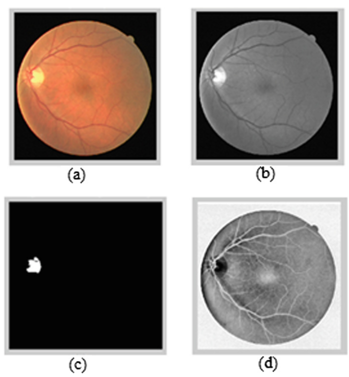

Fig. 5. Optical disc elimination using mathematical morphology approach

3.2 Experiment 2

Structured Analysis of Retina (STARE) consists of 20 fundus images captured by TopCon TRV-50 fundus camera with 35 degrees of FOV. Each image is digitized to 605 × 700 pixels with 24 bits per pixel resolution. Ground truth vessel segmentation was created for all the twenty images which are labelled manually by the professional expert [15]. Thresholding method for OD segmentation was investigated and it is shown in Fig. 6. Figure 6 depicts the original image, grayscale image, segmented part along with the output fundus image after removing the optical disc. It can be seen that for STARE database thresholding function segments all other parts also in the fundus image having similar intensity as optical disc. Thus this technique does not perform better for STARE database.

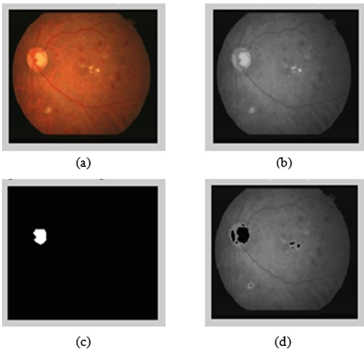

Fig. 6. Optical disc segmentation using thresholding function (a) Input fundus image from STARE database, (b) grayscale converted image, (c) segmented part using thresholding and (d) output fundus image after OD segmentation

Figure 7. gives the output of Region based Growing Segmentation method. It is the visualization of original image along with the output image of optical disc after applying Region Growing Algorithm.

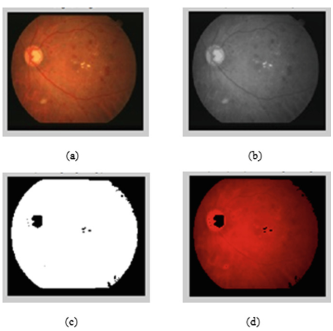

Fig. 7. Optical disc removal using region growing approach (a) Input fundus image from STARE database, (b) grayscale converted image, (c) segmentation using region growing process and (d) output fundus image after OD segmentation using region growing

Optical disc elimination done using MM approach is shown in Fig. 8. It consists of the original fundus image and green channel extracted image in Fig. 8(*a*) and (*b*). Segmented part is shown in Fig. 8(*c*) and the output fundus image after OD segmentation is shown in Fig. 8(*d*). It is clear from the visualization of results obtained from evaluating both DRIVE and STARE databases that MM yields better quality blood vessels after OD removal as compared to the other mentioned two techniques; Thresholding and Region Growing.

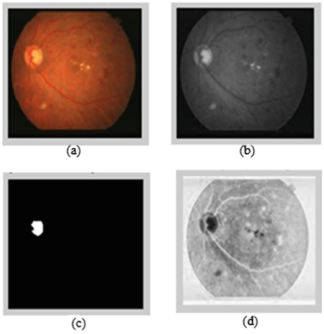

Fig. 8. Optical disc elimination and blood vessel extraction using MM approach

3.3 Extraction of Blood Vessels

After evaluating the optical disc segmentation results using all the approaches, it was revealed that MM approach gives the best results. Fuzzy algorithm is applied on output blood vessels obtained using MM algorithm. The results after applying fuzzy approach are shown in Fig. 9.

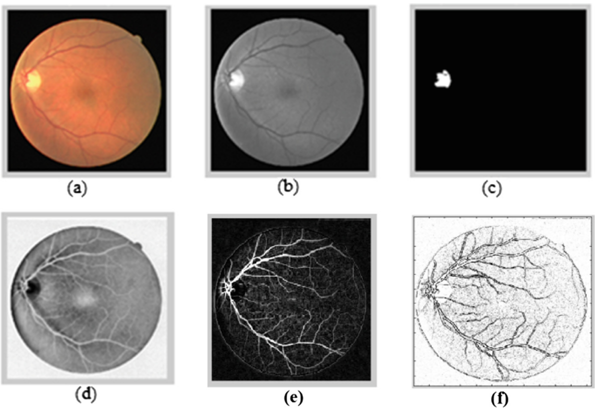

Fig. 9. Blood vessel extraction using proposed approach for DRIVE database image (a) Input fundus image from DRIVE database, (b) green channel converted image, (c) segmented region, (d) CLAHE converted image, (e) blood vessels after OD segmentation and (f) output of blood vessel extraction after applying fuzzy approach

It is seen that proposed approach yields better results for optical disc elimination and also blood vessels are better extracted using this method. Performance assessment of the proposed approach for optical disc elimination and blood vessel extraction is done in Table 2. Area in pixels for the extracted optical disc was calculated. The ground truth of blood vessels were available in the DRIVE database, thus on comparing the extracted blood vessels with the ground truth blood vessels labeled by hand, metrics like RMSE, PSNR, SSIM and run time elapsed are calculated. The range of SSIM is in between 0 to 1 and it is a similarity based parameter providing the statistical similarity information about extracted blood vessels and ground truth blood vessels. RMSE and PSNR are pixel intensity based parameters and they are also exploited in this research work to analyze the image quality of extracted blood vessels. Performance assessment of all the images taken from DRIVE database is done but the results for 10 images are reported in this paper. The ground truth images for original hand labeled images are missing for STARE database therefore the performance evaluation is done only for DRIVE database.

Table 2. Performance assessment parameters of proposed technique for blood vessel extraction using DRIVE database

Sample image	OD Area (pixels)	RMSE	PSNR	SSIM	Runtime elapsed (seconds)
Image_1	2213	0.9619	48.4681	0.8809	2.8248
Image_2	2024	0.9538	48.5420	0.8840	3.0535
Image_3	2036	0.9665	48.4266	0.8790	3.2653
Image_4	2044	0.9403	48.6656	0.8882	2.8248
Image_5	3116	0.9508	48.5690	0.8845	3.1663
Image_6	3694	0.9573	48.5098	0.8822	3.2183
Image_7	4426	0.9549	48.5314	0.8837	2.9538
Image_8	2516	0.9499	48.5772	0.8851	3.1135
Image_9	1935	0.9570	48.5123	0.8826	3.1138
Image_10	2009	0.9600	48.4856	0.8817	3.2743

Blood vessel extraction algorithms discussed in this paper are also compared with the existing approaches in Table 3 and it is revealed that the proposed approach gives the better results in terms of PSNR and MSE as compared to the proposed techniques discussed in [24] and [25]. PSNR should be high for better image quality, and PSNR computed in [24] gives the highest value approximately equal to 8 dB for method employing adaptive median filter. The proposed technique employed in this work has PSNR value of 48 dB which is much higher than reported in [24]. Another comparison is made with the work done in [25] comparing different histogram equalization approaches for comparative analysis of fundus image enhancement techniques. This comparison also reveals that our approach gives the better contrast enhancement as it employs CLAHE approach for histogram equalization which gives highest PSNR value out of all other HE approaches.

Table 3. Tabular comparison of existing techniques with proposed techniques

Sr. No.	Employed techniques	MSE	PSNR
1.	Adaptive median filter (30)	10305.77	8.00
2.	CLAHE (31)	129.49	27.01
3.	Proposed approach	0.96	48.53

4 Conclusion

In this research work, segmentation techniques are exploited for optical disc segmentation. A novel approach is proposed using mathematical morphology for optical disc removal and improving the blood vessel extraction by applying fuzzy algorithm. The experimentation was performed on all the images obtained from both the datasets but due to space constraints results form single image from each of the database are visualised. The proposed approach was concluded the most effective approach for identifying the optical disc to extract the blood vessels near the optical disc area for early diagnosis of diabetic retinopathy. For critical analysis, RMSE, PSNR, SSIM and run time elapsed were calculated, comparing the ground truth blood vessel images obtained from DRIVE database and extracted blood vessels using proposed technique. The future work in this field comprises further image analysis for feature extraction and classification to detect the lesions like MAs, HEMs, EXs, etc. to facilitate ophthalmic services for early detection of DR.

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