Fractal-based Automatic Localization and Segmentation of Optic Disc in Retinal Images

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Abstract— **In this paper, we proposed a novel algorithm to detect optic disc location in retinal images. Optic disc is a bright disk area and all major blood vessels and nerves originate from it. With its high fractal dimension of blood vessel, optic disc can be easily differentiated from other bright regions such as hard exudates and artifacts. Compared with existing algorithms, ours has much lower computational cost and is more robust. With the location known, segmentation of optic disc can then be done with a simple local histogram analysis. The algorithm can be valuable for automated batch processing for early stage retinal disease.**

Index Terms: fractal, histogram, retinal images

I. Introduction

Optic disk (OD) is an important object in retina images and can be served in many purposes. It can be used as a land mark in retina image registration [1]. More efficient searching schemes can be developed for retina image registration by means of OD position. Besides, OD is the origin of major blood vessels and nerves, so it's often used in blood vessel detection algorithms as initial points. Given the fixed position relationship between OD and macular center [2], OD position can also be used as a reference to locate macular area. Due to similar color tone to some other lesions such as hard exudates and cotton wool, accurate OD identification can be valuable to reduce the false positive rate of algorithms designed to detect those lesions. Furthermore, OD area itself contains valuable information for ophthalmologic diagnosis. For instance, the shape and size of OD are important indicators of glaucoma.

OD is characterized as bright yellowish disk, from which, blood vessels and optic nerves emerge. Many schemes have been proposed to detect OD. Early detection schemes aim simply to find the largest clusters of pixels with the highest intensities, while meets their difficulty when large hard exudates coexist in retinal image. Differentiating the two became a challenge. To overcome this, Li and Chutatpe [3] applied Principal Component Analysis (PCA) to each bright region. Based on images in a training set, eigenvectors of typical OD are calculated, new retinal image is projected onto the eigenvectors according to the eigenvalues. The point with the minimum distance between the retinal image and its projection is then chosen to be the center of optic disc. The method is very time-consuming and depends, to a large extent, on the training images, which may affect its correctness for images of different contrast and resolutions.

Other recently proposed techniques exploited the information provided by optic disc contour and vessel structure. Paper [4] relies on pyramidal decomposition and Hausdorff-based template matching technique for large scale object tracking. However, this method has its difficulty to differentiate optic disc from other large bright round objects such as spot artifact or hard exudates that are almost of the same size as optic disc. The algorithm presented in [5] is based on a geometrical directional pattern to model the OD position as converging point of all vessels. It provides a fitting model with respect to the entire vascular structure, with its parameters determined by the vessel directions in the whole retinal image to minimize the weighted residual sum of squares (RSS). The algorithm removes local minimum by introducing a global stochastic simulated annealing (SA) optimization procedure, at the cost of heavy computational burden.

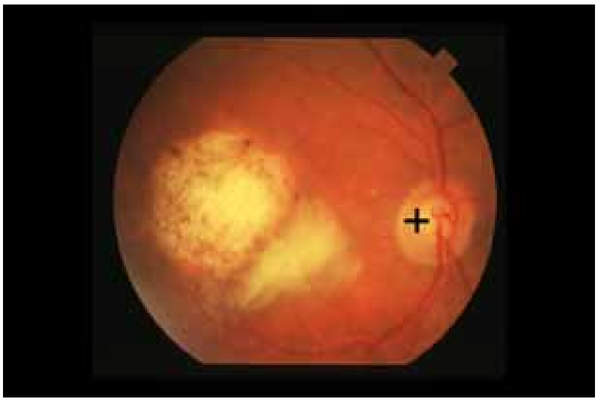
In this paper, we proposed a novel, simple and fast optic disc localization and segmentation method based on local fractal analysis. Candidate OD areas were first selected by detecting all bright spots in a local surrounding. On the binary large blood vessel skeleton map obtained from our previous work [6], fractal analysis is applied around the candidate areas and the one with the highest fractal dimension is considered as the OD. The identification criterion is justified by the fact that OD is the area where all major vessels merge, thus presents the highest fractal dimension compared to other bright regions such as hard exudates and artifacts (Figure 1a). Finally, the OD area is segmented by a local histogram analysis followed by a morphologic erosion procedure.

The rest of the paper is organized as follows. Section 2 presents the algorithm, demonstrates the effectiveness of fractal analysis in our region-based OD detection scheme and introduces the local histogram analysis method to segment the OD. Section 3 discusses the experiment results and evaluates the performance of our algorithm. Conclusions are made in Section 4.

II. Algorithm

A. Locating OD Area Using Fractal Analysis

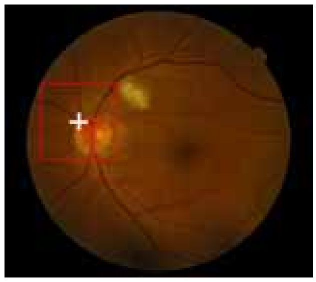
Fractal analysis has been widely used and demonstrated its effectiveness in spatial analysis of branching patterns in the fields of biology. Its key and fundamental concept, self-similarity, describes the geometric pattern that remains constant when viewed at different levels of scaling. Fractal dimension, D_f, is a widely accepted and useful quantitative



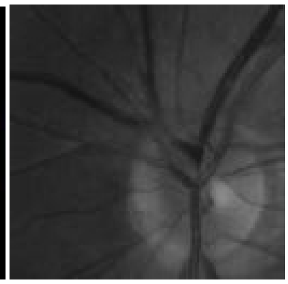
(a)

(b)

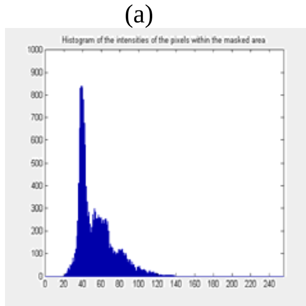
Figure 1 a) Retinal image containing large hard exudates. Position of optic disc marked with black cross. b) Blood vessel skeleton and centers of the bright regions found on the image marked with crosses



(a)



(b)



(c)

(d)

Figure 2 (a) The case that OD position is not accurate enough; (b) the area in the mask window (red square in (a)); (c) intensity histogram inside the mask window (d) 25% pixels count from the highest to lowest intensities.

measure of self-similarity for branching pattern object.

Numerous medial studies have substantiated the fact that retinal circulation of the normal human retinal vasculature is statistically self-similar. It has been reported with strong evidence that the fractal dimension of the blood vessels within the normal human retina is approximately 1.7 [7]. At the present stage, fractal analysis studies in retinal images focus mainly on region-based quantitative analysis of early-stage vascular disease in the human retina. Paper [8] used fractal analysis to characterize the neovascularisation process in diabetic retinopathy and paper [9] demonstrated the feasibility of fractal analysis of region-based vascular change in the normal and non-proliferative diabetic retina.

In our scheme, fractal analysis is utilized to differentiate OD area from other large and bright regions in retinal images due to the fact that OD area is the converging point of all major vessels, thus presenting much higher fractal dimension compared to other bright regions such as hard exudates, which are yellow deposits developing after leakage from retinal capillaries [10] and have few blood vessels within and around them.

In our previous work, we have developed algorithms to extract bright regions and blood vessel effectively [6] (See Figure 1b). Since the OD is the entrance for all the large blood vessels, parameters are tuned so as to preserve the large and median size blood vessels while suppressing the small ones for fewer disturbances. The size ratio of optic disc to the observable retina is usually a fixed value. We found that the ratio is about 1:7~1:7.5 in most images in our hand. To cooperate with the fractal dimension measurement that requires the mask window size to be the power of two (in this paper, maximal mask window size is 128), we resize the testing images to make the diameter of observable retinal region around 500 so that optic disc size is around 70. The values can be flexible as long as the final disc size is "significantly" smaller than 128 (i.e., the disc diameter is around half of the mask window size). We will clarify the reason in Section *B*. In the mask windows with size 128 centered at the centroid of bright areas, fractal dimension is computed. The area with the highest fractal dimension value is considered as the OD.

Box-counting method is used in this paper to calculate the fractal dimension of the binary vessel skeleton for its easy implementation on computer [7]. In box-counting algorithm, the binary image is blanketed repeatedly with square boxes of increasing side length (L=1, 2, 4, 8 .. 128). The number of boxes with side length L used (denoted by N(L)) are counted if and only if the box contains at least one white pixel. A linear least squares regression is applied to make a log-log plot of N(L) versus L. The negative value of line slope is used as the fractal dimension, D_f.

B. Local histogram analysis for OD position correction

Fractal-based analysis has found the rough center of OD in most cases. There are some cases (See Figure 2a), however, where the blood vessels within the optic disk present less contrast value against the optic disk area, thus making them difficult to be detected in batch processing when the blood vessel detection parameters cannot be tuned manually. Under these circumstances, however, the blood vessels in the vicinity of the outer ring of the optic disk are well detected. It

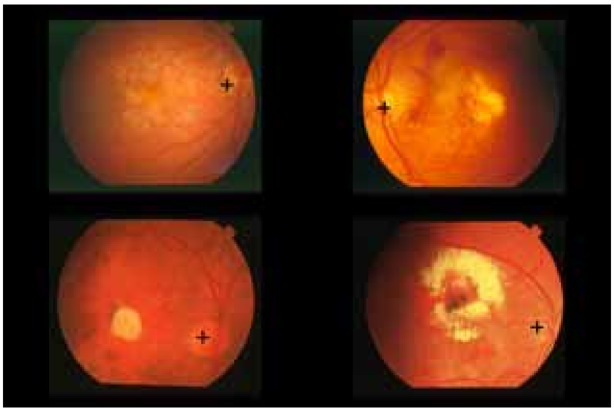


Figure 3 Detection results on images with severe disease

makes the center of the detected OD tend to locate near the outer contour of the real optic disk. A simple local histogram analysis is employed to do the correction. If the maximal mask size is chosen to be at least twice of the optic disc size. The whole disc area will be enclosed in the mask window (See Figure 2b). Noting that the optic disc is the brightest object inside the mask window and it counts about 25% of the number of pixels in the whole mask window, we can, therefore, locate a more accurate OD position by finding a threshold for the top 25% pixels with highest intensities using histogram analysis. The result is shown in Figure 2c. A morphologic erosion procedure is used to remove the salt noise. The centroid of the remaining pixels is the corrected optic disc position (See Figure 2).

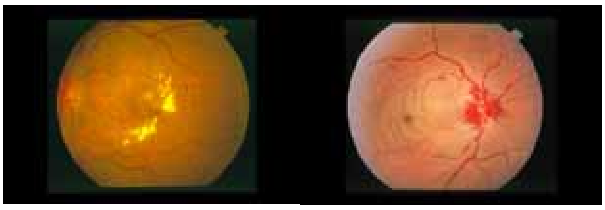
III. Results And Discussion

We tested our scheme for the DRIVE image database [11]. Our algorithm identifies 39 optic discs out of 40 images (including training and testing sets). We also test the algorithm on images with serious anomalies we collected in our projects. Our algorithm demonstrates strong ability to differentiate the true optic disc from bright lesions (See Figure 3).

The algorithm may fail when the optic disc is too dim or blurred (See Figure 4a). In that case, the algorithm in our previous paper failed to find the cluster of bright spot that is the real optic disc, as most existing algorithms did. These circumstances, however, break the assumption that OD is a bright oval disk or they are, indeed the symptoms for severe late stage retinal diseases (see Figure 4b) where automated computer detection for potential retinal diseases is of relatively lower value.

Fractal-based OD detection with histogram analysis correction outperforms the existing OD detection scheme in terms of speed and accuracy. Our algorithm can process an image of size 720*480 in 10 seconds with high true positive rate, while existing algorithms are either very slow [3, 5] or fast but not able to differentiate optic disc from other bright areas [4].

The fact that in most images of normal people and those in early stage of retinal disease the optic disc is a bright region



(a) (b)

Figure 4 (a) the main focus is on the macular area and the optic disk is therefore too dim to be detected based on its brightness. (b) OD has serious blood leaking and loses its characteristic as a bright disc

where large vessels converge makes our scheme quite suitable for automated batch processing in early retina disease screening. Follow-up research may take advantage of the accurate location of OD area to do retina image registration and reduce the false positive rate in retina lesion detection.

IV. Conclusion

A novel optic disc locating algorithm is proposed in this paper based on regional fractal and histogram analysis. The algorithm is superior to the existing algorithms in terms of computation time and accuracy. It has high value in clinic practice for automatic screening of early diabetic retinopathy.

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