Screening of Diabetic Retinopathy – Automatic Segmentation of Optic Disc in Colour Fundus Images

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Abstract

In this paper, a novel approach to automatically segment the optic disc contour using the center point of an optic disc candidate is proposed. The optic disc segmentation algorithm consists of 2 stages. The first stage involves the removal of blood vessels that obscure the optic disc. The blood vessel structures are detected using morphological operations. These detected structures are then removed by anisotropic diffusion smoothing. The second stage involves the detection of edge points belonging to the optic disc contour. A number of one dimensional intensity profiles which pass through the center point of optic disc region are then obtained at multiple angles with fixed angular intervals. The modulus maxima of each intensity profile are identified as a contour point for the optic disc. Among these contour points, some of the outliers are removed by re-positioning to a new position which complies with optic disc's shape using spline interpolation. Using these contour points, a coarse contour of the optic disc is constructed. Testing the approach on 23 colour fundus images demonstrates that the proposed algorithm is able to detect the optic disc contour to an accuracy of 92% to that drawn by a human expert.

Keywords

Optic disc contour segmentation, anisotropic diffusion, GVF snake, spline interpolation

1. Introduction

Diabetic retinopathy contributes to serious health problem in many parts of the world, particularly in advanced countries such as the United States of America and United Kingdom. In the United States alone, diabetic retinopathy affects over 5.3 million citizens aged between 18 and older or 2.5% of overall American population [1]. However, this health problem can be circumvented by screening and treatment at an early stage of the disease.

A computerized screening system can be used for fully automated mass screening. Such systems screen a large number of retinal images and identify abnormal images, which are then further examined by an ophthalmologist. This would save a significant amount of workload and time for ophthalmologists, allowing them to concentrate their resources on surgery and treatment. In many diabetic retinopathy screening systems, the segmentation of the optic disc contour is the first step for automatic detection and extraction of anatomical and pathological structures. It is because the optic disc contour provides useful information for automatic macula localisation [2], tracking for blood vessels structures [3] and [4], and detection of exudates [5]. Therefore, an accurate segmentation of the optic disc contour is absolutely essential.

This paper proposes an automated and robust optic disc segmentation algorithm for the optic disc contour detection in colour fundus images. The algorithm is robust in the sense that the optic disc contour can be segmented regardless of any shapes and at any location. Given the center point of an optic disc, a coarse estimate of optic disc contour can be constructed using the proposed algorithm. The coarse optic disc contour could be used as the initial configuration for a Gradient Vector Field (GVF) Snake algorithm to converge to an accurate contour of an optic disc using fewer iterations and thus lower possibility of converging to very nearby lesions.

2. Related Work

In ADRIS system, proposed by Goh. K. et.al. [6], the accuracy fitting of each ellipse shape is measured by neighborhood accumulation. The ellipse that returns the maximum response of neighborhood accumulation is considered as the optic disc and the outline of the ellipse is taken as the contour of the optic disc. Zheng Liu et al., [7] also proposed a similar approach by employing the Hough Transform on the edge map. The outline of Hough Transform that coincides with the maximum number of edges is taken as optic disc contour. In Alireza Osareh et. al., [8] true contour of optic disc is located by placing a GVF Snake within the homogeneous region of an optic disc. The GVF Snake will converge to the desired contour of the optic disc. F. Mendels et al [9] described a similar technique to identify the underlying boundary of optic disc using active contour approach. In Thomas et al work [10], watershed transformation is applied to locate the boundaries of optic disc with hexagonal shape of structuring element and size .arger than the width of blood vessels.

The proposed algorithm is inspired from [11] which had been employed in liver tumor segmentation in ultrasonic image. However, the proposed algorithm is differs from the method in [11] as well as past approaches in two ways. First, selective filtering using anisotropic diffusion is employed to produce a homogeneous region within optic disc region; to remove unwanted data such as small and tiny capillaries, blood vessels, microaneurysms and haemorrhages. It is differs from the method in [11] which anisotropic diffusion is used to generate a scale space instead of continuous wavelet transform. One advantage of using anisotropic diffusion is that it can generate a scale space where edges localisation is preserved [12]. Edge tracking through scales is not required and thus facilitate faster computation. Second, a coarse estimate of optic disc contour is obtained using a similar procedure in [11]. However, a modification is made on method in [11] for a better pruning of outlier contour points. Spline interpolation is incorporated into proposed algorithm to reposition detected contour points to new position in order to reduce the adverse effect of wrong detection of outlier points. The spline interpolation as the means of detection and pruning of outlier contour points is more robust compare to Mahalanobis distance, as being used in method [11]. The proposed algorithm will be explained in detail in following section.

3. Proposed Algorithm

3.1Overview

The proposed optic disc contour segmentation algorithm starts with the removal of blood vessels in the green colour band using a combination of morphological operations and anisotropic diffusion. The structures of the blood vessels are coarsely detected by applying a closing operation with a disk-like structuring element. Then, the blood vessel structures in the red band are smoothed using anisotropic diffusion until a homogeneous region remains within the optic disc region. After the blood vessel structures are satisfactorily removed, the next step is to construct a coarse estimate of the actual optic disc contour. This method adapted in this work is inspired by [11]. The algorithm proceeds as follows:

Stage 1: Elimination of blood vessels structures

- Detection of blood vessels by means of morphological operation
- Elimination of blood vessels by means of anisotropic diffusion

Stage 2: Construction of coarse optic disc contour

- Collection of contour point candidates
- Filtering outlier contour point by means of spline interpolation

The optic disc contour segmentation algorithm is graphically illustrated in Figure 1.

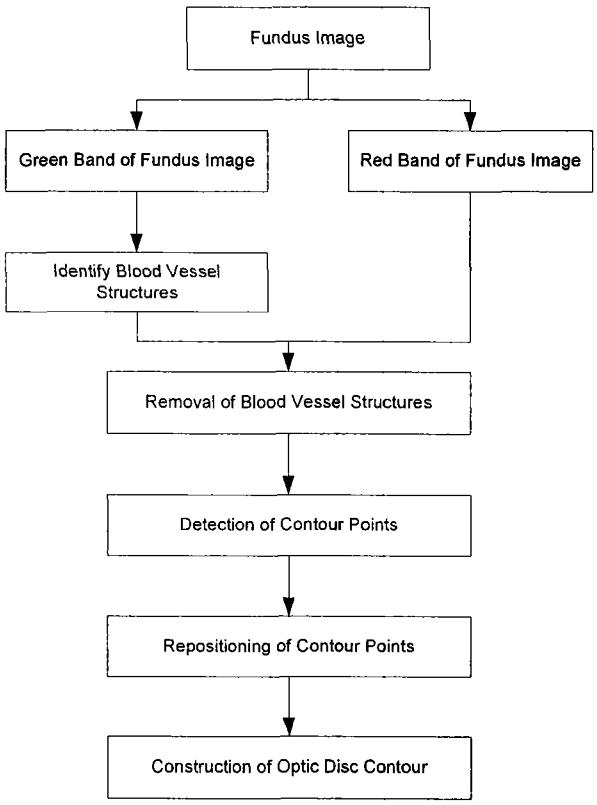


Figure 1: Overall flow of proposed optic disc contour segmentation algorithm

3.2 Choosing the Appropriate Band of Fundus Image

The three primary colour bands possess different information about the anatomical and pathological structures in the retinal image. For instance, in the red colour band, the optic disc is observed as a high intensity region with clearly defined edges. However, the red colour band alone is not sufficient for optic disc segmentation as it is saturated and reveals other high intensity patches that do not correspond to the actual optic disc region. This is shown in Figure 2 (a). The blood vessels that appear within the optic disc region may also cause misdetection of edges of optic disc contour. On the other hand, the optic disc in blue colour band appears as low intensity in low image contrast. Thus, this colour band may not be suitable for analysis in this work. The image obtained from the blue colour band is shown in Figure 2 (b). While the green colour band gives good image contrast for blood vessels structures, the high intensity patch which usually correspond to the optic disc region does not always represent the actual optic disc region. This is evidently shown in Figure 2 (c). In this work, the information from both the red and green colour bands is employed instead of using only one of these primary colour bands.

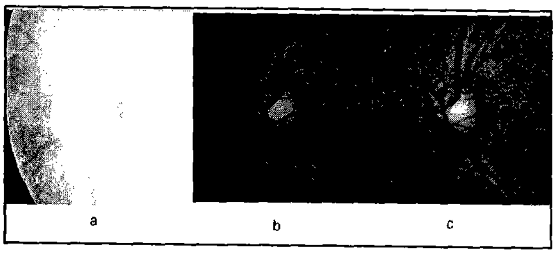
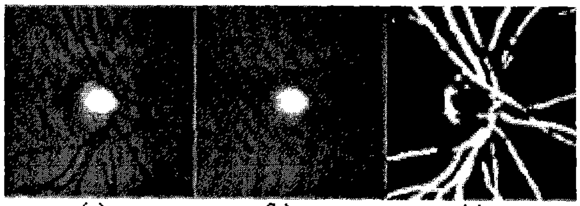


Figure 2: Appearance of the 3 primary colour bands of a typical fundus image. (a) Red band. (b) Blue band. (c) Green band.

3.3 Morphological operations for blood vessel detection

The blood vessels which obscure the optic disc region may complicate the segmentation of the optic disc contour. Therefore, prior to segmentation of optic disc contour, the blood vessels structures are first identified. In this procedure, two morphological operations are applied using a disk-like structuring element that has N pixels radius. A closing operation using this structuring element is applied on the green colour band of the fundus image. The closing operation consists of a dilation followed by an erosion morphological operation.

An absolute intensity difference image map is then obtained by subtracting the morphologically processed image with the original image. With these absolute intensity differences, a cumulative histogram is constructed. The response variable with the number of counts exceeds 90% of the maximum count in cumulative histogram is taken as the threshold. Thus, any absolute intensity difference that exceeds the obtained threshold is assumed as blood vessels structures. Figures 3 (a), (b) illustrate the image prior to and after the morphological operation and Figure 3(c) shows the identified blood vessels structure.



(a) (b) (c)

Figure 3: (a) Green colour band of fundus image before the morphological operations. (b) Green colour band of fundus image after the morphological operations. (c) The identified blood vessels structures

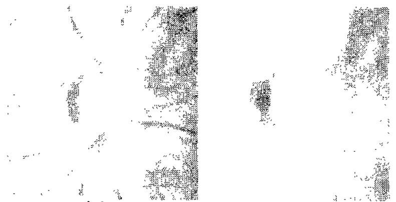
3.4 Removal of Blood Vessels Structures

A selective filtering or non-linear smoothing approach using anisotropic diffusion is applied on the red band of fundus image to smooth unwanted data, such as small and tiny capillaries, haemorrhages, microaneurysms while preserving important features such as the optic disc contour and blood vessels. However, the existence of blood vessels, especially within the optic disc region may cause misdetection of pixels belonging to blood vessels as optic disc contour points. Therefore, the blood vessels structures are eliminated using anisotropic diffusion. The anisotropic diffusion is adapted in such a way that the diffusivity function of the pixels that lie on the identified blood vessels structures is set to unity. This allows more smoothing within the blood vessels structures and at their edges through out all the iterations of anisotropic diffusion. The modified diffusivity function is shown below:

$$g(\nabla I)=\begin{cases} 1 & \text{Within the blood vessels structures} \\ \dfrac{1}{1+\dfrac{|\nabla I|^2}{K}} & \text{Not within the blood vessels structures} \end{cases} \qquad (1)$$

The details regarding the notation used in Equation (1) on anisotropic diffusion can be found in [13].

After several iterations of the anisotropic diffusion process, small features and blood vessels structures are effectively removed while optic disc contour is still well preserved. This facilitates the task of obtaining the true optic disc contour. Figure 4 (a) and (b) show the optic disc region before and after the removal of blood vessels structures using anisotropic diffusion.

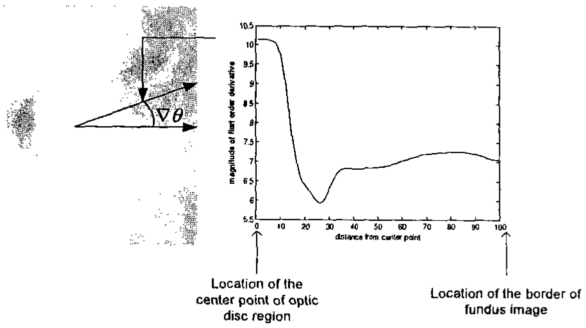


(a) (b)

Figure 4: (a) Before being processed by anisotropic diffusion. (b) After being processed by anisotropic diffusion

3.5 Detection of Contour Points

A number of one dimensional (1-D) intensity profiles are obtained which pass through the center point of optic disc region radially at fixed angular intervals. In this procedure, the angular interval, $\nabla\theta$ between one intensity profile to the next intensity profile is set to one degree. The first order derivative of the intensity profile is then calculated. From this first-order derivative, local maxima points are first identified and subsequently the local maxima point closest to the center of the optic disc is chosen as the contour points. This procedure is repeated for all the radial intensity profiles, as shown in Figure 5.



(a) (b)

Figure 5: Detection of contour points by one dimensional profile at multiple angles. (a) One dimensional intensity profile is drawn by passing through the center point of optic disc region till the border of fundus image. (b) The magnitude of first order derivation corresponds to the drawn profile in (a).

3.6 Repositioning of Contour Point to New Position Using Spline Interpolation

During the contour point detection process, there may be some contour point candidates that do not represent the actual optic disc contour. As stated earlier, these points are known as outliers. A signature is a one dimensional representation of a boundary which is drawn by plotting the distance between the center of optic disc to all contour points as a function of angle [14]. From this signature representation, outlier points that cause abrupt or large variations in term of distance are identified by searching for high gradient magnitude of the first order derivative. Once identified, the positions of these outliers are adjusted to a new position (reposition) which better reflects the true position of the optic disc contour. This new position is estimated using a spline interpolation [15]. Figure 6 (a) and (b) illustrate the signature representation of a detected optic disc contour, before and after the repositioning by spline interpolation.

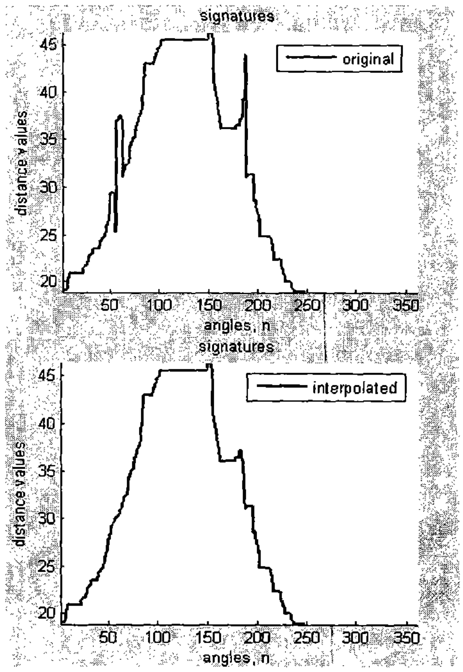
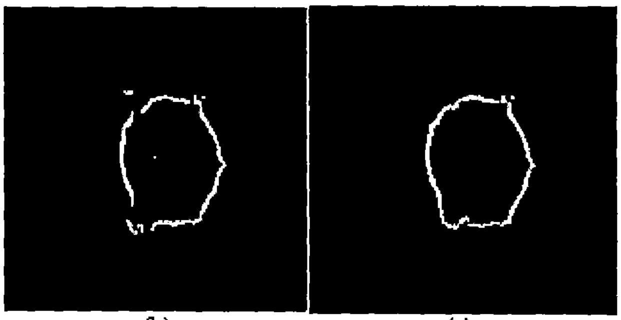


Figure 6: The signature representation for a detected optic disc contour. (a) Original signature representation (above) (b) Modified signature after spline interpolation (below)

Figure 7 (a) and (b) illustrate the obtained contour points before and after the repositioning by Spline interpolation depicted as a two-dimensional image.



(b) (c)

(a) (b)

Figure 7: A two-dimensional representation of the detected contour points of an optic disc. (a) Before preposition. (b) After repositioning using spline interpolation

3.7 Construction of the Coarse Estimate Optic Disc Contour

Using the position-adjusted contour points, a coarse estimate of the optic disc contour is constructed by connecting the detected contour points using a Snake approach. The outcome of this coarse estimate is shown in Figure 7.

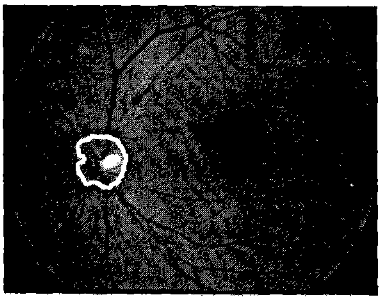


Figure 8: The coarse estimate of optic disc contour is highlighted

4 Result and Discussion

A set of 23 colour fundus images are tested to examine the performance of proposed algorithm. The results obtained using the proposed algorithm is compared to manually labeled images by ophthalmologist, using an overlap measure [3]. The simple and effective overlap measure is given in Eq.2:

$$M = \frac{N(R \cap T)}{N(R \cup T)} \times 100\% \quad (2)$$

where R and T are the two regions to be compared and the $N(\cdot)$ is the amount of pixels in the set. The performance of optic disc segmentation for each fundus image is illustrated as line graph in Figure 8. The proposed algorithm achieved 87% and 95% of maximum and minimum accuracy respectively, and the overall accuracy of 92.0%.

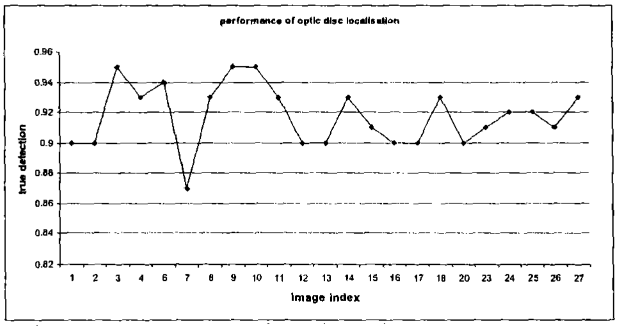


Figure 9: Performance of optic disc segmentation for each fundus image

One of the advantages of the proposed method is that it is more reliable and flexible in detecting contour points for various shapes of optic discs, such as oval, ellipse and circle as compared to method reported in [11]. In [11], the outliers are identified reliably based on the statistical metric of Mahalanobis distance. However, its weakness is that when an optic disc contour is detected as an ellipse form, some of the true contour points may fall outside the statistical range and possibly be considered as outliers. In this method, the statistical range is computed as mean + standard deviation. The said approach only reliably eliminates outliers if the optic disc contours appear as a regular circle. In reality, most optic discs do not appear as regular circles, this is especially so in the fundus image database currently used for this work. Comparative results for outlier contour points elimination between [11] and the proposed method are shown in Figure 9.

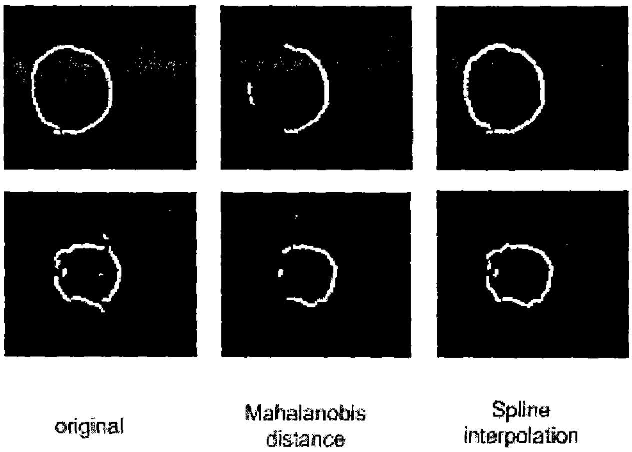


Figure 10: Comparative results for outlier contour points' elimination between [11] and the proposed method.

As observed in Figure 9, some of the contour points are wrongly identified as outliers and are eliminated when Mahalanobis distance is used. However, in the proposed approach, only contour points that produce sudden variation in distance in signature representation are considered as outliers, as shown in the last column in Figure 9.

The assessment of accuracy for optic disc contour segmentation is not an easy task. The hand labeled contour by human graders are not perfect and it may not correspond to the true optic disc contour. Hence, achieving a perfect accuracy of 100% using the overlap measure is impossible since neither the manually labeled optic disc contour nor the automatically segmented contour may correspond to the *true* optic disc contour. In this case, a result of more than 90% is deemed to be fairly accurate.

5. Conclusions

The accuracy and effectiveness of proposed algorithm in comparison to human graders have been evaluated using set of 23 colour fundus images and the results are very promising. With the accuracy of 92.0%, it can be concluded that the coarse estimate optic disc contour is very approximate to the actual optic disc contour. In future work, this result may be further improved by using this coarse optic disc contour as an initial configuration of Gradient Vector Flow (GVF) Snake to find a more accurate contour of the optic disc. The applicability of the proposed automated optic disc contour segmentation for the practical use in a cost-effective mass screening system is being investigated.

6. References

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