AUTOMATED LOCALISATION OF RETINAL OPTIC DISK USING HOUGH TRANSFORM

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ABSTRACT

The retinal fundus photograph is widely used in the diagnosis and treatment of various eye diseases such as diabetic retinopathy and glaucoma. Medical image analysis and processing has great significance in the field of medicine, especially in non-invasive treatment and clinical study. Normally fundus images are manually graded by specially trained clinicians in a time-consuming and resource-intensive process. A computer-aided fundus image analysis could provide an immediate detection and characterisation of retinal features prior to specialist inspection. This paper describes a novel method to automatically localise one such feature: the optic disk. The proposed method consists of two steps: in the first step, a circular region of interest is found by first isolating the brightest area in the image by means of morphological processing, and in the second step, the Hough transform is used to detect the main circular feature (corresponding to the optical disk) within the positive horizontal gradient image within this region of interest. Initial results on a database of fundus images show that the proposed method is effective and favourable in relation to comparable techniques.

***Index Terms*—** retinal imaging, morphological processing, Hough transform, biomedical imaging, optic disk.

1. INTRODUCTION

Fundus images are used for diagnosis by trained clinicians to check for any abnormalities or any change in the retina. They are captured by using special devices called ophthalmoscopes. A typical fundus image with its features marked is shown in the Figure 1. Each pixel in the fundus image consists of three values namely red, green and blue, each value being quantised to 256 levels.

The information about the optic disk can be used to examine severity of some diseases such as glaucoma. Changes in the optic disk can indicate the current state and progression of a certain disease. The location of the optic disk is an important issue in retinal image analysis as it is a significant landmark feature, and its diameter is usually used as a reference length for measuring distances and sizes. It approximately determines the localisation of the fovea or the centre of vision, which is of great importance as lesions in the macular region affect vision dramatically.

Localisation of the retinal optic disk has been attempted by several researchers recently. The optic disc is usually the brightest component on the fundus, and therefore a cluster of high intensity pixels will identify the optic disc location. This works well, unless there are other potential fundus features such as exudates. Principal component analysis has been used by Chutatape and Li to differentiate the optic disc from other sources [1]. They produced a training set using the brightest pixels that were firstly clustered as candidate optic disc regions. Principal component analysis was then applied to project a new image to the 'disc space'. Then, the location of the optic disc centre was found by calculating the minimum distance between the original retinal image and its projection.

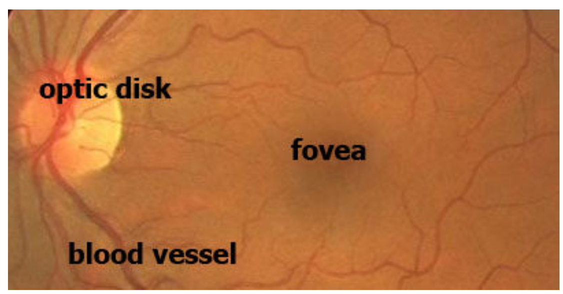

Fig. 1. Colour fundus image showing main features of retina

Sinthanayothin *et al.* correctly identified the location of the optic disc employing the variance of intensity between the optic disc and adjacent blood vessels in 111 of 112 colour fundal images, giving both a sensitivity and specificity of 99.1% [2]. However, this algorithm often fails for fundus images with a large number of white lesions, or strongly visible choroidal vessels. Akita and Kuga localised the optic disc by backtracking the vessels to their origin [3]. This is certainly one of the safest ways to localise the optic disc, but is heavily reliant on successful vessel detection. Mendels *et al* used the morphological filtering techniques and active contours to find the boundary of the optic disc [4]. Walter and Klein used an area threshold to localise the optic disc and the watershed transformation to find its contours [5]. Hoover and Goldbaum correctly identify the optic disc location in 89% of 81 images, 50 of which were diseased retinas using a ''fuzzy convergence'' algorithm [6]. Park *et al* [7] used the repeated thresholding technique to find the brightest particle, then used the roundness of the object to detect optic disk features, finally localised the optic disk by using the Hough transform.

This work seeks to address some of the limitations of these techniques by proposing an alternative approach to retinal optic disk localisation. Morphology is used to locate the brightest region within the image and a Hough Transform is used to detect circular features within the gradient image of the resulting region of interest. The proposed method uses the gradient of the image rather than the intensity of the image as used in [7]. The Hough transform is implemented without using any iteration to reduce the computational complexity. This results in a modest improvement in the localisation success rate in addition to an anticipated reduction in computational cost.

This paper is structured as follows: Section 2 presents the methodology and outlines the main techniques used, while Section 3 presents the results. Conclusions are presented in Section 4.

2. METHODOLOGY

The optic disk appears in colour fundus images as a bright yellowish or white region. Its shape is more or less circular, interrupted by outgoing vessels. Although sometimes due to the nature of the photographic projection it has the form of an ellipse.

Mathematical morphology in image processing is particularly suitable for analysing shapes in images. The two main processes are those of dilation and erosion. These processes involve a special mechanism of combining two sets of pixels. Usually, one set consists of the image being processed and the other a smaller set of pixels known as a structuring element or kernel. Two very important transformations are opening and closing. Intuitively, dilation expands an image object and erosion shrinks it. Opening generally smoothes the contour in an image, breaking narrow isthmuses and eliminating thin protrusions. Closing tends to narrow smooth sections of contours, fusing narrow breaks and long thin gulfs, eliminating small holes, and filling gaps in contours. Algorithms combining the above processes are used to create mechanisms of edge detection, noise removal and background removal as well as for finding specific shapes in images.

The morphological operations we used are as below. Here $f(x, y)$ is a grayscale image function defined on grid Z^2 and B is a binary structuring element.

Dilation

$$(f \oplus B)(x, y) = max\{f(x-s, y-t) | (s,t) \in B\}$$

Erosion

$$(f \ominus B)(x, y) = min\{f(x+s, y+t) | (s,t) \in B\}$$

Opening

$$f \circ B = (f \ominus B) \oplus B$$

Closing

$$f \cdot B = (f \oplus B) \ominus B$$

Reconstruction

$$\rho f(g) = \vee_{n \geq 1} \partial_f^{(n)}(g)$$

In the above, $\vee$ stands for the point-wise maximum and $\partial_f^{(n)}(g) = (g \oplus nB) \wedge f$, where nB is the self-dilation of B (n-1) times and $\wedge$ denotes the point-wise minimum.

The green component of the image is used, since it shows a good variation between the optic disk and the background. As in [2], the local intensity variation of the image is used to find the locus of the optic disc. As the optic disc is a bright pattern, and as the vessels appear dark, the gray level variation in this region is higher than in any other part of the image. Unfortunately, this is only true if there are no exudates on a dark background. Therefore, a shade-correction operator is used in order to remove slow background variations. This has been calculated by subtracting the approximated background from the green channel. The approximated background is calculated by performing a series of morphological opening and closing. The binary image which contains the brightest and the biggest part from the shade corrected image is computed by the area thresholding method. The initial boundary of the optic disk is traced from that binary image. A region of interest (ROI), which consists of only the optic disk, is used to find the contours of the optic disk. The magnitude gradient of the image for the ROI is calculated with the use of morphological operations. Initially morphological closing is performed on the ROI to fill the vessels, and then to remove large peaks morphological opening is performed. Then the image is reconstructed using morphological reconstruction. Then the gradient is calculated by subtracting the eroded ROI from the dilated one.

The boundary of the optic disk and its centre are found by applying the Hough transform to the gradient image. The Hough transform is a method for finding shapes in an image. The basic idea behind the Hough transform is to transform the image into a parameter space that is constructed specifically to describe the desired shape analytically. Maxima in this parameter space then correspond to the presence of the desired shape in image space. The circular Hough transform is almost identical to the Hough transform for lines, but uses the parametric form for a circle:

$$(x-a)^2 + (y-b)^2 = r^2 \qquad (1)$$

where (a, b) is the centre of the circle of radius r that passes through (x, y).

The Hough space is three dimensional. The gradient image is transformed to a set of 3 parameters, representing the accumulator, its centre and its radius. For each feature point, votes are accumulated in an accumulator array for all parameter combinations. The accumulator will have set of edge points; each edge points contribute a circle of radius r in the accumulation space. The accumulation space has a peak where these contributory circles overlap at the centre of the original circle. The centre is an $N\times2$ matrix with each row containing the (x, y) positions of the circles detected in the image. The estimated radius of the circles detected is stored in an $N\times1$ column vector with a one-to-one correspondence to the centre array. The corresponding circle can then be plotted over the original fundus image.

Referring to Fig. 2(a), the green channel of the image is selected as in Fig. 2(b). Fig. 2(c) shows the approximated background which is subtracted from Fig. 2(b) to get the shade corrected image as in Fig. 2(d). This is then thresholded to find the brightest part in the image and the initially traced boundary is marked on the image as shown in Fig. 2(e). From this boundary, the ROI is chosen as a circle centred at the centroid of this detected region, and with a radius of twice the expected radius of the optical disk Fig. 2(f) shows the region of interest.

Fig. 3(a) shows the ROI. Fig. 3(b) shows the gradient image for the selected ROI to which the Hough transform is applied to detect the circular optic disk, as illustrated in Fig. 3(c).

3. RESULTS

The proposed technique was tested on the DRIVE database of retinal images [8]. This consists of 40 fundus images of dimensions 768×584, captured by a Canon CR5 non-mydriatic 3CCD camera with a 45^{o} field of view (FOV). These images contain both normal (healthy) and abnormal retinas. In this study 38 of these images were used (2 images have been excluded for not having visually-detectable optic disks) consisting of 31 normal and 7 abnormal images. The performance of the optic disk localisation was evaluated based on the determined optic disk location with regard to an expert. Our proposed method is capable of localising the optic disk correctly for 36 of these images. The success rate was 94.7%. This was a notable result compared to the method used in [7] achieving 90.25% for the same DRIVE dataset.

The proposed method has also been tested with the STARE dataset [9]. This consists of 20 fundus images of dimensions 605×700, captured by a TopCon TRV-50 fundus camera at 35^{o} FOV. The proposed method is implemented on 17 images consisting of 9 normal and 8 abnormal images (3 images have been excluded for not having visually-detectable optic disks). Our proposed method localised the optic disk correctly in 14 images with a success rate of 82.3%, bringing the overall success rate over both datasets to 90.9%. This compares favourably with published results in this regard [3-7] as below.

Mendels *et al* [4] tested their method on a set of 9 images with a success rate of 100%. Walter and Klein [5] tested their algorithm on 30 images with a success rate of 90%. However, in some of the images, there were small parts missing or small false positives. Hoover and Goldbaum [6] evaluated their method on 81 images with a success rate of 89%. Park *et al* [7] evaluated their method on the DRIVE database with a success rate of 90.25%.

Over both datasets, our method failed to localise the optic disk in 5 out of 55 images. This is due to the ineptness of the shade correction operator and the automatic thresholding.

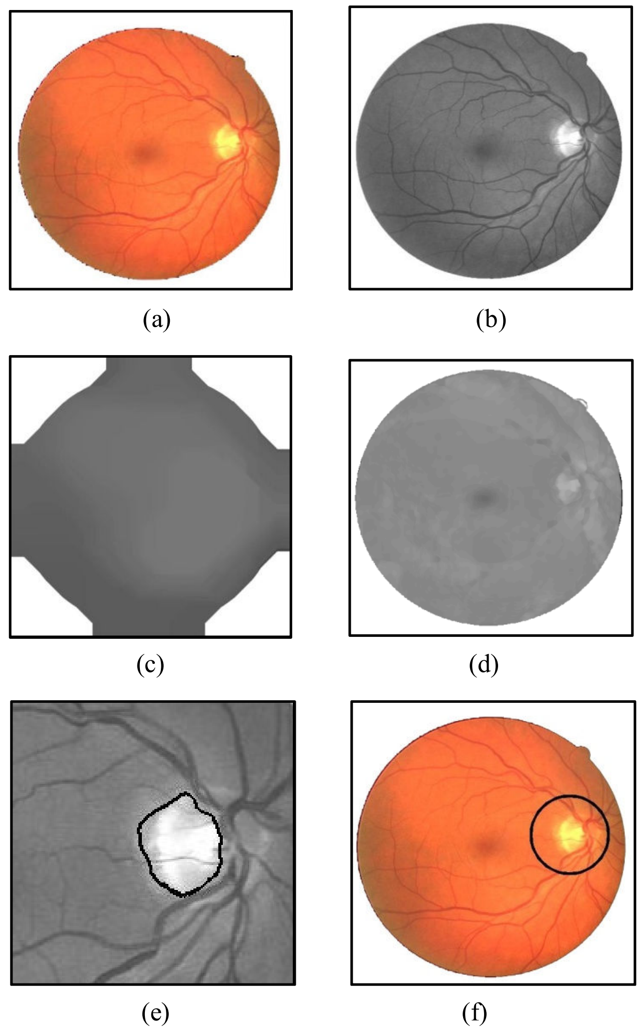

Fig. 2. Results of applying morphological processing to a healthy retinal image: (a) Original fundus image (b) Green channel (c) Approximated background (d) After background removal and filtering of blood vessels. (e) Initial traced boundary (f) ROI for optical disk search.

4. CONCLUSIONS

In this paper, a computer-assisted retinal image analysis system for the localisation of optic disk in colour digital fundus images has been presented. This is achieved by means of morphological processing followed by the circular

Hough transform on the image gradient to detect the contour of the optic disk within a circular region of interest. The number of edge pixels and the number of radii used is reduced by applying Hough transform only to the gradient image, since the computational complexity of the Hough transformation is highly dependent on the number of edge pixels and the number of radii to be matched.

The method can be further improved by making a robust shade correction operator and automatic thresholding. The identification can also be improved by proposing a model which identifies the optic disk shape properly by adjusting the Hough transform to identify both circular and elliptical shapes.

The results obtained thus far are promising and demonstrate the applicability of the proposed system. Further tests should be carried out on the proposed method when more suitable clinical data will be available. Such tests could contribute to further improvements, resulting in more robust and accurate detection that eventually could be adapted for clinical purposes.

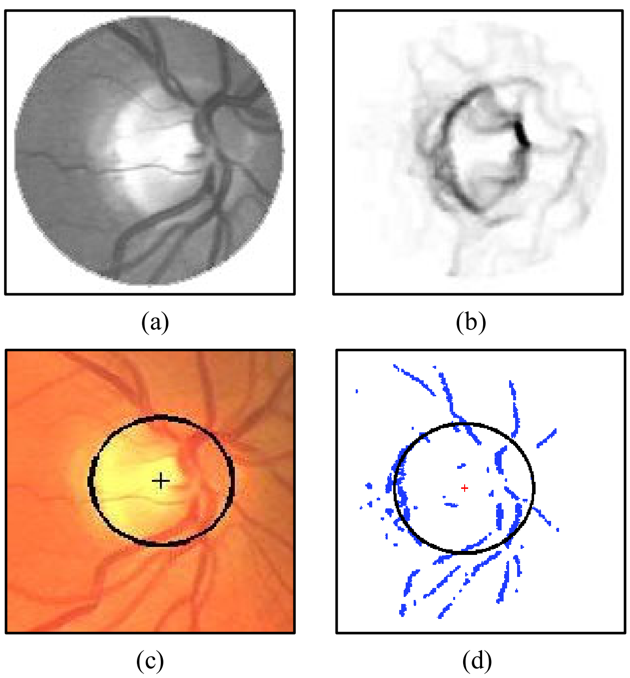

Fig. 3. (a) Close-up of ROI (b) Reconstructed gradient, (c) Detected circle representing optical disk boundary overlaid on original image (d) plot of gradient points and detected circle representing optical disk.

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