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METHOD ARTICLE

Vessel masking and Hough transform for optic disc localisation from retinal images [version 1; peer review: awaiting peer review]

Aziah Ali ¹, Wan Mimi Diyana Wan Zaki ², Aini Hussain², Noramiza Hashim ¹, Wan Noorshahida Mohd Isa¹

¹Faculty of Computing & Informatics, Multimedia University, Cyberjaya, Selangor, 63100, Malaysia

²Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor, 43600, Malaysia

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Abstract

Background: Retinal images can be considered as one of the reliable indicators for symptoms of many ocular diseases such as diabetic retinopathy, macular degeneration and glaucoma. By analysing and tracking changes of important structures on a retinal image, symptoms of ocular diseases can be detected in a timely manner which helps physicians plan early treatment for better disease control. One of the important landmarks on a retinal image is the optic disc (OD), which must be localised to estimate retinal vessel parameters such as vessel width and tortuosity. This paper proposes a method for automatic OD localisation from a retinal image.

Methods: A retinal image is first pre-processed and thresholded to produce a binary image that highlights most retinal vessels on the image. Next, a discrete cosine transform-based smoothing method is employed to replace the detected vessel pixel values on the pre-processed image with values closer to the surrounding neighbour pixel values, effectively masking most vessels on the image. Hough transform is then applied to the vessel-masked image to detect the circle representing the OD on the image, producing the estimated location of the OD center and its estimated diameter.

Results: Applying the proposed method to three different public databases, namely Digital Retinal Images for Vessel Extraction (DRIVE), High-Resolution Fundus (HRF) and Methods to Evaluate Segmentation and Indexing Techniques in the field of Retinal Ophthalmology (MESSIDOR) resulted in an overall detection rate of 99.53%.

Conclusions: The achieved performance by the proposed method is superior to many published methods of OD localization, with a processing time of less than one second for each image. While this has only been validated on one type of retinal images, future investigations may include validation on other types such as

angiograms or scanning laser ophthalmoscopy.

Keywords

Optic disc localisation, fundus image, vessel masking, Hough transform

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Corresponding author: Aziah Ali (aziah.ali@mmu.edu.my)

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Introduction

Retinal image analysis can be very helpful in providing insights into patients' ocular health. By analysing the retinal image, ophthalmologists can detect various symptoms of ocular diseases, which may help to ensure timely treatment of the diseases, thus ultimately decreasing the risk of patients going totally blind. Most hospitals are now equipped with modern fundus cameras that image the patient's fundus to produce a retinal image. **Figure 1** shows a sample of a fundus image. Nerves from the retina converge to form a round or oval optic disc (OD) that sends a focused image onto the retina, in the form of electrical impulses to the part of the brain responsible for visual function. The central part of the retina, known as the macula, is responsible for an important part of the central vision system, while the fovea is the point in the middle of the macula.

With routine retinal screening in place, a huge number of fundus images will need to be analysed daily. This scenario has resulted in a lot of research being conducted on the automatic analysis of fundus images to assist ophthalmologists in efficiently and accurately performing retinal diagnoses.^{1,2} These studies aim to extract important parameters from a fundus image, mostly related to the important landmarks, including the OD, retinal blood vessels, fovea, macula, and any associated anomalies.

A topic of interest regarding fundus image analysis is the automatic localisation of the OD from a fundus image. By detecting the OD, parameters such as its position and radius could be used to estimate other parameters such as vessel width or tortuosity. Normally, when measuring for these parameters from a fundus image, to be considered for parameter calculation the vessels are to be of certain distance close to the OD.³ OD detection would also allow for identification of the eye side from which the image is taken, whether right eye or left eye.

A number of studies have been dedicated to automatically detecting the OD on the fundus image,^{4–8} while others have also attempted at providing a more accurate boundary of the detected OD.^{9–12} The methods used include circular transformation,¹¹ directional local contrast,¹³ probability models,⁶ automatic thresholding³ and deep learning.^{12,14}

Thresholding works in locating the OD in fundus images with high-intensity differences between the OD region and other parts of the image.^{15–18} When dealing with images containing an OD with low contrast against the retinal background or images with pathologies, the thresholding method may fail to detect the OD.¹⁹ A set of points is used to describe the OD boundary by minimising the energy function in active contour-based methods for OD detection.^{8,20–22} While this method may work well, its performance is very much dependent on the initial seed points for the contour model. There is also the risk of being trapped in a local maximum when searching for the OD boundary, especially with images containing pathologies. Extensive review of existing OD segmentation methods can be found in the review literature.^{19,23}

OD localisation focuses more on locating the position of OD center on the fundus image, which is different from the focus of the OD segmentation procedure. In OD segmentation, the general aim is to identify every pixel that belongs to the OD on the fundus. In most applications, OD localisation precedes the OD segmentation step; hence it is important to have an accurate estimate of the OD center through OD localisation to ensure a successful OD segmentation procedure. Since the OD is usually a bright disc-shaped area on the fundus image, some researchers have investigated the use of the Hough transform technique to detect the shape and thus estimate the center of the OD.^{3,24–27} Many researchers employ methods to remove vessel structures from the fundus image, or use vessel masking, to further highlight the OD structure, such as

Figure 1. A sample of a fundus image with important landmarks labeled.

inpainting²⁸ and median filtering.²⁴ Combining Hough transform with vessel masking can be a potential method to efficiently localise the OD in a fundus image, instead of using the methods separately.^{24–28}

Methods

A method inspired by combining existing efficient OD localisation methods, namely thresholding, vessel masking and Hough transform, is proposed to localise the OD centre's position from a fundus image.

The proposed OD localisation method takes a color fundus image as the input. Firstly, the green channel image is extracted from the color image as part of pre-processing. Next, the green channel image is padded around the original region of interest (ROI - the circular non-black area), with additional pixels matching the pixel values along the border. This pre-processing step is similar to Soares' proposed method²⁹ for retinal vessel segmentation, except that the number of iterations for ROI padding is increased to 50 instead of 20. This step helps to minimise the contrast between the ROI and background further so it would not be falsely detected as the OD centre in the following step. The pre-processed image is then resized to a standardised smaller size for faster computation and is converted to a binary image using a global thresholding method, called Otsu's method. The binary image will highlight most vessel structures in the pre-processed fundus image in white pixels, while the retinal background is in black pixels. This method is implemented using the **Matlab** software, which can potentially be translated into **SCILAB** as an open-source alternative.

Next, using the vessel pixel information from the binary image, a discrete cosine transform-based smoothing method is employed on the pre-processed image to replace all the vessel pixel values with values closer to the surrounding neighbours. This vessel masking step will effectively remove most of the vessel structures from the image, resulting in a vessel-masked image. The Hough transform is then applied to detect the circle representing the OD on the image. Once the circle has been detected, the OD centre and the radius can then be estimated to be used in the estimation of important retinal parameters such as cup-to-disc ratio, tortuosity and calibre of the retinal vessels.

Figure 2 depicts all steps involved in OD localisation from a fundus image and their corresponding sample output images.

For validation, it is not necessary for the fundus images to have ground truth vessel segmentation images. In a number of previous studies on OD localisation, a database called Methods to Evaluate Segmentation and Indexing Techniques in the field of Retinal Ophthalmology (MESSIDOR) is used for validation.^{9,11,24,30,31} The MESSIDOR database³² consists of 1200 fundus images captured using a Topcon TRC NW6 non-mydriatic fundus camera with 45 degrees of field of view (FOV). In this study, the OD's centre position and radius are estimated on all 40 images from Digital Retinal Images for Vessel Extraction (DRIVE),³³ 45 images from High-Resolution Fundus (HRF),³⁴ and 1200 images from MESSIDOR, which are all publicly available fundus image databases. The images from another popular benchmark fundus image database, the STructured Analysis of the Retina (STARE) database, are excluded in this evaluation since most of its images do not contain OD. Even for those with the OD in the ROI, the OD is only partially visible.

Figure 2. Overview of the steps for proposed optic disc localization method from a fundus image (OD = optic disc).

Table 1. Sample outputs of optic disc (OD) localization steps applied to fundus images from the Digital Retinal Images for Vessel Extraction (DRIVE), High-Resolution Fundus (HRF) and Methods to Evaluate Segmentation and Indexing Techniques in the field of Retinal Ophthalmology (MESSIDOR) databases.

Database	Pre-processed Retinal Image	Binary image	Vessel-masked image	OD-localised image
DRIVE
HRF
MESSIDOR

Figure 3. Samples of zoomed-in optic disc localisation output on randomly selected images from HRF.

Results & discussion

Table 1 shows sample output images for the main steps in the proposed OD localisation method for the DRIVE, HRF and HUKM databases. The OD-localised image output includes a “+” sign to indicate the estimated OD centre and the green circle denotes the estimated OD radius. **Figure 3** shows zoomed-in images of the OD localisation output from HRF images. It can be seen that the proposed method managed to accurately detect the centre and the radius of the OD, regardless of whether the fundus image contains a clean (normal) or noisy (with pathologies) retinal background.

Following the previous researchers’ method of assessing the OD localisation performance, a method is considered to have successful OD localisation when the estimated location of OD center is within the circumference of the OD itself.³¹ The proposed OD localisation method achieves a 100% correct detection rate for all images in DRIVE and HRF. For the larger MESSIDOR database, only six images out of 1200 images result in either wrong detection or non-detection of the OD, hence 99.5% successful rate. These results are summarised in **Table 2** below.

Table 3 shows the performance comparison of the proposed method against published methods in the literature. The proposed method outperforms all considered methods except for Yu’s method that achieved 99.67% detection rate. On average, this translates to a 99.53% detection rate for all the validated databases. The processing time for OD localisation is less than one second for every image tested, regardless of the original image resolution. Shorter processing time is achieved because the proposed method employs image resizing, however this does not compromise the detection rate. This method is efficient and accurate for practical application of OD localisation in clinical settings.

Table 2. Result of optic disc localization in four databases (Digital Retinal Images for Vessel Extraction [DRIVE], High-Resolution Fundus [HRF], and Methods to Evaluate Segmentation and Indexing Techniques in the field of Retinal Ophthalmology [MESSIDOR]).

Database	Number of images	Correct output	False output	Detection rate (%)
DRIVE	40	40	0	100
HRF	45	45	0	100
MESSIDOR	1200	1194	6	99.50
All	1285	1279	6	99.53

Table 3. Comparison of optic disc localization results against published methods (DRIVE = Digital Retinal Images for Vessel Extraction, HRF = High-Resolution Fundus, MESSIDOR = Methods to Evaluate Segmentation and Indexing Techniques in the field of Retinal Ophthalmology).

Author	Database	Detection rate (%)
Proposed	DRIVE	100
	HRF	100
	MESSIDOR	99.50
Aquino <i>et al.</i> ⁹	MESSIDOR	99.00
Lu ¹¹	MESSIDOR	98.77
Yu <i>et al.</i> ³¹	MESSIDOR	99.67
Salih <i>et al.</i> ³⁰	DRIVE	100
	MESSIDOR	98.91
Gui <i>et al.</i> ⁵	DRIVE	100
	MESSIDOR	99.25
Dietter <i>et al.</i> ⁴	DRIVE	100
	HRF	100
	MESSIDOR	98.91

Conclusion

In this paper, we have proposed an efficient method for localising the OD in a fundus image. The method involves the use of vessel masking to remove vessel structures from the image and Hough transform to locate the circular object on the vessel-masked image, which is the OD. The output will be in the form of the coordinates of the OD center together with the estimated radius of the OD, which can also be visualised on the fundus image. Validation of the proposed method on three different public databases, namely DRIVE, HRF and MESSIDOR resulted in an overall detection rate of 99.53%. The achieved performance is superior to many published methods available, with a much-reduced processing time of less than one second for each image. The proposed method has only been validated on one type of retinal image, which is a fundus image produced by a fundus camera. In the future, retinal images using other imaging modalities such as angiogram or scanning laser ophthalmoscopy can further validate the proposed optic disc localisation. Another interesting direction for future research is accurate segmentation of the OD boundary for more accurate parameter estimation. The output of the method may prove to be useful for diagnosing ocular diseases, which relate to parameters such as cup-to-disc ratio and vessel width parameters. Automating the step for OD localisation can help develop a fully automated computer-assisted retinal diagnosis system in the future.

Data availability

Source data

The DRIVE database can be accessed at <https://drive.grand-challenge.org/>, HRF at <https://www5.cs.fau.de/research/data/fundus-images/> and MESSIDOR at <https://www.adcis.net/en/third-party/messidor/>.

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