Biomedical Signal Processing and Control 40 (2018) 91–101

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Multiscale sequential convolutional neural networks for simultaneous detection of fovea and optic disc

Baidaa Al-Bander [a,c], Waleed Al-Nuaimy [a], Bryan M. Williams [b], Yalin Zheng [b,*]

[a] Department of Electrical Eng. and Electronics, University of Liverpool, Liverpool L69 3GJ, UK
[b] Department of Eye and Vision Science, University of Liverpool, Liverpool L7 8TX, UK
[c] Department of Computer and Software Engineering, University of Diyala, Iraq

ARTICLE INFO

Article history:
Received 10 December 2016
Received in revised form 2 August 2017
Accepted 10 September 2017

Keywords:
Diabetes
Fovea detection
Optic disc detection
Convlutional neural networks

ABSTRACT

Detecting the locations of the optic disc and fovea is a crucial task towards developing automatic diagnosis and screening tools for retinal disease. We propose to address this challenging problem by investigating the potential of applying deep learning techniques to this field. In the proposed method, simultaneous detection of the centers of the fovea and the optic disc (OD) from color fundus images is considered as a regression problem. A deep multiscale sequential convolutional neural network (CNN) is designed and trained. The publically available MESSIDOR and Kaggle datasets are used to train the network and evaluate its performance. The centers of the fovea and the OD in each image were marked by expert graders as the ground truth. The proposed method achieves an accuracy of 97%, 96.7% for the detection of the OD center and 96.6%, 95.6% for the detection of the foveal center of the MESSIDOR and Kaggle test sets respectively. Our promising results demonstrate the excellent performance of the proposed CNNs in simultaneously detecting the centers of both the fovea and OD without human intervention or handcrafted features. Moreover, we can localize the landmarks of an image in 0.007s. This approach could be used as a crucial part of automated diagnosis systems for better management of eye disease.

1. Introduction

The knowledge of the optic disc (OD) and fovea (macula center) locations in the retina is considered essential for the diagnosis and screening of many retinal diseases, such as glaucoma, diabetic maculopathy (DM) and age-related macular degeneration (AMD). The significance of detecting the fovea is that the closer a lesion is to it, the more likely the lesion is to cause visual impairment or blindness. On the other hand, the OD center is often regarded as a reference point for locating other retinal structures. For example, it can be used as the starting point for tracking retinal vessels in blood vessel tracking algorithms [1]. In addition, the OD diameter (ρ) is usually used as the reference to measure the size and location of other anatomical and pathological structures in the retina. On average the vertical OD diameter is about 1800 μm.

The OD appears as a bright yellowish oval region within color fundus images through which the blood vessels enter the eye. The macula is the center of the retina which is responsible for our central vision. The fovea is a small depression in the center of the macula. It has a darker appearance compared to the surrounding retinal tissue due to the high concentration of macular pigment. Fig. 1 shows a color retinal fundus image with the key anatomical structures denoted. The location of the fovea center is about 2.5 ρ from the optic disc center. The foveal radius is between 1/3 and 1/4 of the macula radius which is roughly equal to one optic disc diameter (ρ) [2,3].

Recently, the automatic localization and detection of retinal anatomical structures from digital fundus images has received increasing attention in the medical image processing community [19–22]. This may support the development of computer aided diagnosis (CAD) tools for the better management of eye disease. Despite considerable effort in this field, the problem of localizing the centers of the OD and the fovea remains unsolved in retinal fundus image analysis.

In this paper, a multiscale sequential deep learning technique is proposed which is aimed at detecting the centers of the OD and the fovea. The main contributions and advantages of this work are summarized as follows:

* Corresponding author at: Department of Eye and Vision Science, Institute of Ageing and Chronic Disease, University of Liverpool, 6 West Derby Street, Liverpool L7 8TX, UK.

E-mail addresses: hsbalban@liverpool.ac.uk (B. Al-Bander), wax@liverpool.ac.uk (W. Al-Nuaimy), bryan@liverpool.ac.uk (B.M. Williams), yalin.zheng@liverpool.ac.uk (Y. Zheng).

http://dx.doi.org/10.1016/j.bspc.2017.09.008
1746-8094/

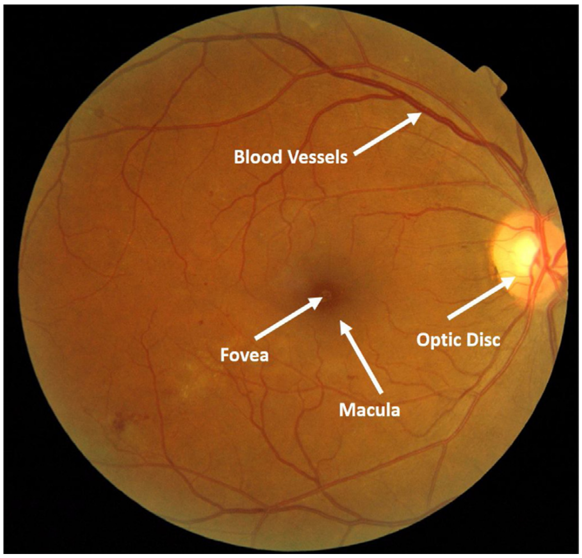

Fig. 1. An example fundus image illustrating the key retinal anatomical structures. Note the darker appearance at the fovea and blood vessels originating at the optic disc.

1.The application of deep convolutional neural networks to the detection of retinal landmarks is novel and promising. We develop a suitable convolutional neural network to detect specifically the optic disc and fovea centers.

a. Speed and autonomation: This results in a fast method requiring no user input.

b. Independence: The method is not dependent on other techniques succeeding such as segmentation or detecting other landmarks.

c. No handcrafted features: Since features do not need to be manually defined, we avoid the difficulty encountered by conventional machine learning algorithms in identifying the best feature set that represents the data. This also removes the requirement of a skilled technician to identify such features manually which takes a considerable amount of time and can produce subjective results, particularly with a large dataset.

d. Accurate simultaneous detection: We detect more than one position simultaneously, retaining high accuracy for each.

e. Robustness: The method is robust in the sense that it continues to work well even on poor quality images.

2. We develop a multiscale approach to convolutional neural networks to focus on the region of interest.

a. Improved Accuracy: This approach allows the method to focus on the region of interest, removing redundant background data from consideration and facilitating refinement of the localisation. This results in significantly increased accuracy in the cases of the fovea and the optic disc.

3. Inter-dataset training and evaluation using multiple datasets.

a. Generalisation: This demonstrates generalisation of the method to new data, from separate datasets and graders, and captured from different devices.

4. We incorporate variable optic disc radius (R) into evaluation criteria.

a. Evaluation accuracy: Incorporating this variable measure into our testing allows more accurate evaluation while others' use fixed R value for evaluation.

The remainder of this paper is organized as follows. Section 2 provides a brief review of the previous work related to the detection of the OD and the fovea. Section 3 describes the proposed methodology for detecting the OD and fovea locations. The experiments and results are described in Section 4. This work is discussed in Section 5 and the paper is concluded in Section 6.

2. Related work

In the literature, there has been a number of studies conducted to determine the locations of the fovea and OD. Many of these studies only locate either the OD or fovea and not both. Below is a brief review of the major algorithms published in the literature for detecting the OD, followed by fovea detection methods.

Many of the reported methods use geometric information of the vascular tree to detect the OD [4–8]. Hoover and Goldbaum [4] exploited the spatial relationship between the OD and retinal blood vessels and proposed a fuzzy convergence algorithm to locate the origination point of the blood vessel network. This origination point was considered as the OD center in the retinal fundus image. Foracchia *et al.* [5] proposed a geometrical model to calculate the general direction of retinal blood vessels at any given location in an image using the coordinates of the OD center as the two model parameters. The simulated annealing optimization technique was used to identify these two parameters. Furthermore, Fleming *et al.* [6] presented a method based on the elliptical form of retinal blood vessels to obtain the approximate locations of the OD and fovea. The circular edge of the OD and the darker appearance of the fovea were exploited to refine these approximated locations. In addition, Tobin *et al.* [7] used accurate vasculature segmentation results for optic disc detection by determining density, average thickness, and average orientation of the blood vessels in relation to the position of the OD. Youssif *et al.* [8] described a method that can detect the optimal OD center point by measuring the difference between the matched filter output and the vessels' directions.

Niemeijer *et al.* [9] formulated the problem of detecting the OD and foveal centers as a regression problem. They utilized a kNN regressor to measure the distance in an image to the object of interest at any given location using a set of features extracted at that location. Furthermore, a method based on Sobel operators and the Hough transform for the detection of the OD in retinal fundus images was formulated by Zhu *et al.* [10]. They determined the center and radius of the OD by approximating the margin of the optic nerve head into a circle using the Hough transform. Moreover, Lu et al. [11] designed a technique based on the circular transformation to locate the circular shape of the optic disc and color variation across the OD boundary. The center and the boundary of the optic disc were located by exploiting the pixels with the maximum variation along radial line segments.

Yu *et al.* [12] presented a method for detecting the optic disc location using template matching techniques. The OD location was determined using the characteristics of the vessels on the OD. In [13], Dehghani et al. proposed a histogram based method which uses four images from the DRIVE dataset as a template to locate the center of the OD where each histogram represents one color from the RGB color image components (red, blue, and green). The template was constructed by calculating the average of these histograms. Harangi *et al.* [14] adapted the most recent OD detectors and organized them into an ensemble and complex framework in order to merge their strengths and maximize the accuracy of OD detection. To determine the final OD position, a maximum-weighted clique was founded. Recently, Calimeri *et al.* [15] have presented a method based on fine-tuned convolutional neural network to localize the OD location.

Many of the fovea localization approaches presented in the literature have exploited the vasculature and other contextual information. Li and Chutatape [16] presented a model-based approach by combining the information provided by the main vessel arcades and the low intensity pixels in the fovea region. A