RetinaCAD - Retinal Computer-Aided Diagnosis System

Behdad Dashtbozorg[1,2]
behdad.dashtbozorg@fe.up.pt

Ana Maria Mendonça[1,2]
amendon@fe.up.pt

Susana Penas[3,4]
susanaapenas@gmail.com

Jorge Polónia[3]
jjpolonia@gmail.com

Aurélio Campilho[2,5]
campilho@fe.up.pt

[1]INEB - Instituto de Engenharia Biomédica, Porto, Portugal

[2]Faculdade de Engenharia, Universidade do Porto, Porto, Portugal

[3]Faculdade de Medicina, Universidade do Porto, Porto, Portugal

[4]Centro Hospitalar São João, Porto, Portugal

[5]INESC TEC - INESC Science and Technology, Porto, Portugal

Abstract

This paper presents an automatic application that provides several retinal image analysis functionalities, namely vessel segmentation, vessel width estimation, artery/vein classification and optic disc segmentation. A pipeline of these methods allows the computation of important vessel related indexes, namely the Central Retinal Arteriolar Equivalent (CRAE), Central Retinal Venular Equivalent (CRVE) and Arteriolar-to-Venular Ratio (AVR), as well as various geometrical features associated with vessel bifurcations.

1 Introduction

Among several features associated with vascular changes, the Central Retinal Arteriolar Equivalent (CRAE), Central Retinal Venular Equivalent (CRVE) and Arteriolar-to-Venular Ratio (AVR) have been frequently used as indicators for the early detection, diagnosis, staging and follow-up of some systemic diseases, namely diabetes, hypertension, and vascular disorders, since they can reflect the narrowing or dilation of the retinal blood vessels caused by these diseases [4, 9]. These diseases also change the pattern of vessel branching, thus making the measurement of bifurcation geometrical features a useful tool for the diagnosis or prediction of such pathologic conditions [1].

In this paper, we introduce the RetinaCAD System, which is an automated application for a fast and reliable measurement of CRAE, CRVE, AVR values, as well as several geometrical features of the retinal vasculature. The evaluation of the system on images of a dataset from a local hospital shows a low failure rate and a significant correlation between the values calculated for distinct images of both eyes of the same patient.

2 RetinaCAD System

The RetinaCAD is a fully automatic system for the segmentation and classification of retinal structures and for the measurement of vascular features. This system can analyse optic disc centered retinal images with variable resolution and camera field of view (FOV). Fig. 1 shows the main interface of this application. In this section, we briefly describe the main tools for the detection and classification of retinal structures that were implemented in the RetinaCAD system.

2.1 RetinaCAD Image Analysis Tools

The main retinal image analysis tools provided by this application are: 1) vessel segmentation; 2) optic disc localization; 3) optic disc segmentation; 4) region of interest determination; 5) graph representation of the vascular tree; 6) A/V vessel classification.

1) Vessel Segmentation Tool: This tool is used for finding the vessels, and is the first stage for vessel caliber estimation and initial optic disc (OD) localization. The methods described in [7, 8] are applied for vessel segmentation. Fig. 2(b) illustrates the vascular tree which is generated by the tool for the original image of Fig. 2(a). Vessel caliber measurement

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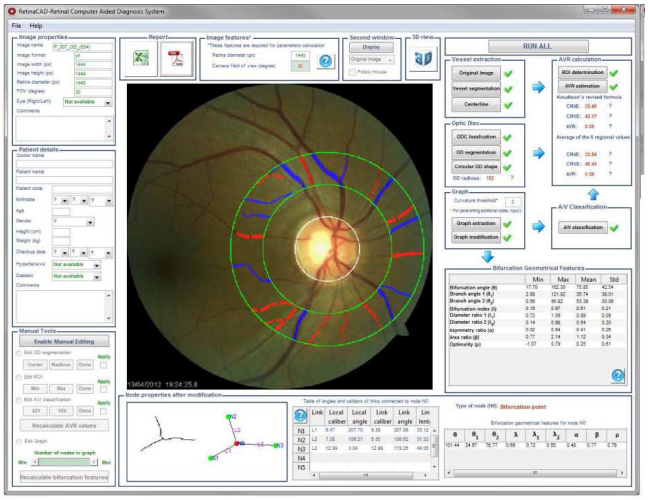


Figure 1: RetinaCAD interface.

is based on the distance transform of the segmented vascular tree; the result of this transform in each vessel pixel is its distance to the closest boundary point, d. After that, for each vessel centerline pixel, the vessel caliber value, vc, is estimated by $vc = 2d - 1$.

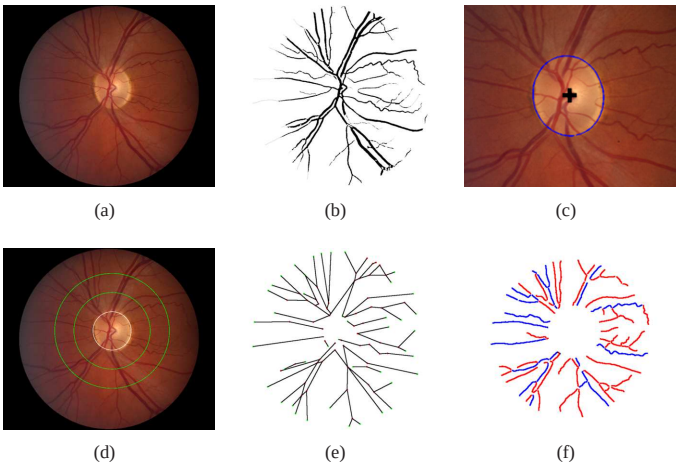
2) Optic Disc Localization Tool: The initial optic disc (OD) location is obtained following the approach based on the entropy of vascular directions described in [6] (Fig. 2(c)).

3) Optic Disc Segmentation Tool: A multiresolution sliding band filter (SBF), centered in the initial OD location is used for segmenting the OD boundary [2] (Fig. 2(c)). The final optic disc center (ODC) and OD radius are found by fitting a circle to the extracted boundary (Fig. 2(d)).

4) Region of Interest Determination Tool: The CRAE, CRVE and AVR values are calculated from the calibers of the vessels inside a specific region of interest (ROI), defined as the standard ring sector centered on the ODC, within 2 to 3 disc radius from the OD margin [4]. The corresponding ROI for CRAE, CRVE and AVR calculation is shown in Fig. 2(d).

5) Graph Representation Tool: The vessels centerline image is obtained by applying an iterative thinning algorithm to the vessel segmentation result. Then the graph nodes are extracted from the centerline image by finding the intersection points, the bifurcation points, the high-curvature points and the terminal points . After that each vessel segment is represented by a link between two nodes (Fig. 2(e)). The graph representation tool can display local and global features of the links (vessel segments) and nodes (bifurcation/intersection points), namely the caliber and the angle between vessel segments as well as the type of intersection (crossing or bifurcation).

6) Artery/Vein Classification Tool: This tool is based on the graph representation of the retinal vasculature as described in [3]. This method classifies the entire vascular tree by deciding on the type of each vessel intersection point (graph nodes) and by assigning one of two labels to each vessel segment (graph links). Final classification of a vessel segment as an artery or a vein is performed through the combination of the graph-based labeling results with intensity information from original color image. The result of A/V classification for the whole image is shown in Fig. 2(f).



(a) (b) (c) (d) (e) (f)

Figure 2: (a) Input image; (b) Vessel segmentation result; (c) Initial OD location (black cross) and OD boundary (blue); (d) ROI (delimited by the two green circles) and circular OD margin (white circle); (e) Graph representation of vascular tree; (f) A/V classification result.

Table 1: Comparison of Mean ± standard deviation (SD) and Pearson correlation between images of the right and left eyes.

Measurements	RetinaCAD				BDES [10]	Leung [5]
	Mean ± SD		Mean error±SD	Corr.	Corr.	Corr.
	Right eye	Left eye				
CRAE (μm)	158.1±15.9	161.9±16.9	11.2±8.5	0.66	0.71	0.70
CRVE (μm)	252.3±24.4	255.9±24.9	16.1±12.6	0.67	0.74	0.77
AVR	0.63±0.09	0.64±0.08	0.06±0.05	0.54	0.49	0.54

Corr.: Pearson's correlation coefficient.

2.2 Measurements

The CRAE and CRVE values are calculated based on Knudtson's revised formulas [4]. The AVR is defined as the quotient between CRAE and CRVE. For the AVR calculation, the ROI is equidistantly sampled to provide six regions. For each region, the six largest arteries and the six largest veins are identified, and the regional AVR is calculated. The final AVR estimate for the complete image is the average of the six regional values.

The branching angles are the basic measurements related to a bifurcation, and these features are obtained from the graph representing the vascular tree, as mentioned before. The branching angles and vessel segment calibers are used to derive features, such as the bifurcation index, asymmetry ratio, diameter ratio, area ratio and optimality [1].

3 Results

The system was evaluated using the images of a dataset from Centro Hospitalar São João (CHSJ dataset). This dataset contains 564 images from 141 subjects, where for each subject there are four images, two from the right eye and two from the left eye; the two images of each eye were acquired with two different FOV values (45° and 30°). The images of this dataset were used for investigating the robustness of the system to the use of distinct images of the same subject, through the assessment of the correlation between measurements from images of the right and left eyes and from images of same eye with different FOV. For the 564 images that were analysed using RetinaCAD, the results for 11 subjects were not accepted as a consequence of errors in A/V classification or OD segmentation. Although these errors can be solved using the manual modification tool which is included in this application, all the images of the subjects where the automatic procedures have failed were excluded. In the following, we discuss the results obtained for 520 images from 130 subjects.

The mean error and the Pearson correlation coefficient between measurements from the right and left eyes in the CHSJ dataset are shown in Table 1, where the correlation coefficients reported by the Beaver Dam Eye Study (BDES) [10] and Leung *et al.* [5] are also included. These results show a good correlation between right and left eyes for CRAE and CRVE and a moderate correlation for AVR, being similar to those reported in [10] and [5]. In order to evaluate the robustness of the methods in RetinaCAD, we have compared the results of the CRAE, CRVE and AVR values in images of the same eye that were acquired with a different FOV (45° and 30°). As can be observed in Table 2, all indicators show a small mean error and there is a significant correlation between images of the same eye that were acquired in distinct conditions, thus indicating the good performance and consistency of RetinaCAD.

Table 2: Comparison of results between images of the same eye with 45° and 30° FOV.

Measurements	Mean ± SD		Mean error±SD	Correlation coefficient
	FOV: 45°	FOV: 30°		
CRAE (μm)	154.7±17.5	162.9±16.4	11.4±8.8	0.76
CRVE (μm)	245.6±25.1	260.9±23.7	18.8±12.3	0.80
AVR	0.64±0.08	0.63±0.08	0.05±0.03	0.73

4 Conclusions

We have developed a user-friendly system, RetinaCAD, that is able to automatically detect, measure and classify two main retinal landmarks, the optic disc and the vessels. RetinaCAD can measure several vascular features that are recognized as indicators for some prevalent systemic diseases. We have demonstrated that the correlation between right and left eyes was good for the CRAE and CRVE values, which suggests that the measurements from one eye can provide adequate information about the changes in vessel calibers. After comparing the measured values for images of the same eye but with different FOV, a significant correlation and a low mean error were achieved, thus allowing the conclusion that RetinaCAD is adequate both for research and for general clinical use.

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