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Optic disk feature extraction via modified deformable model technique for glaucoma analysis

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Abstract

A deformable-model based approach is presented in this paper for robust detection of optic disk and cup boundaries. Earlier work on disk boundary detection up to now could not effectively solve the problem of vessel occlusion. The method proposed here improves and extends the original snake, which is essentially a deforming-only technique, in two aspects: knowledge-based clustering and smoothing update. The contour deforms to the location with minimum energy, and then self-clusters into two groups, i.e., edge-point group and uncertain-point group, which are finally updated by the combination of both local and global information. The modifications enable the proposed algorithm to become more accurate and robust to blood vessel occlusions, noises, ill-defined edges and fuzzy contour shapes. The comparative results on the 100 testing images show that the proposed method achieves better success rate (94%) when compared to those obtained by GVF-snake (12%) and modified ASM (82%). The proposed method is extended to detect the cup boundary and then extract the disk parameters for clinical application, which is a relatively new task in fundus image processing. The resulted cup-to-disk (C/D) ratio shows good consistency and compatibility when compared with the results from Heidelberg Retina Tomograph (HRT) under clinical validation.

Keywords: Boundary detection; Optic disk; Cup; Snake; Deformable model; Fundus image

1. Introduction

Optic disk with bright-white region inside called pallor is one of main components on the fundus image as shown in Fig. 1(a). It is the entrance of the optic nerve and blood vessels to the retina. The 3-D shape of the optic disk is an important indicator of various ophthalmic pathologies. For an instance, the optic disk becomes bigger and deeper in the eyes with glaucoma. Clinicians quantify the cupping of the optic disk to evaluate the progression of glaucoma, where cup is defined at certain depth down from the disk edges. Cup and disk boundaries act as the references to quantitative measurements of the disk parameters, such as cup-to-disk (C/D) vertical ratio, C/D area ratio, etc., which are the important parameters for diagnosis. The existing ophthalmic instrument used to analyze the optic disk such as Optical Coherence Tomography (OCT) and Heidelberg Retina Tomograph (HRT) are based on scanning laser technique that can provide a colorless or pseudo-color 3-D visualization. The clinicians must manually place the disk boundary on the 3-D image as the reference, and then the cup boundary can be generated from the disk contour based on 3-D depth information. Since the image created from OCT or HRT is not true color image, the 2-D color fundus image is still referred to by most clinicians for the estimation of disk and cup boundaries. As an effective solution to this, a fully automated approach of cup and disk boundary detection is

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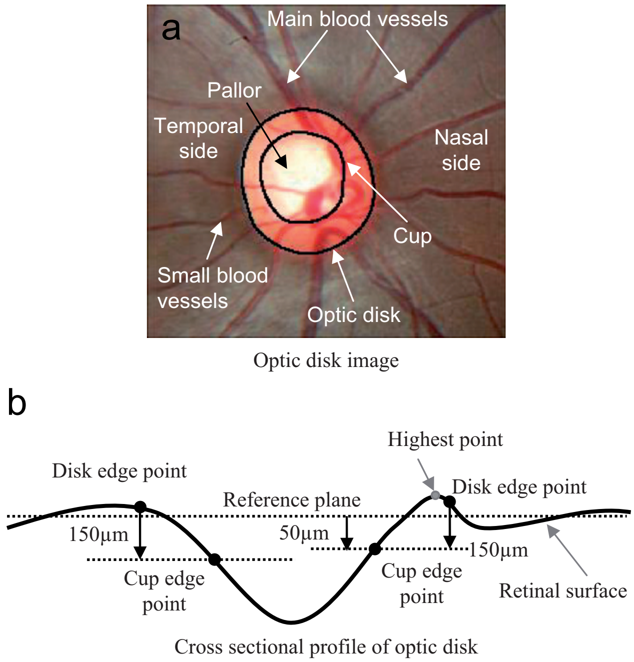

Fig. 1. Definition of cup and disk contours: (a) optic disk image; (b) cross sectional profile of optic disk.

presented in this paper to provide essential disk parameters for clinical analysis and pathological monitoring.

The optic disk generally appears as a bright circular or elliptic region. The methods of optic disk boundary detection can be separated into two steps: optic disk localization and disk boundary detection. Correct localization of the optic disk may improve the accuracy of disk boundary extraction. Many existing approaches can be used to locate the optic disk with reasonable success. Sinthanayothin [1] located the position of the optic disk by finding the region with the highest local variation in the intensity. Tamur [2] and Pinz [3] applied Hough transform to obtain optic disk center and the outer circle of disk boundary. Recently, a principal component analysis (PCA) model based approach was used in Ref. [4], and template matching was used in Refs. [5–7]. Hoover [8] utilized the geometric relationship between the optic disk and main blood vessels to identify the disk location, similar approaches were introduced in Refs. [9,10]. Correctly locating the optic disk is the first and essential step for optic disk segmentation. Subsequently the disk center is estimated and used to initialize the disk boundary.

Interference of blood vessels is one of the main difficulties to segment the optic disk reliably and accurately. This problem is very similar to other boundary detection and image segmentation problems in medical imaging area that still require robust solution. Currently, deformable models offer a reasonable approach for boundary detection and image segmentation which can be roughly classified into two categories: free-form deformable models, such as snakes, and parametrically deformable models, such as active shape models (ASMs). Mendels et al. [11] and Osareh et al. [6] extracted the optic disk boundary by GVF-snake algorithm, in which the blood vessel was first removed by morphology in the preprocessing step. Walter et al. [12] also used morphological filtering techniques to remove the blood vessels and then detected the optic disk boundary by means of shade-correlation operation and watershed transformation. Although the morphology preprocessing helps reduce the effect of blood vessels, it could not totally remove the effect. The resulted boundary was distorted in the regions with outgoing vessels. Li and Chutatape [13,14] used a PCA method to locate the optic disk and an ASM to refine the disk boundary. Although this approach could indirectly handle blood vessel occlusion problem with moderate accuracy, by using shape models, the fuzzy shapes of optic disk due to various pathological changes were not easy to be represented by a number of shape models, which might reduce the accuracy of the result. Parametrically deformable models (ASM method) are suitable for use when more specific shape information is available and the detected object has relatively uniform shape with limited variation. However, in optic disk boundary detection, pathological changes may arbitrarily deform the shape of optic disk and also distort the course of blood vessels. Hence, deformable templates may not be able to sufficiently encode various shapes of optic disk from different pathological changes. Lowell et al. [7] segmented the optic disk by a contour deformation method based on a global elliptic model and a local deformable model with variable edge-strength dependent stiffness. However, the authors indicated that the performance to the images with variably pathological changes still needed to be further improved. A level set approach was introduced in Ref. [15], which can segment the objects with arbitrarily complex shapes. The advantage of this approach is its ability to evolve the model in the presence of sharp corners, cusps, shapes with pieces and holes, etc. Nevertheless, many of these problems are different from those encountered in the boundary detection of optic disk. How to remove the influence of blood vessels is still the main difficulty to the employment of the above-mentioned methods to the optic disk boundary detection.

Cup is the depressed area inside the optic disk, hence the 3-D depth is the primary feature of the cup boundary, for which the automated detection is a relatively new task and challenging work in fundus image processing. So far, very few researchers focused their work on cup boundary detection due to the fact that the 3-D image is not easily available. Results of disk and cup boundaries were shown in Ref. [16], however, the authors did not clearly describe how to obtain these boundaries.

Since 3-D images are not generally available, some definitions are provided to estimate the cup boundary on 2-D images. Previously, the clinicians used the pallor to estimate the cup boundary, while pallor is defined as the area of maximum color contrast inside the disk area. However, in many cases, there is no obvious pallor in the disk area.