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Automated retinal nerve fiber layer defect detection using fundus imaging in glaucoma

Rashmi Panda[a,*], N.B. Puhan[a], Aparna Rao[b], Debananda Padhy[b], Ganapati Panda[a]

[a] School of Electrical Sciences, IIT Bhubaneswar, India
[b] Glaucoma Diagnostic Services, L. V. Prasad Eye Institute, Bhubaneswar, India

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ABSTRACT

Retinal nerve fiber layer defect (RNFLD) provides an early objective evidence of structural changes in glaucoma. RNFLD detection is currently carried out using imaging modalities like OCT and GDx which are expensive for routine practice. In this regard, we propose a novel automatic method for RNFLD detection and angular width quantification using cost effective redfree fundus images to be practically useful for computer-assisted glaucoma risk assessment. After blood vessel inpainting and CLAHE based contrast enhancement, the initial boundary pixels are identified by local minima analysis of the 1-D intensity profiles on concentric circles. The true boundary pixels are classified using random forest trained by newly proposed *cumulative zero count local binary pattern* (*CZC-LBP*) and *directional differential energy* (*DDE*) along with Shannon, Tsallis entropy and intensity features. Finally, the RNFLD angular width is obtained by random sample consensus (RANSAC) line fitting on the detected set of boundary pixels. The proposed method is found to achieve high RNFLD detection performance on a newly created dataset with sensitivity (SN) of 0.7821 at 0.2727 false positives per image (FPI) and the area under curve (AUC) value is obtained as 0.8733.

1. Introduction

Glaucoma is a degenerative and progressive optic neuropathy which ranks as the second most disabling and blinding disease worldwide (Quigley and Broman, 2006). Early diagnosis is the key to prevent progressive and irreversible damage to retinal nerve fibers' functionality. Funduscopic sign of the retinal nerve fiber layer (RNFL) defect provides an early objective evidence of structural changes in glaucoma which is caused due to the loss of retinal ganglion cell axons (Hoyt et al., 1973; Lundstrom and Eklundh, 1980). Before the visual field defect begins, the ganglion cells have already sustained a loss of about 50% (Lee et al., 2004). Current imaging techniques like optical coherence tomography (OCT), GDx offering RNFLD assessment are expensive and require careful interpretation by experts. Moreover, these imaging techniques are not feasible solution for mass screening and routine checkup of glaucoma in peripheral settings. In this regard, computer-aided RNFLD detection using redfree fundus image provides a practical solution for accurate and efficient glaucoma risk assessment.

RNFLD region appears as a wedge shaped arcuate structure radiating from the optic disc (Fig. 1). As compared to the background, the RNFLD is more distinguishable near the optic disc (OD) region than the periphery. RNFLD region continues to widen with the gradual progression of glaucoma over time (Yoo and Park, 2011). Despite the importance of RNFLD detection, a limited number of methods are found in the literature for its automated detection using fundus imaging.

Recent studies have performed RNFLD thickness prediction by estimating the correlation coefficient between fundus image patch features and corresponding optical coherence tomography (OCT) image patch thickness using various regression models (Kolar et al., 2013; Odstrcilik et al., 2014; Odstrcilik et al., 2010). Prior to the correlation computation, bimodal image registration process was carried out between OCT and fundus images. It helps in accurate OCT-RNFL thickness mapping in fundus images. In (Kolar et al., 2013), Kolar et al. considered first order statistics (mean, standard deviation, kurtosis, skewness, Shanon's entropy) as features from fundus image patches. Odstrcilik et al. used Gaussian Markov Random Field (GMRF) and Local Binary Pattern (LBP) texture features from manually selected patches (Odstrcilik et al., 2014; Odstrcilik et al., 2010). These methods require expensive OCT imaging modality as gold standard during image registration. OCT imaging modality also entails extensive infrastructure and skilled technicians to perform any test.

In (Joshi et al., 2012; Lamani et al., 2014), another class of methods could detect RNFLD patches of pre-determined size in the fundus image without the additional requirement of OCT imaging. Since RNFLD

* Corresponding author.
E-mail address: rp14@iitbbs.ac.in (R. Panda).

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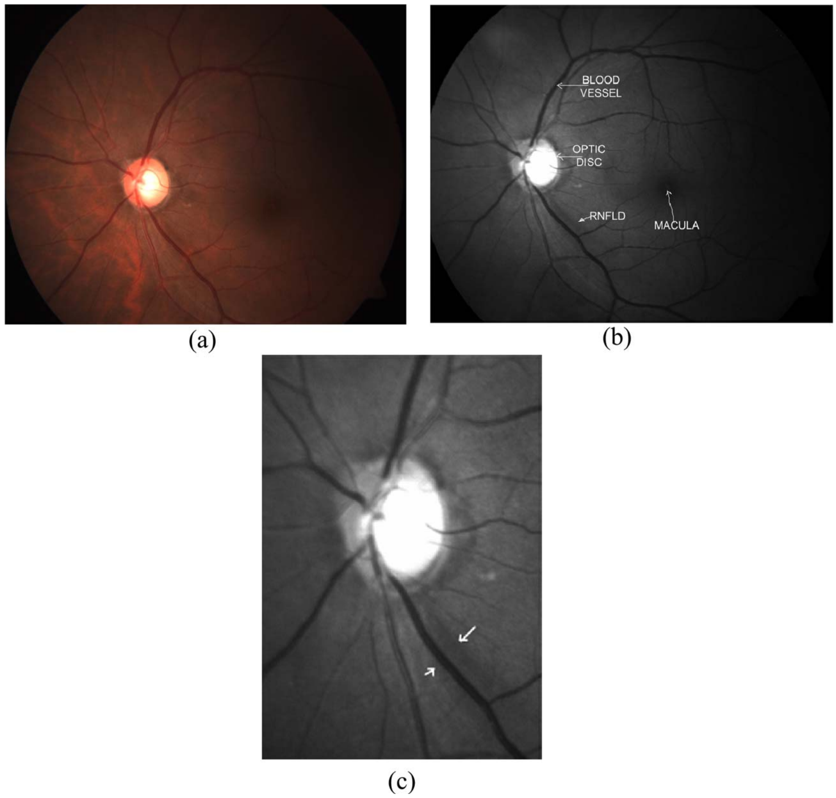

Fig. 1. (a) Color fundus image having RNFLD. (b) Redfree fundus image showing diagnostically interesting structures. (c) The enlarged RNFLD region is marked between arrows with blood vessel passing through it.

patch is different from its adjacent patch, Joshi et al. computed the intensity based dissimilarity features between adjacent patches to train the classifiers (Joshi et al., 2012). The patch classification is performed by combining decisions obtained from the k-NN and Nearest Mean Scaled classifiers. Lamani et al. proposed a new method based on texture and fractal descriptors followed by SVM classification (Lamani et al., 2014). It is observed that the RNFLD boundary is not explicitly detected in (Kolar et al., 2013; Odstrcilik et al., 2014; Odstrcilik et al., 2010; Joshi et al., 2012; Lamani et al., 2014); instead, a selected fundus image patch is classified if it contains RNFLD or not.

In (Oh et al., 2015), Oh et al. proposed a new method to detect the RNFLD boundaries. In this method, Canny's operator was applied to detect the edges of RNFLD region followed by Hough transform based line detection. Among the detected lines, the false positives are reduced by applying conditional decision rules based on the average intensity, vertical length, and angular location. In this method, several false positives are not eliminated through implementing the conditional rule based classification. Muramatsu et al. (2010) applied Gabor filtering for RNFLD enhancement after removal of the retinal blood vessels. The candidate RNFLD boundary pixels are detected as a function of mean and standard deviation of neighborhood intensities. Then, the false positives are reduced by applying the ANN classifier. The main limitation is that it uses several empirically determined parameters in defining the function between the RNFLD boundary and neighborhood intensities.

Our proposed method is aimed towards automated detection of the RNFLD boundary and its angular width measurement. RNFLD boundary detection still remains a challenging task as the contrast between RNFLD and background is very low (Fig. 1). RNFLD region intensity also varies significantly from image to image and it is less distinguishable towards the periphery. Apart from that, macula and blood vessels being darker than the background pose significant difficulty in automated detection. In this paper, the newly proposed RNFLD boundary detection method involves the following steps:

- The blood vessels are first segmented and inpainted. Contrast limited adaptive histogram equalization (CLAHE) (Pizer et al., 1987) is then applied to achieve better RNFLD visibility.
- The candidate RNFLD boundary pixels are found by applying existing wavelet based local minima analysis of the 1-D intensity profiles extracted from several concentric circles around OD region in the preprocessing step.
- We have proposed novel features such as *Cumulative Zero Count Local Binary Pattern (CZC-LBP)* and *Directional Differential Energy (DDE)* along with Shannon and Tsallis entropy and intensity based features. The extracted feature vectors train the random forest classifier for accurate RNFLD boundary detection.
- To measure RNFLD angular width, the detected boundary pixels are line fitted using the Random Sample Consensus (RANSAC) algorithm (Fischler and Bolles, 1981).
- The proposed method's performance is analyzed and compared on a new dataset of glaucomatic fundus images acquired from L. V. Prasad Eye Institute, Bhubaneswar, India.

The organization of the paper is as follows. The proposed method is described in Section 2. Then, experimental results and discussion on the new RNFLD dataset is given in Section 3. Finally, conclusion and future works are presented in Section 4.

2. Methodology

The proposed method is elaborated in this section by considering the redfree image shown in Fig. 1(b) for demonstration purpose. Redfree is preferred to color fundus image (CFI), because it is associated with better contrast interms of RNFLD visibility. Moreover, the appearance of CFI can vary with patient age and fundus pigmentation.