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Novel expert system for glaucoma identification using non-parametric spatial envelope energy spectrum with fundus images

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ABSTRACT

Glaucoma is the prime cause of blindness and early detection of it may prevent patients from vision loss. An expert system plays a vital role in glaucoma screening, which assist the ophthalmologists to make accurate decision. This paper proposes a novel technique for glaucoma detection using optic disk localization and non-parametric GIST descriptor. The method proposes a novel area based optic disk segmentation followed by the Radon transformation (RT). The change in the illumination levels of Radon transformed image are compensated using modified census transformation (MCT). The MCT images are then subjected to GIST descriptor to extract the spatial envelope energy spectrum. The obtained dimension of the GIST descriptor is reduced using locality sensitive discriminant analysis (LSDA) followed by various feature selection and ranking schemes. The ranked features are used to build an efficient classifier to detect glaucoma. Our system yielded a maximum accuracy (97.00%), sensitivity (97.80%) and specificity (95.80%) using support vector machine (SVM) classifier with *nineteen* features. Developed expert system also achieved maximum accuracy (93.62%), sensitivity (87.50%) and specificity (98.43%) for public dataset using *twenty six* features. The proposed method is efficient and computationally less expensive as it require only *nineteen* features to model a classifier for the huge dataset. Therefore the proposed method can be effectively utilized in hospitals for glaucoma screening.

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1. Introduction

Glaucoma is one of the eye disorders caused by optic nerve damage leading to partial or complete blindness. It is an irreversible and chronic condition which progressively damage the optic nerve [1,2]. It is estimated that by 2020, there will be approximately 80 million people worldwide affected by glaucoma [3–5].

The nerve fibers can be represented by an annular region between cup boundary and the optic disk (OD) known as neuroretinal rim [3] and the fluid pressure inside the eye is referred to as intraocular pressure (IOP) [6,7]. Thus leading to the blockage of outflow of aqueous humor. This will damage the optic nerve which transmits the information from retina to the brain [4,5]. The loss of optic nerve fibers are probably due to high IOP. The deterioration of optic nerve fibers lead to the decrease in the thickness of retinal nerve fiber layer (RNFL) called cupping which is a significant cause for glaucoma progression [3,8]. An increased cup to disk ratio (CDR) indicates the decrease in the quantity of healthy neuro-retinal tissue and hence displaying a glaucomatous change [8]. The healthy eye usually has a CDR of 0.3 [6,9].

Glaucoma can be broadly classified into the three stages (mild, moderate and severe) depending on the CDR in the fundus image [10,11]. Mild stage indicates the progress of glaucoma hinting the enlargement of the cup and CDR at this stage is usually between 0.4 and 0.5. Moderate will be in the range 0.5–0.7 and severe glaucoma is an advanced stage where the CDR is usually more than 0.7 [11]. In moderate cases, the central vision may not be affected. But if not diagnosed and treated, the severe stage of glaucoma can eventually lead to blindness [11–13].

Digital fundus image analysis is valuable to understand the natural development of the disease which relies on computational techniques to make qualitative assessments of the eye [14–17]. Fundus image is a 2D projection of the retinal structures. The OD is a bright circular or elliptical region partially occluded by blood vessels. In 2D retinal fundus images, OD can be divided into a central bright zone called the optic cup and peripheral region called the neuroretinal rim [18]. In comparison with optical coherence tomography (OCT)/ Heidelberg retina topography (HRT) machines, the fundus camera is economical, easier to operate and is appropriate to estimate various eye conditions [9]. The geometric parameters that measure the changing structures of Optic Nerve Head (ONH) such as the diameter of the OD, area of the OD, cup diameter, area of the rim, and mean cup depth are vital in diagnosing this disorder [14]. The CDR is computed as the ratio of the vertical cup diameter to the vertical disk diameter clinically. A larger CDR generally indicates a higher risk of glaucoma and vice versa. A non-invasive, portable and cost effective glaucoma diagnosis tools are the most essential requirement in primary healthcare centers [19–21].

There are many techniques proposed to calculate CDR which uses segmentation of optic disk and the cup [22–24]. It involves contour based approach [25], fuzzy convergence [26], template based method [27], Hough transform [28] and geometric model based technique [29]. Joshi et al. (2012) [30] have proposed a method to find CDR based on depth discontinuity model with mean CDR error of 0.09. A morphological method is proposed in [31]. Xu et al. (2011) [32] have proposed a method to find CDR which coupled feature extraction with SVM classifier. Thresholding and edge detection based methods are also proposed in [33].

Various CAD techniques are reported in the literature for automated detection as well as classification of normal and glaucoma classes [34–36]. A unique method for glaucoma diagnosis is developed in [37] using higher order spectra (HOS) features and textures. They reported an accuracy of more than 91% using 60 fundus images. Dua et al. (2012) [38] proposed a method which uses energy signatures obtained using 2D discrete wavelet transform (DWT). The experiment was performed on 60 fundus images and achieved an accuracy of 93%. Mookiah et al. (2012) [39] proposed an automated system using HOS and DWT features with 95% accuracy, 93.33% sensitivity and 96.67% specificity. Kim et al. (2011) [40] have used fractal analysis (FA) as the groundwork for multiclass prediction of the progression of glaucoma. The box-counting method is used to obtain monofractal features while the multifractional Brownian motion method is used to obtain multifractal features, thereby incorporating texture and multiresolution analysis. Noronha et al. (2014) [41] developed a new method using HOS cumulants features. They achieved maximum of 92.65% accuracy, 100% sensitivity and 92% specificity. Yousefi et al. (2014) [42] developed a method to detect glaucomatous progression using different machine learning classifiers. The experiment was conducted on 632 images and the AUROC (95% CI) of 0.88 is achieved when selecting 10 best features using random forest tree classifier. Ceccon et al. (2014) [43] developed method based on Bayesian network concurrently to classify early glaucoma and cluster data into different stages of disease. They have achieved a sensitivity of 50% and specificity of 90% for pre diagnosis data whereas 85% sensitivity and 90% specificity for post diagnosis data. Maheshwari et al. (2017) [44] have developed a model using 2D empirical wavelet transform and achieved 98.33% accuracy for 60 images. The same group have extended their work using variational mode decomposition and achieved 95.19% accuracy for 488 fundus images [45]. Recently Acharya et al. (2017) [46] have proposed a method using texton and local configuration patterns. They reported a maximum accuracy of 95.70% using kNN classifier for 702 fundus images.

It can be observed from the literature that the existing techniques for glaucoma screening involve, manual, semi-automated and fully automated diagnosis. Manual and semi-automated methods are tedious and prone to inter and intra observer errors while reading the images. Hence, this paper presents a novel datamining technique for glaucoma screening using non-parametric GIST descriptor. The proposed method initially developed an optic disk (OD) segmentation technique followed by feature representation using Radon transform (RT). The effect of change in illumination and color on Radon transformed image is compensated using modified census transform (MCT). Further, spatial envelope features are computed from non-parametric MCT images and the dimensions of the extracted spatial envelope features are reduced using locality sensitive discriminant analysis (LSDA). Reduced features are selected and ranked using *t-test* based statistical measures.