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Automated classification of glaucoma stages using higher order cumulant features

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ABSTRACT

Glaucoma is a group of disease often causing visual impairment without any prior symptoms. It is usually caused due to high intra ocular pressure (IOP) which can result in blindness by damaging the optic nerve. Hence, diagnosing the glaucoma in the early stage can prevent the vision loss. This paper proposes a novel automated glaucoma diagnosis system using higher order spectra (HOS) cumulants extracted from Radon transform (RT) applied on digital fundus images. In this work, the images are classified into three classes: normal, mild glaucoma and moderate/severe glaucoma. The 3rd order HOS cumulant features are subjected to linear discriminant analysis (LDA) to reduce the number of features and then these clinically significant linear discriminant (LD) features are fed to the support vector machine (SVM) and Naïve Bayesian (NB) classifiers for automated diagnosis. This work is validated using 272 fundus images with 100 normal, 72 mild glaucoma and 100 moderate/severe glaucoma images using ten-fold cross validation method. The proposed system can detect the early glaucoma stage with an average accuracy of 84.72%, and the three classes with an average accuracy of 92.65%, sensitivity of 100% and specificity of 92% using NB classifier. This automated system can be used during the mass screening of glaucoma.

1. Introduction

Glaucoma is a group of eye disorder that produce increased intraocular pressure (IOP) within the eye [1]. The higher IOP in the eye is usually caused by an imbalance in the production and drainage of the fluid in the eye which over a period of time damage the optic nerve causing vision loss [2]. The progress of glaucoma usually goes undetected until the optic nerve gets irreversibly damaged resulting in varying degrees of permanent vision loss [3]. It has been reported that almost 14 million people worldwide and 3 million people in the United States have glaucoma [4]. By 2020, it is estimated that approximately 79.6 million people worldwide will be diagnosed with glaucoma [5]. Also it has been reported that there is an elevated IOP of about 2% in the population between 40 and 50 years old and 8% over 70 years old making them vulnerable to loss of vision [6] and even blindness.

Diagnosing the symptoms of glaucoma in an early stage helps to save the vision loss [7]. The American Academy of Ophthalmology recommends a routine screening once in every 2–4 years, for people between the age group of 40–64 years and in every 1–2 years, after 65 years of age which might help in detecting the disease in its early stage [8]. Geometric parameters of the optic nerve head (ONH) are used to diagnose and to measure the progression of the glaucoma. The geometric parameters measure the changing structures of the ONH such as the diameter of the Optic disk (OD), area of the OD, cup diameter, area of the rim, and mean cup depth [9]. The treatment for the glaucoma involves medical management, trabeculectomy, laser surgery and drainage implants [10]. Mass screening of the patients helps to diagnose the glaucoma in the early stage and can help to save from the surgery [11].

The main characteristics of glaucoma are the deterioration of optic nerve fibers and astrocytes followed by a high IOP. The deterioration of optic nerve fibers decreases the thickness of retinal nerve fiber layer (RNFL). The degeneration of astrocytes and axons leads to the changes in the ONH configuration and thereby decreasing the functional capability of retina. The loss of astrocytes and axons expands the cup and makes the neoretinal rim thinner [12]. Opthalmoscopy or stereo fundus photography of ONH can easily detect these changes and are widely used by ophthalmologists to document the disk, rim, cup areas and disk diameter [13].

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Digital fundus image analysis is valuable in understanding the natural development of the disease which relies on computational techniques to make qualitative assessments of the eye [14]. These methods can reduce inter-observer and intra-observer variability errors arising during the screening of the disease by clinicians. Various morphological features like disk, cup and rim areas, disk diameter and cup to disk (*C*/*D*) ratio extracted from the digital fundus image can help to diagnose the glaucoma [15].

C/*D* ratio is one of the key parameter used by the ophthalmologists while screening the glaucoma [16]. A healthy OD contains more than 1.2 million fibers passing through it which makes the size of the cup very small. Glaucoma causes ONH to loose the optic nerve fibers resulting in increase in the size of the cup. The progress of glaucoma leaves optic nerve with very less optic nerve fibers causing the cup to enlarge [17]. An increased *C*/*D* ratio indicates the decrease in the quantity of healthy neuro-retinal tissue and hence, glaucomatous change [16]. The normal *C*/*D* ratio typically equals to 0.3 [18]. Glaucoma can be broadly classified into the following stages, depending on the *C*/*D* ratio and presence of focal notches (inferior or superior) on the fundus image [19].

- Mild glaucoma: The progress of glaucoma starts with the loss of nerve fibers causing the damage to the optic nerve with a normal visual field or very less vision loss (side or peripheral) [20]. As a result the size of the cup enlarges and the *C*/*D* ratio at this stage is usually between 0.4 and 0.7.
- Moderate/severe glaucoma: This is an advanced stage of glaucoma where the presence of a small number of optic nerve fibers causes severe damage to optic nerve [21]. The *C*/*D* ratio at this stage is usually more than 0.7. This stage also shows the presence of focal notches (inferior or superior) [22] and optic nerve hemorrhages. In moderate cases the central vision may not be affected. But if not controlled, the severe stage of glaucoma can cause the central vision loss [18]. Typical normal, mild, moderate and severe glaucomatous fundus images are shown in Fig. 1.

While evaluating the patients for glaucoma the ophthalmologist monitors three things. First the intra-ocular pressure which is measured using a Goldmann applanation tonometer [23]. Second the visual field analysis which is carried out using the Humphrey field analyzer [24] that generates a computerized print out marking areas within the central 30° of patient's visual field. The final parameter is the optic nerve head (ONH) appearance [25]. In the screening programs these parameters play a significant role in identifying the patients with glaucoma. Since the measurement of IOP and visual fields are not suitable for mass screening, detection of OD plays a major role in diagnosing glaucoma suspects [26] by measuring cup to disk ratio. Hough transform [27], geometric parametric model [28], fuzzy convergence [29], contour model based approaches [30] and template matching [31] are the few techniques used to detect the ONH automatically.

Manual and semi-automated diagnosis of glaucoma is tedious, time consuming and may cause observer variability errors (intra/inter) while assessing the structural abnormalities of the eye by different clinicians. The diagnostic outcome might get affected even if there is a small error in the segmentation. Hence, a computer aided diagnosis (CAD) can help the clinicians to overcome these problems and can be used as adjunct tools by the clinicians to cross check their diagnosis [32,33]. These CAD tools analyze the entire input image and extract the salient features. CAD techniques do not depend on the individual segmentation and measurement of the various geometric parameters because even a small error in the segmentation may lead to wrong diagnosis [34]. The CAD methods are fast, inexpensive and can be executed even without an expert's assistance.

Fig. 2 shows the block diagram of the proposed system which is divided into offline and real time system. Image pre-processing is the first step in the offline mode where the entire set of fundus images (normal, mild and moderate/severe) is pre-processed. The 3rd order HOS cumulants features are then extracted after applying the Radon transform on the pre-processed fundus images. Analysis of variance (ANOVA) test is conducted for the evaluation of clinical significance of the extracted features. The ground truth (given by the ophthalmologist) about the different classes to which the fundus image belongs as well as the extracted significant feature set are then fed into the classifier. The classifier performance is measured using a ten-fold cross validation strategy. In the real time mode, the fundus images are pre-processed first and the significant features are extracted from them and fed to the trained classifier for classification. It then performs the classification into normal, mild glaucoma and moderate/severe glaucoma classes based on the extracted significant features.

The present paper is organized as follows: The images used for this study, pre-processing, feature extraction by HOS cumulants and LDA is explained in Section 2. Classifiers used for automated diagnosis namely, SVM and NB are discussed in Section 3. The result obtained is presented in Section 4. Result is discussed in Section 5 and the paper concludes in Section 6.

2. Methods

2.1. Data acquisition

This study uses the fundus images acquired from a TOPCON non-mydriatic fundus camera TRCNW200 which provides 3.1 megapixels fundus images. The fundus images were collected from the Ophthalmology department of KMC, Manipal, India. The ophthalmologists of the department have certified these photographs

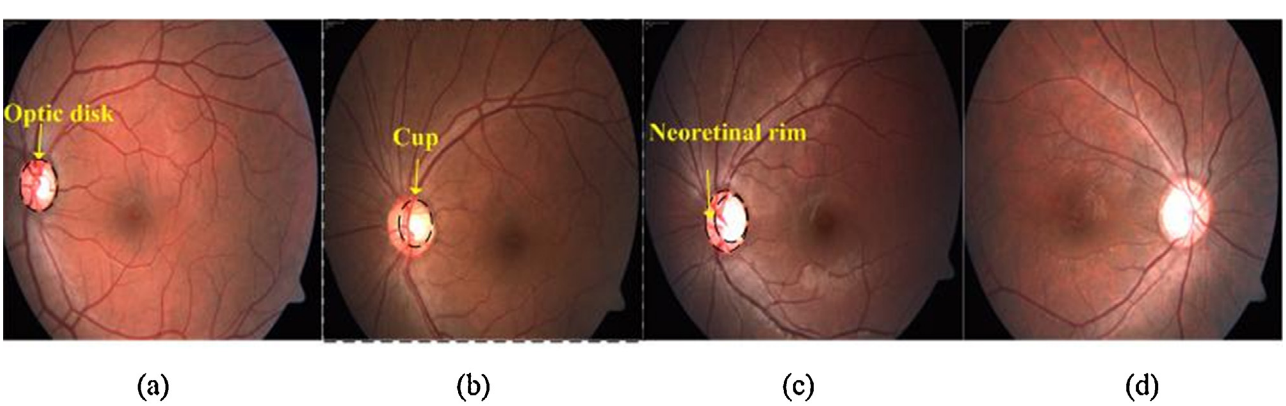

Fig. 1. Typical fundus images: (a) normal, (b) mild glaucoma, (c) moderate glaucoma, and (d) severe glaucoma.