International Journal of Medical Informatics 110 (2018) 52–70

Contents lists available at ScienceDirect

International Journal of Medical Informatics

journal homepage: www.elsevier.com/locate/ijmedinf

An automated and robust image processing algorithm for glaucoma diagnosis from fundus images using novel blood vessel tracking and bend point detection

Soorya M.[a], Ashish Issac[b], Malay Kishore Dutta[b,*]

[a] Department of Computer Science & Engineering, Amity University, Noida, India
[b] Department of Electronics & Communication Engineering, Amity University, Noida, India

ARTICLE INFO

Keywords:
Glaucoma
Retinal image processing
Mathematical morphology
Optic disc
Optic cup
Vessel tracking

ABSTRACT

Glaucoma is an ocular disease which can cause irreversible blindness. The disease is currently identified using specialized equipment operated by optometrists manually. The proposed work aims to provide an efficient imaging solution which can help in automating the process of Glaucoma diagnosis using computer vision techniques from digital fundus images. The proposed method segments the optic disc using a geometrical feature based strategic framework which improves the detection accuracy and makes the algorithm invariant to illumination and noise. Corner thresholding and point contour joining based novel methods are proposed to construct smooth contours of Optic Disc. Based on a clinical approach as used by ophthalmologist, the proposed algorithm tracks blood vessels inside the disc region and identifies the points at which first vessel bend from the optic disc boundary and connects them to obtain the contours of Optic Cup. The proposed method has been compared with the ground truth marked by the medical experts and the similarity parameters, used to determine the performance of the proposed method, have yield a high similarity of segmentation. The proposed method has achieved a macro-averaged f-score of 0.9485 and accuracy of 97.01% in correctly classifying fundus images. The proposed method is clinically significant and can be used for Glaucoma screening over a large population which will work in a real time.

1. Introduction

Glaucoma is considered to be one of the most prominent eye diseases which is capable enough of causing an irreparable damage to the human eye in today's world. It is an optic neuropathy which is responsible for causing impairment of optic nerve head. This damage is progressive and can even cause complete vision loss. The aberrations caused in the flow of the fluid present in the human eye is considered as one of the many factors that cause Glaucoma. These aberrations may result in an increased intra-ocular pressure which ultimately damages the optic nerve, thereby causing loss of nerve fibers. If the progression of the damage to optic nerve is not monitored, it may result in blindness.

Glaucoma can be majorly classified into four types, namely, primary open angle glaucoma, angle-closure glaucoma, secondary glaucoma and normal tension glaucoma. If the eye's seepage structure becomes ineffective over the time, this condition is termed as primary open angle Glaucoma. The drainage system's incompetence may result in steady gain in the eye pressure and the damage done to the optic nerve is slow and painless. But in case of angle-closure glaucoma, the seepage system is blocked all of a sudden. The blockage of the system may advance slowly or occur all of a sudden. The main cause of secondary glaucoma can be substantial physical damage, eye irregularities, medications and surgeries. In case of normal tension glaucoma, the intra-ocular pressure inside the eye remains within a specified range but still can be a cause of damage to the optic nerve.

Detailed and prompt examination is imperative for fruitful treatment of any medical disorder. Computer Aided Diagnosis (CAD) may prove useful for screening of diseases over an enormous population and may be favorable and suitable as compared to the physical analysis performed by medical experts. It will enhance, boost and aid the clinical health-care in the progressing nations where there is scarcity of qualified, skilled and competent ophthalmologists.

Some image processing related work based on the segmentation and analysis of optic nerve head from the fundus images for detection of Glaucoma has been reported and described in the literature. Maheshwari et al. [1] has proposed the use of empirical wavelet transform for detection of glaucoma from fundus images. Cheng et al.

* Corresponding author.
E-mail addresses: alevoorsoorya01@gmail.com (S. M.), issac017@gmail.com (A. Issac), malaykishoredutta@gmail.com (M.K. Dutta).

https://doi.org/10.1016/j.ijmedinf.2017.11.015
Received 20 August 2017; Received in revised form 1 November 2017; Accepted 22 November 2017

[2] has proposed the use of reconstruction coefficients obtained from sparse dissimilarity-constrained coding (SDC) for cup-to-disc ratio calculation and used it as parameter for Glaucoma identification. Cheng et al. [3] has proposed a method which uses CDR as an important parameter for Glaucoma detection from fundus images. In this method, the optic disc and cup are segmented using histograms and center surround statistics, which classify a pixel as super-pixel or not. Kim et al. [4] has proposed a fractal analysis based approach to determine the progression of Glaucoma using a multiclass prediction. Joshi et al. [5] has proposed an OD parameterization technique for segmented OD and OC. The optic cup boundary has been determined by identifying the vessel bends. Finally, vertical and area CDR are calculated to classify an image as normal or glaucoma affected. Acharya et al. [6] has proposed the use of higher order spectra and texture features for classification of a fundus image as Glaucoma. Joshi et al. [7] has proposed a depth-discontinuity based approach to determine cup boundary which is followed by calculation of cup-to-disc area ratio for Glaucoma detection from a fundus image. Dua et al. [8] proposes a wavelet features based algorithm to analyze the energy distribution in the fundus images. The wavelet features are subjected to feature ranking process and fed to a classification system with different cross validation approaches. Aquino et al. [9] has proposed a template based approach for segmentation of optic nerve head from fundus images. Some mathematical morphological and edge detection based operations are performed on the optic nerve head. Finally, Circular Hough Transform is used to approximate the optic disc boundary. Gonzalez et al. [10] has proposed a graph cut technique for segmentation of blood vessels from fundus images. The segmented vasculature is used to localize the optic disc and Markov Random Field image reconstruction technique is used for detection of optic disc boundary. Hu et al. [11] has proposed the use of both Optical Coherence Tomography (OCT) and fundus images for blood vessel segmentation. The k-Nearest Neighbor (k-NN) based classification approach is employed to segment vessels from fundus images and map them to OCT volumes for correct vessel segmentation. Morales et al. [12] has proposed a mathematical morphology and Principal Component Analysis (PCA) based approach for segmentation of optic disc. PCA decomposes the RGB image to a gray scale image with features which can aid in optic disc segmentation. Roychowdhury et al. [13] proposes a classification based approach for localization and segmentation of optic disc boundary in a fundus image. Some mathematical morphological, region based features and Gaussian Mixture-Model based classification approach is used for classification of pixels as OD or non-OD. Miri et al. [14] has proposed a multi-modal approach for segmentation of optic disc and cup contours by combining information from fundus images and OCT volumes. Niemeijer et al. [15] proposes a method in which distance based regression has been utilized to locate the optic disc and fovea in a fundus image. Bock et al. [16] has proposed an algorithm utilizing dimensionality reduction and classification techniques for generation of a Glaucoma Risk Index which signifies the performance of Glaucoma detection. Hoover and Goldbaum et al. [17] has proposed a method where fuzzy convergence has been employed to determine the point of origin of blood vessels and is ultimately used to locate the optic disc in the fundus image. Chrastek et al. [18] has proposed the use of mathematical operations followed by circle estimation techniques like Hough Transform and Active Contour model for segmentation of optic disc from fundus images. Marin et al. [19] has proposed the use of mathematical morphological operations and intensity threshold followed by Hough Transform for segmentation of optic disc from the fundus images. Krishnan and Faust et al. [20] has proposed the use of higher order spectra (HOS), Trace Transform (TT) and Discrete Wavelet Transform (DWT) features for training a SVM classifier which has been used to classify images as Glaucoma or Normal. Foracchia et al. [21] has proposed the use of directional pattern and geometric parametric model for determination of blood vessels originating point which has been used to identify the optic disc in fundus images. All these works seem to be encouraging, still there emerges a need for highly competent and productive algorithms based on image processing for real time mass screening of Glaucoma. Such algorithms may prove valuable for humanity.

1.1. Contributions of the proposed work

1. The main contribution of the proposed work is a fully automated system for Glaucoma diagnosis from a digital fundus image. The proposed Glaucoma detection system is completely automatic and computationally efficient. The glaucoma identification has been performed on the basis of cup-to-disc ratio, which is a globally accepted clinical parameter used by ophthalmologists worldwide. The proposed system is adaptive, invariant to image quality and robust to noise.
2. Another contribution lies in the use of adaptive threshold for an efficient segmentation of the optic disc from fundus images. The red channel containing only the super pixels is subjected to histogram smoothing and this histogram is used to determine an adaptive threshold for segmentation of optic disc from the image. The threshold is made adaptive by selection of statistical features, such as standard deviation and mean, from the image. This makes the threshold selection completely independent of any other image in the same or different database. The independent selection of the threshold adds to the quality of the system and makes it more robust to the illumination changes across images and databases.
3. Another important contribution of the proposed method lies in the strategic framework to robustly reject the false candidates using geometrical features to efficiently segment the optic disc from normal and non-uniformly illuminated or abnormal/affected fundus images. The robustness is achieved by creating a framework based on geometrical features such as eccentricity, solidity, circularity and ratio of major to minor axis to separate the artifacts and exudates from OD in red channel of the fundus image. Apart from red channel, the blue channel has also been used for estimating the optic disc from fundus images which contain choroid vessels.
4. Another significant contribution is the use of a novel method for accurate and computationally efficient blood vessel tracking in fundus images. The blood vessels in a fundus image tend to possess a Gaussian structure [22]. This means that if an intensity profile across the cross-section of a blood vessel is analyzed, then it is observed to have an inverted Gaussian profile. The centerline of the blood vessel tends to be the darkest and this intensity increases slightly towards the extreme points across the cross-section. So, the accuracy of detecting the accurate bend points completely depend on the accuracy of segmented blood vessels. The results of proposed method are encouraging and the system is computationally efficient and can be used as real-time tool for Glaucoma screening.

The paper is structured as follows: Section 2 discusses commonly faced challenges in the field of fundus imaging for detection of Glaucoma using computer-vision techniques. Section 3 discusses the introduction to fundus image and database used for experimentation. Section 4 discusses the proposed methods employed for optic disc and cup segmentation from the digital fundus images. Section 5 discusses the results obtained during the implementation of proposed methodology and performance parameters to determine the accuracy of the proposed work. Section 6 discusses some findings and important conclusions for the proposed work. Also, some future work is mentioned.

2. Commonly faced challenges in computer based diagnosis of glaucoma

There are many challenges which are commonly related to computer-aided Glaucoma diagnosis which makes it difficult to find the best