Automated Detection of Glaucoma using Fundus Image: A Comprehensive Review

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Abstract: Glaucoma is an eye disease that gradually affects the optic nerve and may cause permanent loss of vision if it is not diagnosed and treated early. Ophthalmologists currently use several non-invasive imaging methods for glaucoma diagnosis, including Optical Coherence Tomography (OCT), Heidelberg Retinal Tomography (HRT), Scanning Laser Polarimetry, and color fundus imaging [4]. Although OCT, HRT, and Scanning Laser Polarimetry provide useful information for diagnosis and disease assessment, these techniques can be expensive and often require specialized equipment and experienced professionals. Fundus imaging is a comparatively simple and cost-effective alternative that can be used to examine important features of the optic nerve and retina. This has encouraged researchers to develop computer-based algorithms for the early and accurate detection of glaucoma from fundus images. Therefore, this paper presents a review of existing research methods and recent developments in glaucoma detection using fundus images.
Keywords: Glaucoma; fundus image; cup-to-disc ratio; optic disc; optic cup

Introduction

“Glaucoma is one of the leading causes of visual impairment globally as stated by the World Health Organization (WHO) and is responsible for a significant proportion of cases of blindness” [1]. A study published in the British Journal of Ophthalmology reported that the number of people affected by glaucoma-related visual disability was about 60.5 million in 2010 and was anticipated to surge to nearly 80 million by 2020 [2]. “The impact of glaucoma is particularly significant among women and individuals living in regions such as Africa, India and Asia” [2]. These inclinations emphasizes the significance of detecting glaucoma at an early stage with the aim of providing treatment before permanent damage to the eye occurs.

“A fundus image of the posterior region of the retina generally shows three important anatomical structures: the macula, the optic disc (optic nerve head), and the retinal blood vessels, as illustrated in Figure 1” [11]. These structures provide important information for assessing the condition of the eye and are therefore widely considered in computer-assisted glaucoma detection.

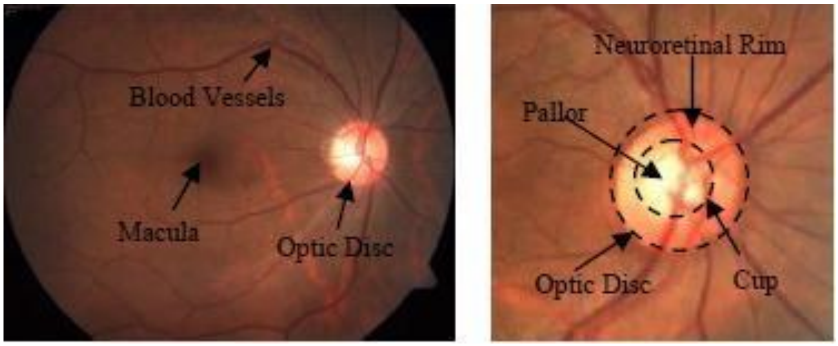

Figure 1: Fundus image highlighting the major anatomical features [4].

Related work

Fundus images provide a clear view of the major structures present in the retina. The optic disc emerge as a relatively large and bright region, usually with a yellowish or whitish appearance. “The optic cup is positioned at the center of the optic disc and is generally the brightest portion of this region” [11]. The retinal blood vessels form a network that supplies nutrients and oxygen to the retina [11]. “At the optic disc, the retinal nerve fibers come together and form the optic nerve head” [3, 11].

The retinal vascular network consists mainly of larger veins, which usually appear darker red, and smaller blood vessels, which have a lighter reddish appearance. “The optic cup can be observed as a relatively empty area in the central part of the optic disc and is enclosed by retinal nerve fibers” [11]. “In glaucoma, the gradual loss of these nerve fibers causes the optic cup to become larger over time. A healthy optic nerve comprises of approximately 1.2 million nerve fibers, and therefore the optic cup normally occupies only a relatively small portion of the optic disc” [3]. “The relationship between the dimension of the optic cup and the optic disc is commonly expressed using the cup-to-disc ratio (CDR)” [3,11]. Ophthalmologists commonly use this ratio as an important measure for evaluating glaucoma.

In order to classify remote sensing images, Cheng-Hsuan Li et al. [5] presented SVM-based method that employs both spatial and contextual information. “Using a hyperspectral image dataset containing 16 classes, their method achieved an overall accuracy of 95.5%, a kappa accuracy of 94.9%, and an average class accuracy of 94.2%” [5]. Fereidoun A. Mianji [9] presented a numerical approach aimed at solving spectral unfixing problems. The study pointed out that some existing methods do not consider important statistical characteristics of the extracted samples, which can result in less accurate solutions in practical situations [6].

Sumeet Dua et al. [7] “introduced a wavelet-based energy feature to identify glaucoma and achieved a classification accuracy of 93%”. N. Annu. et al. [8] “investigated the use of wavelets, Principal Component Analysis (PCA), and Probabilistic Neural Networks (PNN) for glaucoma detection”. Their outcomes showed accuracies of about 90% using PCA-PNN and 95% using the DWT-PNN approach [8].

Heidelberg Retina Tomography (HRT) [4] “is another imaging technique employed in glaucoma assessment. It is a confocal laser scanning system established by Heidelberg Engineering and is capable of generating three-dimensional images of the retina”. These images allow structural changes in the optic nerve head, also known as the optic disc or papilla, to be measured quantitatively [5, 9].

As glaucoma progresses, the optic cup generally becomes larger, which can influence the intensity and brightness characteristics of the fundus image. Therefore, in addition to structural measurements, other image characteristics such as entropy, mean intensity, variance, texture, and pixel intensity can be useful for glaucoma analysis. For this reason, accurate detection and localization of the optic disc is an significant initial step in automated glaucoma screening from fundus images.

The proposed study presents an automated computer-based framework for glaucoma assessment. The system is designed to identify the optic disc, determine the boundaries of the optic disc and optic cup, and automatically calculate the cup-to-disc ratio [11].

Methodology for Optic Disc Localization

“Accurately locating and segmenting the optic disc is an important step in developing an effective automated retinal screening system” [11]. Identifying the optic disc is usually performed at an early stage because its location is needed for subsequent analysis of various retinal abnormalities. Although the optic disc is generally circular, its size and shape can vary between individuals [11].

“Some researchers have used the known anatomical relationship between the optic disc and the macula to assist in optic disc localization” [12]. “The distance between these two structures was used as prior information, with the optic disc located at about 2.5 times the disc diameter from the macula” [12]. Therefore, macula detection can also be used as an initial step for locating the optic disc in fundus images [10, 12].

Akara Sopharak et al. [17] and Feroui Amel et al. [18] “proposed methods that recognize the optic disc by first detecting the brightest region in the luminance channel of a CIELAB color image”. A mask was then generated around this region. “Morphological reconstruction was applied to refine the selected area, and the difference between the original and reconstructed images was used to extract the region of interest containing the optic disc” [17,18].

“G. G. Rajput et al. identified the optic disc by analyzing its brightness, shape, and size. They then used a correlation coefficient-based method to select the most suitable candidate region corresponding to the optic disc” [13].

Methods for Detecting the Optic Disc and Cup Boundary

Accurately identifying the optic disc boundary is challenging as its size, shape, and color can differ considerably between fundus images. The existence of blood vessels emerging from the optic disc can also make the boundary irregular or discontinuous. Since retinal blood vessels are highly concentrated around the optic disc, their distribution can be used as useful information for locating and identifying the disc boundary [11].

Several methods have been proposed for optic disc boundary detection. In some studies, the optic disc was first identified using a correlation coefficient and then a circular boundary was fitted using the Hough Transform. A radius ranging from 45 to 55 pixels was considered for detecting the circular region of the optic disc [13, 16 17]. Another study proposed a semi-automated approach in which four points were manually marked along the optic disc boundary. These points were then used to construct a snake model for estimating the complete boundary [18].

Researchers have investigated various image-based features for identifying and classifying glaucoma. "In one method, wavelet energy features, the cup-to-disc ratio (CDR), and an intensity threshold were used as inputs to train an Artificial Neural Network (ANN). In order to detect the fundus images with glaucoma or not, the trained model is employed successively" [19]. Researchers have also used Artificial Iintelligence and Deep Learning techniques for glaucoma detection [21-24].

Proposed Methodology

"The automated glaucoma analysis has been done due to the fact that the optic disc and optic cup usually appear as bright regions with respect to the surrounding retinal area" [14, 15, 29]. On the other hand, methods that mostly depend on threshold or average intensity values can occasionally give inaccurate bright retinal lesions, mainly prominent exudates, for the optic disc [13,17,18], as shown in Figure 2. Hence, leads to improper segmentation which effect the accuracy of the cup-to-disc ratio calculation. "This limitation has been addressed using the proposed methodology which focuses on enhancing the detection and segmentation of both the optic disc and optic cup. Hence more exact and consistent estimation of the cup-to-disc ratio can be obtained" [13,17.18].

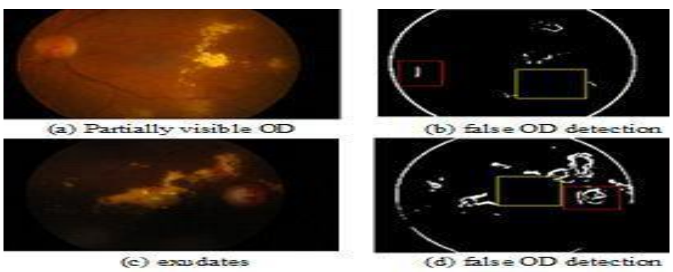

Figure 2: False Optic Disc Detection

In order to classify between optic disc and optic cup, the 3- sigma statistical approach has been adopted in the proposed method. Further GV Snake contour model is employed to mark and outline the boundaries of both optic disc and optic cup regions. The accuracy of optic disc and optic cup identification is improved by following the series of image processing techniques.

Expected Result

The proposed technique will be developed and implemented in MATLAB. The expected outcomes of the study are given below:

a) Minimizing incorrect detection: The method is expected to reduce the possibility of detecting bright exudates as the optic disc. To improve the accuracy of optic disc detection, characteristics such as its size, brightness, and shape will be examined before carrying out connected component analysis.

b) Improving pixel identification: The 3-sigma control limit approach will be used to classify pixels more effectively into optic disc and optic cup regions. This is expected to improve the accuracy of identifying both structures.

c**)** Less manual involvement**::** The proposed system will automate most of the steps involved in detecting the optic disc and optic cup. As a result, the dependence on manual observation and intervention during the image analysis process can be reduced.

Conclusions

The literature survey indicates that fundus imaging can be an effective alternative for glaucoma detection due to its simplicity, lower cost, and suitability for automated image analysis. There are limitations with respect to existing techniques: 1) Techniques based on pixel intensity, masking, or circular fitting occasionally fails to detect the optic disc properly. 2) The detection process becomes more complex where macula is used as a reference. 3) The manual intervention is required to determine the boundaries of the optic disc and optic cup.

The limitations of the existing techniques are overcome by adopting the proposed methodology. The manual intervention is avoided using proposed technique as it incorporate both image-processing and statistical features to improve the detection of the optic disc and optic cup. Hence, the proposed approach is simpler, more reliable, and robust solution for glaucoma detection than various existing techniques.

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