



## Research paper

# A new expert system based on fuzzy logic and image processing algorithms for early glaucoma diagnosis



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## ABSTRACT

Decision-making systems based on images have increasingly become essential nowadays mostly in the medical field. Indeed, the image has become one of the most fundamental tools for both clinical research and sicknesses' diagnosis. In this context, we treat glaucoma disease which can affect the optic nerve head (ONH), thus causing its destruction and leading to an irreversible vision loss. This paper presents a new glaucoma Fuzzy Expert System for early glaucoma diagnosis. Original ONH images are first pre-treated using appropriate filters to remove the noise. Canny detector algorithm is then used to detect the contours. Main parameters are then extracted, after having identified elliptical forms of both optic disc and excavation. This operation is performed by using Randomized Hough Transform. Finally, a classification algorithm, based on fuzzy logic approaches, is proposed to determine patients' conditions. Our system is advantageous as far as it takes into consideration both instrumental parameters and risk factors (age, race, family history. . .) which make an important contribution to the valuable identification of cases suspected to have glaucoma.

The proposed system is tested on a real dataset of ophthalmologic images of both normal and glaucomatous cases. Compared with other existing systems, the experimental results show the superiority of the proposed methods. The percentage of good predictions is more than 96%, reaching an improvement of 1–9% over earlier methods.

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## 1. Introduction

Regular monitoring and control of optic nerve's head structure should become a part of routine clinical management of glaucoma since the early detection and treatment of such a retinal eye disease is crucial to save the loss of vision. In fact, the patient may become blind if he does not receive any treatment [1]. The British Journal of Ophthalmology estimates that by 2020 about 79.6 million people worldwide will be diagnosed with glaucoma. However, being a chronic disease, glaucoma remains incurable. Indeed, as it is a "neurological" it affects nerve cells, which once destroyed, they cannot be replaced [2]. Therefore, its early diagnosis and treatment can prevent the vision loss [3]. The manual assessment of the optic nerve head via ophthalmoscopy or digital imaging, such as scanning laser tomography (SLT), scanning laser polarimetry (SLP) and optical coherence tomography (OCT), is recommended as clinical tools to detect glaucoma [4]. But, despite their benefit, they are not

available to the great majority of physicians because of their cost [5].

The cup-to-disc ratio (CDR) and "Inferior, Superior, Nasal, and Temporal" (ISNT) rule are 2 key indicators to assess the ONH. The CDR is defined as the ratio of the diameter of the optic cup to the diameter of the optic disc. As glaucoma progresses, optic nerve fibers gradually disappear. Thus, the optic cup becomes larger with respect to the optic disc which increases the CDR [6]. In least developed countries such as Tunisia which is the subject of this study, the CDR is usually obtained via manual measurement by an ophthalmologist. However, observing ONH changes manually is a time-consuming process, and its accuracy varies according to the ophthalmologist's experience.

Since early detection of this disease is essential to prevent the permanent blindness, many efforts have been made on automatic detection of Glaucoma at an early stage.

Bock et al. presented an automated glaucoma classification system that does not depend on the segmentation measurements [7]. They took a purely data-driven approach which is very useful in large-scale screening. The proposed algorithm undertakes a standard pattern recognition approach with a 2-stage

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classification step. In this study, various image-based features were analyzed and integrated to capture glaucomatous structures. Certain independent-variation diseases such as size differences, illumination in homogeneities and vessel structures are removed in the pre-processing phase. This system got 86% success rate on a data set of 200 real images of healthy and glaucomatous eyes.

Hatanaka et al. proposed a technique for the detection of glaucoma [8]. Using for this the vertical CDR. Canny edge detection filter was used for the detection of the optic disc edge. The edge of the cup area on the vertical profile was calculated by the threshold technique. Finally, the vertical cup-to-disc ratio was found out. They also presented, in their study, a recognizing glaucoma method by calculating “cup-disc” ratio. The method correctly identified 80% of glaucoma cases and 85% of normal cases.

A system based on cup-to-disc (CDR) ratio calculation was proposed by Chandrika et al. [9].  $CDR > 0.3$  indicates glaucoma and  $CDR \leq 0.3$ , is considered as normal image. This technique was also used by Sobia Nazi et al. [10]. However, CDR is not a good predictor of whether the eye is glaucomatous. In fact, there are occasions when people who were diagnosed inappropriately as having glaucoma due to their large cups in the presence of a large disc and healthy rim tissue and still other occasions in which glaucoma was missed because the cupping was small. Thus, the use of this method is limited if the CDR is not compared to the size of the disc.

Novel discrete wavelet feature-based techniques for fundus images' features extraction and glaucoma detection were proposed by Kim et al. to identify glaucomatous cases [11].

Mei Hui Tan et al. proposed a new method based on detecting notching in the optic cup [12]. They used for this fundus images' features such as area of blood vessels in Inferior, Superior, Nasal and Temporal side near to optic disc (ISNT ratio), and distance between optic disc center and optic nerve head.

Texture features of the Fundus image and its variations are studied and analyzed by D. Yadav et al. [13]. Cases' classification was performed by the use of neural network classifier [13]. The technique of high order spectra (HOS) is also adopted by KP. Noronha to extract main features from digital images of optic nerve head. Images are then classified using support vector machine (SVM) and Naïve Bayesian (NB) classifiers [14].

Feature Extraction technique is also adopted by Raja et al. Based on the hyper analytic wavelet transformation, statistical features are extracted and then classified using SVM [15].

A. Issac et al. proposed an automatic image processing system for glaucoma detection. Their method was based on the use of the discriminatory parameters of glaucoma infection, such as cup to disc ratio (CDR), neuro retinal rim (NRR) area and blood vessels in different regions of the optic disc [16].

A. Singh et al. presented an automatic image processing based method for glaucoma diagnosis [17]. Their work is based on feature extraction from the segmented and blood vessel removed optic disc.

A new expert system mainly based on segmentations of OD and optic cup is also presented by P. Mittapalli et al. to diagnose glaucoma [18]. The segmentation is performed by using active contour model.

Man Hu et al. presented a method for automatic optic cup segmentation that utilizes both color difference and vessel information from fundus images to determine the optic cup boundary [19]. The proposed method showed clear advantages over both the ellipse fitting method, which relies only on color information, and the vessel bends interpolation method, which depends on vessel bends information. However, this method is only confined to achieve an automatic optic cup segmentation without providing cases' classification and making a decision concerning the patient's state.

S. Maheshwari et al. presented a new method for an automated diagnosis of glaucoma using digital fundus images [20]. Main

features such as Kapoor, Renyi and Yager entropies, and fractal dimensions are extracted from Variational mode decomposition components.

This paper is mainly based on a new method that achieves an accuracy of 96.15% in classification of glaucoma using fundus images. Indeed, the proposed technique outperforms accuracy of previous comparable works [7,11–13,16,17,20]. Further detailed comparative study is provided in Section 6.

Besides, despite their great interest, all of the aforementioned algorithms consider only the instrumental parameters and the analysis of the instrument-based examinations' results without reference to some other important risk factors for glaucoma development such as genetics and family background, age and race. Apart from diagnostic potential, decisions about treatment and follow-up schedules may be improved by reference to the risk factors.

This paper describes a new strategy for computer-aided analysis of ophthalmological images in which image processing algorithms have been developed for the detection of the optic papilla and the extraction of parameters essential for the diagnosis of glaucoma. These parameters will serve as input of the second part where mathematical algorithms based on fuzzy logic engines have been developed to determine the condition of a patient potentially suffering from glaucoma.

The paper is outlined as follows. Section 2 presents background information of the main methods used in the designed system. Section 3 describes the structure of our proposed system. Section 4 will be devoted to presenting the different images processing methodologies and steps followed to extract the key parameters for glaucoma recognition. As for the section 5, it will evoke the conception of the decision-making system based on fuzzy logic techniques. The system's final results are discussed in Section 6. The final part presents the conclusion and the future prospects of the work.

## 2. Background

This section briefly describes the basics of Canny operator and Hough Transform algorithms.

### 2.1. Canny operator

The Canny operator has been developed to be optimal following three criteria: good detection, good location and uniqueness of the answer [21]. To achieve these objectives, the canny filter follows 4 steps [22].

- (1) Filtering out the noise through the use of Gaussian Filter.
- (2) Performing a gradient measurement on the image in both orthogonal directions. Gradient magnitude and gradient direction are computed using the Eqs. (1) and (2):

$$\|G\| = \|\nabla I\| = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2} \quad (1)$$

The contour direction is determined by:

$$\theta = \arctan\left(\frac{G_x}{G_y}\right) \quad (2)$$

Where  $I$  is the light intensity in the image.

- (3) Non-maximum suppression for the gradient magnitude.
- (4) Adding and connecting edges through an hysteresis thresholding.

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