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Glaucoma Detection Using Fundus Images of the Eye

Dr. B. Kedarnath, Mohammad Mohiddin, Md. Shazia Samreen, K. Sai Priya, O. Shiva Kumar
Department of Electronics and Communication Engineering, Guru Nanak Institute of Technology, Ibrahimpatnam, Rangareddy 501506, Telangana, India

Abstract:
Glaucoma is one of the leading causes of irreversible blindness in people over 40 years old. In Colombia there is a high prevalence of the disease, being worse the fact that there is not enough ophthalmologists for the country's population. Fundus imaging is the most used screening technique for glaucoma detection for its trade-off between portability, size and costs. In this paper we present a computational tool for automatic glaucoma detection. We report improvements for disc segmentation in comparison with other works on the literature, a novel method to segment the cup by thresholding and a new measure between the size of the cup and the size of the disc. Results were obtained from a set of fundus images in collaboration with the Center of Prevention and Attention of Glaucoma in Bucaramanga, Colombia, where the percentage of success of glaucoma detection was of 88.5%.
Keywords: glaucoma detection, disc segmentation, veins seg- mentation, cup segmentation, image processing

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I. INTRODUCTION

Glaucoma is the first cause of irreversal blindness since it affects the eye's optic nerve. In most of the cases patients do not experience symptoms of vision loss until advanced stages. According to Mohammadi [1] and Jeyaraman [2], it is estimated that in developed countries, at least half of glaucoma patients feel no signals of the disease, which is expected to be worse in developing countries. In a study of glaucoma prevalence from worldwide published data [3], [4] found that by 2020, over 11.1 million people will be bilaterally blind from primary glaucoma. In

[3] was also reported the increasing economical cost of treatment of glaucoma in advanced stages. In Colombia, the Ministry of Health and Social Security estimates that there is around 296,000 blind people for several causes, having glaucoma a prevalence of 3.9% in people over 40 years old in Bucaramanga [5]. This gets worse by the fact that in the country, based on the population in 2011, there are 2 opthalmologists for 100,000 patients [6].

The damage in the optic nerve is due to elevated pressure in the eye, which is caused by either overproduction of aqueous humor or by the blockage of the drainage system of this liquid. There is also evidence of the incidence of genetic family background in the appearance of the disease. There are several tests that can be performed in a patient with suspected glaucoma, such as tonometry to measure the eye's pressure, gonioscopy to see if angle is open or closed, optical coherence tomography (OCT) and funduscopy or fundus imaging to see the retina and the optic nerve as shown in Figure 1.

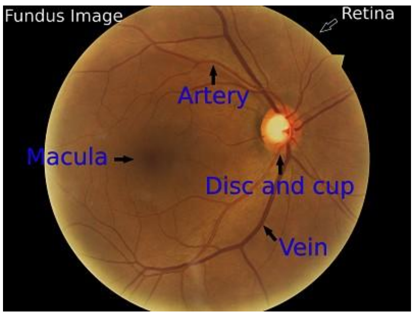

Figure 1. Fundus image and important parts of the eye

The retinal fundus image is used to measure the thickness of the retinal nerve fiber layer (RNFL) to diagnose glaucoma. It is one of the non invasive techniques most used by ophthalmologists. Its major advantage is that images can be taken easily for either healthy and non healthy retinas [7], it is also portable and not difficult to use for any health professional, specially in screen- ing campaigns among population without access to health care services.

The thickness of the RNFL is calculated by measuring the proportion among the size of the optic nerve (named disc) and the size of the excavation inside the optic nerve produced by the increasing eye's pressure (named cup). This parameter is known as the Cup-to-Disc ratio (CDR).

Several works has been done for automatic glaucoma detection based on color fundus images [8], where the main difficulty is to provide an accurate estimation of the CDR. Anusorn et al [9] pro- poses a method for disc segmentation using edges detection. This method has problems if the eye has peripapillary atrophy which is a disease that alterates the edges of the disc. For segmenting the cup it uses as threshold one third of the highest grayscale intensity, however, the distance between the disc pixels and the cup pixels is not always the same, which makes difficult the segmentation among images taken from different persons. Another problem is to detect the cup edges when it is starting to grow in the early stages of the disease.

Dhumane and Patil [10] use superpixel segmentation to detect both disc and cup by means of a clustering algorithm, with a sensitivity of 88% and accuracy of 90.9%. It has a drawback when the excavation is growing in the nasal-temporal direction, since in that direction there is more presence of blood vessels that hide the cup.

Ayub et al [11] propose the cup and disc segmentation using RGB and HSV color models and K-mean clustering. The method has 92% of accuracy, but they do not take into account the vascular system that goes throughout the disc which interferes with the precision of detecting the correct pixels that belong to the disc.

Nikam and Patil [12] implement the disc and cup segmentation with an ellipse fitting algorithm, where the fitting of the area is done by minimizing a distance cost function. They also provide a user interface developed in MATLAB.

In this work we present a computational tool for automatic glaucome detection from fundus images of the eye. We propose a novel method for cup segmentation, which shows an improvement in the accuracy compared to other methods. The algorithms have been tested using a set of images provided by the Prevention and Attention Center of Glaucoma in Bucaramanga, Colombia. The organization of the paper is as follows, in section 2 we present the methods for the segmentation of disc, cup and blood vessels, as well as the measurement of the Cup-to-Disc Ratio (CDR). In section 3 we do the discussion of the results and finally, we present the conclusions and future work.

II. RELATED WORK

In practice, what doctors do to determine if a patient has glaucoma or not, is to do a visual estimation of the CDR by observing the fundus image of both eyes of the patient. For the very well trained specialist this task can take around one to three minutes to give a diagnostic, however is prone to subjectivity. There is also the fact that it could be very demanding when this is done in screening campaigns where at the end, each specialist has hundreds of images to read. The CDR is calculated as follows,

$$\text{CDR} = \frac{areaCup}{areaDisc} \quad (1)$$

if the CDR 0.6 it is glaucomatous, otherwise it is not. According

to this, and as it was studied along the literature review, in order to do the automatic glaucoma detection, the first step is to obtain the segmentation of the disc and the cup as shown in Figure 2.

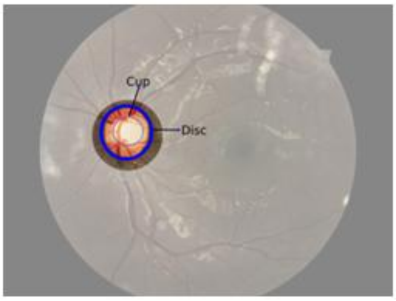

Figure 2. Disc and cup location

In the following subsections are described the methods im- plemented to obtain both segmentations as well as for the blood vessels.

Disc segmentation

Because of the predominant orange background of the retina in the fundus image, we used the red channel to obtain the segmentation of the disc. The first step is to segment the disc, the channel that offers best results to do this is the red channel, for this, it was necessary an algorithm to fix the initial threshold in order to localize the disc inside the retina. To estimate the average amount of pixels necessary to be considered a disc, it is calculated the following parameter according to the work in [10],

$$P_{avg} = \frac{\pi * D^2}{7.33 * 8} \quad (2)$$

where the D is the diameter of the retina in pixels. This value is taken as a reference to find the threshold for segmentation.

From the image histogram, starting from 255 down to 0, if the amount of pixels among two consecutive grayscale tones is bigger than Pavg, it computes the proportion of pixels between these two grayscale tones and selects the highest tone as the threshold if such proportion is bigger than 10%.

In this work we propose an improvement to the method presented in [10], since that threshold is not always accurate for the disc segmentation. We impose three conditions to evaluate the accuracy of the segmentation, they are the proportion of height versus width of the shape of the blob that contains the disc which has to be similar to an elliptical shape, the location of such blob, and the amount of pixels inside the blob has to be less than Pavg. The algorithm computes iteratively the accuracy of the highest threshold until the three conditions are met.
To meet the condition of location we designed a filter which is a matrix with ones in the area that contains the disc and zeros in the other parts as shown in Figure 3.

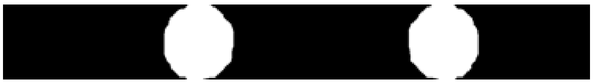

Figure 3. The designed filter

The filter has two white blobs to have into account that the image could be either from the right or left eye. The coordinates of the center of the actual blob must agree with the 31% of height and the 43% of width of the whole image for the left eye, and 69% of height and 43% of width of the whole image for the right eye as illustrated in Figure 4.

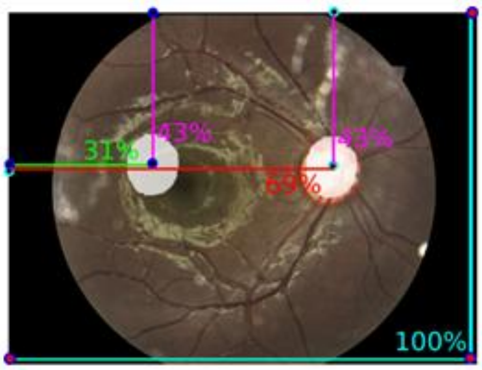

Figure 4. The designed filter modified for an eye

Eye vessels segmentation

Before segmenting the cup it is mandatory to segmentate the blood vessels coming from the disc, since the curvature of the vessels helps to detect the edge of the cup in the nasal (N), superior (S) and inferior (I) quadrants of the disc, following the ISNT division used by the ophthalmologists as shown in Figure 5. It is important to notice that according to the specialists experience, the excavation forces the vessels to move towards the nasal direction, which is a fact to have into account to detect the nasal edge of cup.

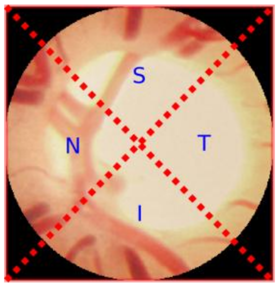

Figure 5. Disc quadrants

In this step the green channel of the fundus image is used. An important artifact that should be removed is the macula, for this, the method proposed by Dash and Bhoi in [13] is followed, where the original image in the green channel is convolved by a mean filter in order to blur the edges of the vessels. Then, a subtraction between the original image and the blurred one is done to remove the macula. From there, a new threshold is computed to isolate the blood vessels.

Cup segmentation

Since the pixel intensities of the excavation are brighter than the pixels of the disc, the blue channel is used to sementate the cup. The ISNT rule is applied to divide the optical disc into 4 segments: Inferior, Superior, Nasal and Temporal (see Figure 5). The first three segments are used to detect the boundaries of the blood vessels inside the cup, for which, the centroid of each segment is computed following the method proposed in [14]. The temporal segment is used to detect the external boundary of the cup.

To find a good threshold, we propose an algorithm that works only on the temporal quadrant. It builds *m* arrays of size 1 *n*, where *n* is the number of pixels from the center to the border of the disc; *m* is the number of pixels on the arc of the temporal quadrant (see Figure 6); it avoids the vessels pixels. For each array it finds the position of its maximum gray intensity and computes the average gray value of their neighbours pixels; the same is done with the minimum gray intensity. With this, it builds an array of the average of maximums and an array of the average of minimums. From each of these arrays are discarded the elements that are higher than one standard deviation, this is done iteratively until each array only has the values that are less than the standard deviation. These values are averaged and this is the threshold to segmentate the cup.

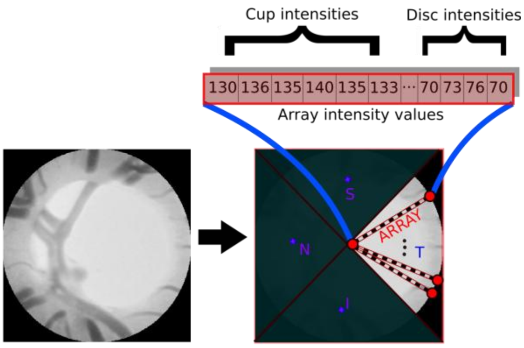

Figure 6. Obtention of the temporal disc arrays

Cup-to-Disc Ratio measurement

Once the disc and the cup have been properly segmented, we can proceed to measure the Cup-to-Disc Ratio. We implemented two methods whose precision is compared with the specialist's diagnostic. The first method places a reference point at the center of the optic disc and measures both the distance from this point to the border of the segmented cup (denoted by R_C), and the distance from the center to the border of the optic disc (denoted by R_d). This is done at several places around the disc as is shown in Figure 7*a*). Then, a geometric mean is used to obtain the mean radius, which is a number between 0 and 1. If this number is greater than
0.6 the eye is classified as suspicious for glaucoma and the patient should be addressed for further treatment. The other method takes the size of the areas and computes the proportion between both as in equation 1 (see Figure 7*b*)).

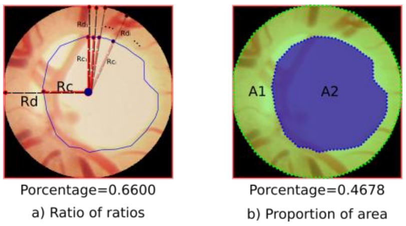

Figure 7. Methods of Cup-to-Disc Ratio measurement

III. RESULTS

Disc location results

To be able to segment the blob of the disc by location using the filter described in section 2.1, it was necessary to compute first the average location of the center of the disc (measured as the percentage of the disc center with respect to the border of the image), which is the reference position to properly place the filter. We used 30 images to obtain this average location, the values are shown in the following plots, where the red line indicates the average location of the 30 images. For the X-axis it is 69.26% and for the Y-axis it is 43.13%.

Figure 8. Relative position of the disc for 30 eyes in the X-axis

Disc segmentation results

Tests were conducted over 16 fundus images. The accuracy obtained for the disc segmentation using the algorithm proposed by [10] was 92% and for our improved method was 95%, which overcomes the problems due to noise, macular generation, or instrument acquisition. Results are shown in Figure 10 for fundus images from two different patients, where the segmentations using both methods are compared.

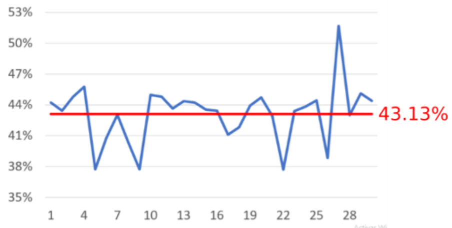

Figure 9. Relative position of the disc for 30 eyes in the Y-axis

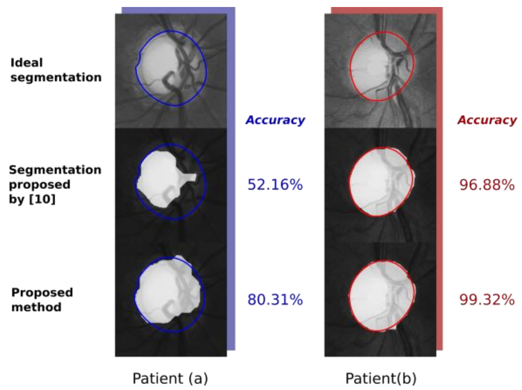

Figure 10. Disc segmentation results

Glaucoma detection results

We performed the measurements over a set of 26 fundus images of both healthy and non-healthy eyes, where the opthal- mologists provided their estimated CDR for each image. Results coming from our algorithm were compared with those reference estimations as shown in Figure 11, where are presented the compar- isons between the doctor estimation, the output with the algorithm of ratio of ratios and the output of the algorithm of proportion of areas. The absolute error was 8.6% and the relative error was 19.2%. There was a success of 88.5% for the detection of the glaucomatous cases.

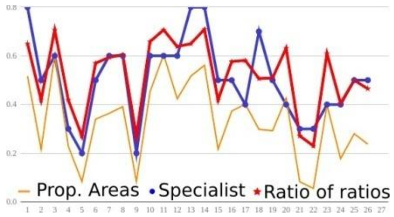

Figure 11. Comparison between the algorithm and the specialist's estima- tion

IV. CONCLUSIONS AND FUTURE WORK

The presence of the cup in the disc is a strong indicator of glaucoma, a method to detect glaucoma was presented here by properly detecting the location of the cup. The disc segmentation was done by thresholding, the vessel segmentation was done using edge detection, and for the cup segmentation it was presented a method that uses the vessels and the cup intensities. Future work concerns to obtain a bigger dataset of fundus images to make a deeper test of the algorithm. The vessels segmentation requires an improvement due to some fails in different images and residual noise after the segmentation. The use of convolutional neural networks is part of the future work to improve the classification.

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