GUI Based Optic Disc and Cup Characterization from Fundus Images

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***Abstract*—The aims of this project were twofold: (1) to develop an accurate, yet simple and efficient algorithm that estimates the optic cup-to-disc ratio from input retinal images (a critical feature in the evaluation of glaucoma), and (2) to implement this algorithm in a graphical user interface (GUI) that can aid optometrists and other trained professionals in this characterization process. The first aim addresses the possibility of having this diagnostic tool implemented in devices that can be transported to areas currently devoid of appropriate medical care at low prices. Both goals have been completed successfully. The developed algorithm works as follows: by selecting the center point of the optic disc and optic cup on a retinal image, radial lines are projected outward in a circular pattern that detect the edges by determining the greatest change in pixel intensity. The points of greatest difference are connected to form polygonal approximations of the desired features. The areas of the polygons are calculated and the ratio between the two areas is determined, providing a reliable estimate to the relevant cup-to-disc ratio.**

***Keywords*—glaucoma detection, optic cup, optic disc, graphical user interface, GUI, edge detection, radial lines, dead zone.**

I. Introduction

Glaucoma affects 60 million people worldwide, and is the leading cause of vision loss in the United States. [1] Glaucoma is a disease that damages the eye's optic nerves due to increased intraocular pressure. [2] Increased intraocular pressure results from partially or fully blocked drainage canals located around the iris, which prevent the aqueous humor from draining appropriately. When intraocular pressure increases, a force is asserted on the optic nerve, which restricts blood flow through the blood vessels. This can result in permanent, irreversible damage. [2] Symptoms of glaucoma include nyctalopia, peripheral vision loss, light sensitivity and blurred vision. [2] If glaucoma is detected at an early stage, the symptoms can be mitigated through medication or surgery. [2]

One characteristic that is associated with the presence of glaucoma is an increased optic cup-to-disc ratio. [3] The optic cup is the central portion of the optic disc that lacks nerve fibers. When glaucoma progresses to a severe state, the area of the cup increases and approaches the outer edge of the optic disc. Therefore, as the cup-to-disc ratio increases, the likelihood of glaucoma increases. It is desirable to develop accurate, efficient, and simple methods of characterizing this feature in order to make the diagnostic procedure easy and affordable to implement in medical practice.

II. Methods

Figure 1 displays the general procedure for performing this disc and cup characterization. The first step in the process is the determination of a center point from which radial lines will be launched. This is done in our GUI by manually clicking a center point based on visual inspection of the fundus image.

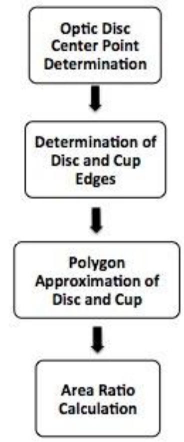

Figure 1: Flow chart of algorithm

From this point, the edges of the cup and disc are detected using an algorithm that tracks pixel intensities along the radial lines projected outward from the designated center point. Each line consists of a discrete number of intensities sampled at a certain step size along the radial line. [4] This sampling does not actually begin until a specified "dead zone" has been cleared, which is a predefined circular region in which no samples are taken in order to avoid mistaking blood vessels for disc and cup edges (the vessels converge right near the center of the optic disc). The sampling locations are described by the following formulas:

$$\boldsymbol{x(j) = x_c + d * \cos(\theta) + p * (j-1) * \cos(\theta)} \quad (1)$$

$$\boldsymbol{y(j) = y_c + d * \sin(\theta) + p * (j-1) * \sin(\theta)} \quad (2)$$

In equations (1) and (2), $\boldsymbol{x_c}$ and $\boldsymbol{y_c}$ refer to the $\boldsymbol{x}$ and $\boldsymbol{y}$ pixel coordinates of the center point, $\boldsymbol{x(j)}$ and $\boldsymbol{y(j)}$ refer to the $\boldsymbol{x}$ and $\boldsymbol{y}$ coordinates of sample $\boldsymbol{j}$ along a radial line projected at angle $\boldsymbol{\theta}$ to the horizontal. The variables $\boldsymbol{d}$ and $\boldsymbol{p}$ refer to the dead zone radius and step size, respectively.

For most of the lines, the sample locations do not fall on an integer pixel location, and thus the average of the four surrounding pixels is used to interpolate the intensity at these points. The change in intensity is determined between each consecutive pair of pixels along a line, and the point at which the greatest derivative is found is deemed an edge point of the disc. The derivative used is a simple discrete derivative shown here:

$$\boldsymbol{D(i,j-1) = M(i,j-1) - M(i,j)} \quad (3)$$

In equation (3), $\boldsymbol{D(i,j-1)}$ refers to the derivative $\boldsymbol{D}$ at the previous step $\boldsymbol{(j-1)}$ along radial line $\boldsymbol{i}$. The term $\boldsymbol{M(i,j-1)}$ is the interpolated pixel intensity at the previous step on radial line $\boldsymbol{i}$, and $\boldsymbol{M(i,j)}$ is the interpolated pixel intensity at the current step.

The same process is then repeated to find the cup edges, except the lines only travel to the disc edge this time so that the next highest derivative is located. This means the success of the cup characterization is highly dependent on the success of the disc characterization. In an attempt to eliminate outlier points, the mean distance between the center point and disc edge points is calculated and compared to each of the individual distances. The same process is repeated for the cup characterization. Some upper and lower tolerance is allowed, while points whose distances lie outside this allowed range are replaced by a point of median distance. This median filtering of outliers prevents any one outlier from greatly skewing the characterization.

Once the edges of the optic cup and disc are located using the radial line technique, the edge points are directly connected, creating two polygons. The areas of the two polygons are calculated and a ratio is determined.

We developed this algorithm in Matlab, and presently a fully functional GUI exists in which one can adjust the various parameters (such as the dead zone radius) and view the updated edge point detection and area ratio calculation live.

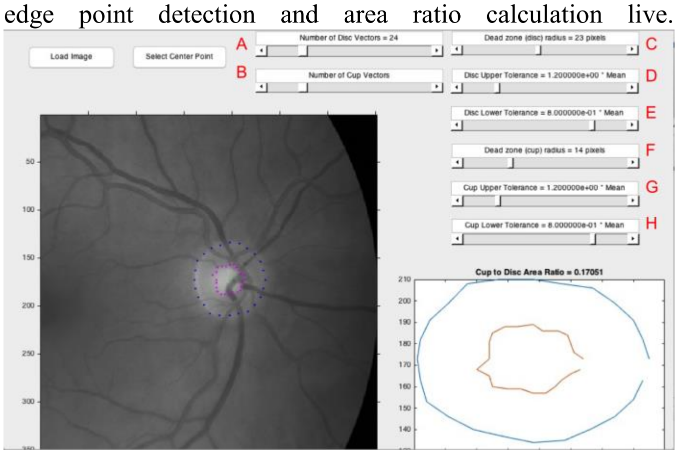

Figure 3: MATLAB GUI; The image on the left is the retinal image with disc (blue) and cup (purple) points shown. The plot on the bottom right depicts the polygonal approximations and cup to disc ratio (displayed above it). The "Load Image" and "Select Center Point" buttons allow a retinal image to be loaded, resized to focus on the optic disc, and can be clicked to select the center point. The 8 slider bars allow the following to be adjusted: A) The number of radial lines used for the disc edge detection B) The same parameter described in A, but for the cup detection. C) The dead zone radius for disc detection described in text. D) The upper tolerance of allowed distances between center and disc. E) The lower tolerance. F, G, H) Same parameters described in C, D, and E, but for cup detection instead of disc.

III. Results

The described algorithm can successfully locate the disc and cup edges on a number of retinal images. However, the values of some of the parameters can greatly influence the effectiveness of the algorithm, which makes the implementation of this algorithm in the GUI very useful. The ability to actively adjust various parameters described in Figure 2 allows one to see how each variable affects the characterization algorithm, and in turn make appropriate adjustments that improve the characterization for any particular image. Figure 3 demonstrates this usefulness by showing the results of using three different values for the dead zone radius during optic disc detection. In this figure the optic cup points have been suppressed for clarity. For this image, when the dead zone radius is set to 15 pixels, the optic disc points (circular points in figure 3) undershoot the apparent visual disc perimeter. When it is increased to 45 pixels, there is an overshoot (triangular points). A decrease in the dead zone to 30 pixels results in a very accurate outline of the optic disc (arrow shaped points). The algorithm reruns each time a slider is adjusted. The result of any adjustments can be seen and evaluated in real time which increases the efficiency of parameter optimization

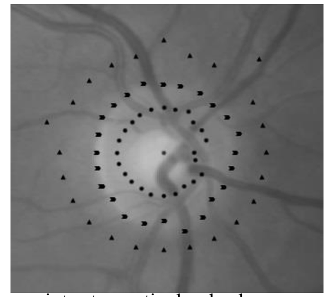

Figure 2: Each set of points shows the disc points at a particular dead zone radius setting; triangle set-45 pixels, arrow set-30 pixels, circle set-15 pixels.

IV. Discussions

The current functionality of this algorithm in Matlab shows promise for the evaluation of glaucoma on a variety of platforms. However, there are many improvements that can be made in future development. As mentioned previously, it would be desirable to have this same algorithm implemented in a cheap medical device that could be produced at low costs and potentially be used in developing parts of the world where medical care is subpar. In particular, the Blackfin Low Power Imaging Platform Board (BLIP) is one affordable option from Analog Devices that can run the developed algorithm. Additionally, the need for these special "dead zone" parameters could be removed by developing a method of automatically detecting and either removing or ignoring blood vessel disturbances. One possibility we have started to examine is the identification of pairs of derivative peaks of opposite signs, a phenomenon typically indicative of blood vessel edges. This implementation would make the algorithm more robust since the regions that should be ignored would be tailored to the blood vessel geometries of each image. The GUI could also be used to further investigate correlations between cup-to-disc ratio and the presence of glaucoma. With this tool, it would be very easy and efficient to get ratio estimates for thousands of known sample images, and use this data to more accurately determine risk indices for glaucoma based on the cup-to-disc ratio.

V. Acknowledgment

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