AUTOMATIC DETECTION OF THE OPTIC DISC USING MAJORITY VOTING IN A COLLECTION OF OPTIC DISC DETECTORS

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ABSTRACT

This paper proposes an efficient method for locating the optic disc in retinal images automatically using majority voting scheme and data fusion. We show that instead of inventing a new algorithm which ends up being a minor variation on an old idea, the fusion of different optic disc (OD) detectors can enhance the overall performance of the detection system. The optic disc centre candidates of different optic disc detectors are marked in the image and a circular template is fit on each pixel in the image to count the outputs of these algorithms that fall within the radius. The location with maximum number of optic disc centre candidates is the hotspot and is used to localize the optic disc centre. An assessment of the performance of the combined optic disc detector versus detectors working separately is also presented. Our method achieved highest performance (overall 100% correct detection).

Index Terms — Biomedical optical imaging, Computer aided analysis, Image analysis, Image processing

1. INTRODUCTION

The automatic detection of the position of the optic disc (OD) is an important step in the automatic analysis of the retinal images. The OD is a circular shaped anatomical structure with a bright appearance. It is the location where the optic nerve enters the eye. If the position and the radius of the OD are detected correctly, then they can be used as references for approximating other anatomical parts e.g. the fovea. Moreover, information about the OD can be used to examine the severity of some diseases such as glaucoma. It is often needed to mask the OD out for bright lesion detection (exudates, cotton-wool spots) because of its similarity in brightness and color in a diseased retina. Several approaches have been proposed to automatically localize the OD. For example, in [1] morphological filtering and active contours are used to find the boundary of the OD, while in [2] morphological operations are combined with Hough transform to localize the OD. Here, the proposed method consists of two steps: first, a circular region of interest is found by isolating the brightest area in the image by means of morphological processing, and then, Hough transform is used to detect the main circular feature (corresponding to the OD) within the positive horizontal gradient image within this region of interest. In [3], a kNN regression is used to find the relationship between the dependant variable $d$, representing the distance to the optic disc centre, and a feature vector measured around a circular template. A series of other interesting algorithms includes [4-8]. However, it is difficult to determine which one is the best approach because good results were reported for healthy retinas but less precise on a difficult data set i.e., the diseased retinas with variable appearance of ODs in term of intensity, color, contour definition etc. The current literature is rather poor regarding the comparison of different algorithms and performance evaluation on common databases. In the proposed approach, we have combined the output for the optic disc centre of different optic disc detectors and tested a majority voting scheme with a circular template to detect the correct position of the OD center. The criterion for the selection of the algorithms to be combined is an open issue, however, our selection was based on robustness, detection performance and low computational time. In the rest of the paper, section 2 presents some existing optic disc detection algorithms which we have used in our proposed system. Section 3 presents the proposed procedure, while section 4 discusses the results. Section 5 gives conclusion and further recommendations.

2. DESCRIPTION OF ALGORITHMS

In this section we present some state-of-the-art OD detectors that were selected for the proposed majority voting scheme. For the forthcoming majority voting all these algorithms were implemented to return the OD centre as a single pixel.

2.1. Based on Pyramidal Decomposition

This algorithm relies on three assumptions. First, the image is centered on the macula or optic disc, second, the OD
represents a bright region (not necessarily the brightest) and finally, the form of the OD is approximately circular. Based on the hypothesis that the optic disc is roughly a circular patch of bright pixels surrounded by darker pixels Lalonde et al. [6] propose to locate the candidate OD regions on the green plane of the original image by mean of pyramidal decomposition (Haar-based discrete wavelet transform). In the low resolution image pixels which have the highest intensity values compared to the mean pixel intensity over the search area were selected as possible candidates. Next, smoothing is done within each of these regions and the brightest pixel is selected as a possible OD center point and its confidence value is computed as the ratio of average pixel intensity inside a circular region centered at the brightest pixel and the average intensity in its neighborhood.

2.2. Based on Edge Detection

In this method, Lalonde et al. [6] search the area identified by the pyramidal decomposition (see section 2.1) for a circular shape. To reduce the number of regions of interest, contiguous regions were aggregated into a single zone. A binary edge map is obtained by performing Canny edge detection in the region of interest first, and then a thresholded image \( I_T \) is obtained with a special threshold value computed from noisy edge map. The search for the OD contour is performed using an algorithm based on Hausdorf distance. The Hausdorf distance provide a degree of mismatch between two sets of points, defined as

\[
H(A, B) = \max(h(A, B), h(B, A)) \text{ with } h(A, B) = \max_{a \in A} \min_{b \in B} \|a - b\|
\]

Several circular templates of variable sized diameters were used to compute the Hausdorf distance between the templates and thresholded image \( I_T \) containing edges. Hence, a percentage of matches are computed, and if the certain proportion of the pixels template is found to overlap edge pixels in \( I_T \) then the location is retained as the centre point of a potential OD candidate.

2.3. Based on Entropy Filter

Sopharak et al. [7] presented the idea of detecting the optic disc by entropy filtering. The original RGB image is transformed into HSI color space, median filtering is applied to remove possible noise and for contrast enhancement Contrast Limited Adaptive Histogram Equalization (CLAHE) is done to the I band. After preprocessing, optic disc detection is performed by probability filtering, using the following equation:

\[
H(I_x) = - \sum_{i=0}^{255} P_i(x) \log P_i(x)
\]

Where \( P_i \) is the probability mass function of the pixel intensities \( I_x \) in a local neighborhood of \( x \). Binarization is done with Otsu’s algorithm [9] to separate the complex regions from the smooth ones, and the largest connected region with an approximately circular shape is marked as a candidate for the optic disc.

2.4. Based on Fuzzy Model

Hoover et al. [8] described a method based on a fuzzy voting mechanism to find the optic disc location. The method uses the convergence of the blood vessel network as the primary feature for detection. In the absence of a unique and strongly identifiable convergence, the brightness of the nerve is used as a secondary feature. The input to the algorithm is a binary segmentation of the blood vessels. The segmentation is achieved by thinning the vessel image and relabeling the branch points as background, thus, breaking up the foreground (vessel network) into segments that contain two end points each. Each line segment (vessel) is extended at both ends by Fuzzy element \( R \) (\( R = 15 \) pixels). The area of this fuzzy segment contributes a vote to its constituent pixels. The summation of votes at each pixel produces an image map where each pixel contains a value proportional to its strength of convergence. The map is then blurred and thresholded to produce one point of strongest convergence.

2.5. Based on Hough transformation

Ravishankar et al. [10] tried to track the optic disc by combining the convergence of the only thicker blood vessel initiating from it and high disk intensity properties in a cost function. On initially resized image to standard resolution (768 × 576), a grayscale closing operation is performed on the green channel image. This step is followed by thresholding and median filtering to obtain the binary image of the blood vessels. The segments of the thicker blood vessels skeleton are modeled as lines found by the Hough Transform (HT). The dataset of lines generated is reduced by removing those lines with slopes \( \theta < 45^\circ \). This reduced dataset of lines is intersected pairwise to generate an intersection map. The map is dilated to make the region of convergence more apparent. A weighted image is produced by combining this dilated intersection map and preprocessed green channel image. A cost function is defined to obtain the optimal location of the OD, that is a point which maximizes the cost function.

For an impression, see Figure 1 for the output of these five algorithms together with the manually selected center.

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3. FUSION OF THE OPTIC DISC DETECTORS

Overall, we have combined the outputs of the five algorithms discussed in section 2 in the data fusion step. The individual outputs of the algorithms for the optic disc center are marked with different colors spots in Figure 1 and their co-ordinates are stored in a vector list. Next, a circular template of radius $R$ is fit on each pixel in the image and outputs of candidate algorithms that falls within the radius of the predefined circular template are counted. The radius $R = 45$ adjustment for the OD radius is influenced by the fact that clinically this is the average OD radius at the investigated resolution.

The centre of the circular template covering the maximum number of optic disc detector outputs in its radius is considered to be a hot spot for the optic disc. There can be more hot spots covering the maximum number of optic disc detector outputs in their radius, hence they together define a hot spot region, the patch with highest probability as the optic disc (Figure 2a). To find a single centre of the optic disc, the centre of gravity of the outputs is computed as the final centre of the optic disc. That is, if the output centers of the individual algorithms are $(x_1, y_1), (x_2, y_2), \ldots, (x_N, y_N)$, respectively, then the final OD center $(x_{cg}, y_{cg})$ is computed as the center of gravity of these pixels:

$$
x_{cg} = \frac{\sum_{i=1}^{N} x_i}{N}, \quad y_{cg} = \frac{\sum_{i=1}^{N} y_i}{N}
$$

Figure 2b shows the centre of the optic disc found by the combination of outputs and its respective circular zone, detected as optic disc. In this example, four individual algorithms ($N=4$) had their outputs in the hotspot region.

4. RESULTS AND DISCUSSION

We tested the five algorithms listed in section 2 on the publicly available DRIVE [11] database, which contains 61 images of two different resolutions ($565 \times 584, 730 \times 490$). The methods have been evaluated on the basis of two criterions i.e., to fall inside the manually selected optic disc patches (see Figure 3), and to be close to the manually selected OD center.

Table 1 shows the correct detection of the OD location based on optic disc patch, where the proposed combined method achieved the maximum accuracy. Table 2 shows the performance of the methods in a radius of 45 and 25 pixels from manually selected optic disc center. The percentage detection rate of the proposed approach is higher than the rest of the algorithms in case of 45 pixel radius but the rest of the algorithms are also quite close. However, when the radius is decreased to 25 pixels the combined approach outperformed the individual methods as we can see a very
high detection rate of 98% which proves the precision of the proposed combination. The only miss of the combined approach is for a diseased retina (Figure 4), where the detected centre is not highly accurate but still inside the OD region.

Table 1. Detection rates to fall inside manually selected OD

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Detection Rate</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyramidal Decomposition</td>
<td>51/61</td>
<td>83%</td>
</tr>
<tr>
<td>Edge Detection [6]</td>
<td>60/61</td>
<td>98%</td>
</tr>
<tr>
<td>Entropy Filter [7]</td>
<td>60/61</td>
<td>98%</td>
</tr>
<tr>
<td>Fuzzy Model [8]</td>
<td>39/61</td>
<td>64%</td>
</tr>
<tr>
<td>Hough transformation[10]</td>
<td>51/61</td>
<td>83%</td>
</tr>
<tr>
<td><strong>Proposed Combination</strong></td>
<td>61/61</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2. Detection rates with a radius of 45 and 25 pixels from ideal OD centre

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Accuracy 45 pixels</th>
<th>Accuracy 25 pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyramidal Decomposition</td>
<td>82%</td>
<td>49%</td>
</tr>
<tr>
<td>Edge Detection [6]</td>
<td>96%</td>
<td>88%</td>
</tr>
<tr>
<td>Entropy Filter [7]</td>
<td>96%</td>
<td>83%</td>
</tr>
<tr>
<td>Fuzzy Model [8]</td>
<td>60%</td>
<td>27%</td>
</tr>
<tr>
<td>Hough transformation[10]</td>
<td>83%</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Proposed combination</strong></td>
<td><strong>98%</strong></td>
<td><strong>98%</strong></td>
</tr>
</tbody>
</table>

So far, no conflicts reported in the majority voting of the outputs on any of the images in the test database, however, if there is a tie then such cases can be handled by associating weights to the algorithms outputs or by giving preference to the hotspot which contain the best performing algorithms output, e.g. Edge Detection [6] and Entropy Filter [7].

5. CONCLUSION

This paper is about our choice of combining the outputs of a collection of optic disc detectors to get a robust method for the detection of optic disc center. We have used a majority voting based scheme that count the number of outputs of the algorithms falling in a specified radius circle, and is marked as a hotspot. The centre of gravity of the disc centers reported by these algorithms is selected as the recommended optic disc center. Our method achieved highest performance, and closest to the manually selected optic disc center chosen by a retinal specialist. This proposed combination is just one possibility, there is still room for further improvement through further research by combining other methods. Weights can also be assigned to the algorithms according to their performance and computational needs.

6. ACKNOWLEDGEMENT

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7. REFERENCES


