ULTRAFAST OPTIC DISC LOCALIZATION USING PROJECTION OF IMAGE FEATURES

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ABSTRACT

Optic Disc (OD) localization is a fundamental step in developing computer-assisted diagnostics. In this work, an ultrafast method to locate the OD in retinal fundus images is presented. The proposed method is based on transforming the localization problem into two 1D problems by projecting the image features onto two perpendicular directions. Image features such as the directionality of the retinal vessels, the brightness and the size of the OD have been used in the current method. Two publicly available databases were used to evaluate the accuracy and the computation time of the proposed technique. The OD was correctly located in 71 out of 81 of the STARE images (87.6%) with computation time of 0.8 seconds per image. The OD was also successfully located in all the 40 images (100%) using the DRIVE database.

Index Terms— Retina, optic disc, localization, projection, image features

1. INTRODUCTION

Retinal diseases, whether primary or secondary to other diseases such as diabetes mellitus, affect millions of people all over the world. With the advances in retina imaging modalities, an ophthalmologist needs to examine a large number of retina images to diagnose every patient’s eye. Therefore, there is a significant need to develop computer-assisted diagnostic tools for retinal image analysis.

A fundamental step in retinal image analysis is to localize the optic disc (OD) [1]. The optic disc (OD) is the portion of the optic nerve that is visible in a view of the retinal fundus. In a typical retinal image, the OD appears as a round region which is brighter than its surroundings; see Fig. 1(a). The OD location can serve as a seed for segmenting the OD, locating other structures such as the fovea, and/or acting as a landmark for image registration.

Although the OD may have well defined features and characteristics, developing fast and robust methods to automatically localize the OD is not an easy task. This is mainly due to retinal pathologies that alter the appearance of the OD significantly. A successful technique for localizing the OD should account for large variation in OD size, color and location among diseased retinal images.

Several OD localization methods are available in literature. These methods can be classified into two main categories, appearance-based methods and model-based methods [2]. Appearance-based methods use the round shape and high intensity as unique features for the OD. These methods include techniques such as simple threshold, highest average variation, and Principle Component Analysis (PCA) [3]. Although appearance-based methods are simple, they fail in pathological retinal images where pathologies have similar properties to the OD.

On the other hand, model-based methods depend on the fact that all retinal vessels originate from the OD. These methods incorporate techniques such as geometrical models [1], template matching [4], and convergence of vasculature [5, 6]. Although these techniques have relatively high accuracy, they are highly dependent on successful segmentation of retinal vasculature and computationally very expensive. In [6], a new OD localization method based on vasculature convergence has been described. The method achieves an accuracy of 98.77% in STARE database, but it takes 3.5 minutes per image to successfully locate the OD.

In this work, a novel technique for OD localization is proposed. The technique achieves accurate results in a very fast manner (fraction of a second) relative to the currently available techniques. The main idea is to decompose the two-dimensional problem of OD localization into two one-dimensional problems by projecting certain image features onto two perpendicular axes.

2. THEORY & METHODS

2.1 Image features

An essential observation in this work is that the OD is the emerging region of all retinal blood vessels. The vessels originate from the OD mainly in a vertical direction and then start to branch horizontally. They branch further into smaller blood vessels (in all directions) to cover most of the retina. This causes the OD to be the unique region within the image that possesses the following two features. First, it contains high density of (nearly) vertical vessels. Second, the areas above and below the OD contain low density of horizontal edges. Although, other regions in the retina may have high density of vertical vessels, they are always encapsulated between the two main horizontal branches of the retinal vessels.
2.2 Optic disc localization as two 1D problems

Given the above image features, it is interesting to notice that the image features along a vertical line are enough to determine the horizontal location of the OD. If this is successfully achieved, then the vertical location of the OD can be determined by searching the image features along a vertical line located at the determined OD horizontal location. That is, the localization process is split into two steps. In the first step, the image features are projected onto the horizontal axis to determine the horizontal location of the OD. In the second step, the vertical location of the OD is determined by projecting the image features onto the vertical axis. This has the advantage of significantly reducing the computation time as will be shown below. Details of the two steps are discussed in the next two sections.

It is worth noting that the areas outside the camera aperture (circular region) are excluded using a binary mask generated by thresholding the red component of the image based on the method described in [7].

2.3. Determining the horizontal location of the OD

Consider a sliding window whose width and height are equal to double the thickness of a main vessel (0.2 mm approximately) and the image height, respectively. Let this window scan a retinal image from left to right and examine the image features within this window. For simplicity, assume that the only image features of interest are the image's horizontal and vertical edges.

Fig. 1(a) shows a retinal image with the sliding window placed over it. When the window is located over the OD, it encloses a large number of vertical edges and almost no horizontal edges. At any other location in the image, the window may enclose a large number of vertical edges, but it will also contain a large number of horizontal edges.

The horizontal location of the OD is identified as the location where the sliding window encloses the maximum number of vertical vessels, represented by pixels of low intensity. Based on this observation, the projection of pixels' intensity values inside the window returns a minimum value at the location of the OD. The algorithm used to locate the horizontal location of the OD is described below.

2.3.1. Algorithm 1

1. Define a **sliding window** with dimensions (image height, $2 \times$ main vessel width)
2. Get an image of horizontal edges ($E_h$) and an image of vertical edges ($E_v$)
3. Calculate $EdgeDiff = |E_h| - |E_v|$; where $|$ is the absolute operator
4. Slide the window over the image from right to left and at each location,
   i) Calculate $F = \text{sum of } EdgeDiff$
   ii) Calculate $G = \text{sum of pixels’ intensity values}$
   iii) Calculate the ratio $Hposition = F / G$
5. The horizontal location of the optic disc (OD_H) is the location of the maximum value in $Hposition$

Fig. 1: (a) A retina image showing the sliding window, sliding direction and projection direction. (b) Plot of the projection of image features onto the horizontal axis ($Hposition$).

Fig. 1(b) shows the resulting $Hposition$ values for the shown image. The graph shows that the horizontal location of the OD is identified as the unique location in the image at which the sliding window returns a maximum peak. The graph also shows that the response of the technique to features in the image other than the OD is insignificant despite the presence of optic disc-like structures.

2.4. Determining the vertical location of the OD

To determine the vertical location of the OD, the image features are projected onto a vertical axis. A vertically sliding window is defined to scan the image from top to bottom. The height and width of the window are equal to the diameter of the OD and the image width, respectively. In order to improve the accuracy and reduce the computation time, the projection of image features is constrained to a neighborhood of the pre-determined horizontal location of the OD by defining a region of interest (ROI). The height and width of the ROI are equal to the height of the image and the diameter of the OD, respectively.

Fig. 2(b) shows an example of a retinal image with the sliding window placed over it. When the sliding window is located over the OD, it encloses a large number of both vertical and horizontal edges. At any other location inside the ROI, the sliding window encloses fewer edges.

The location of the OD is identified as the location where, the sliding window encloses maximum average intensity and a thin slice at the center of the window encloses minimum average intensity. The slice height and width are equal to the sliding window height and double the thickness
of a single main vessel, respectively. The algorithm used to locate the vertical location of the OD is described below.

2.4.1. Algorithm 2  
Consider a rectangular ROI of dimensions (image height, OD diameter) centered at the OD_H determined from algorithm 1, and do the following,

1. Define a sliding window with dimensions (OD diameter, image width)
2. Define a thin slice with dimensions (OD diameter, 2 * main vessel width)
3. Calculate $EdgeSum = |E_H| + |E_V|$, where $|$ is the absolute operator
4. Slide the window over the image from top to bottom and at each location,
   i) Calculate: $F = \text{sum of } EdgeSum$
   ii) Calculate: $G_i = \text{sum of image intensity values of pixels inside the slice}$
   iii) Null the intensity values of pixels inside the slice
   iv) Calculate: $G_2 = \text{sum image intensity values of pixels inside the window}$
   v) Calculate the value $V_{position} = F \times (G_2 - G_1)$
5. The vertical location of the optic disc (OD_V) is the location of the maximum value in $V_{position}$

Fig. 2(a) shows the resulting $V_{position}$ values for the shown image. The graph shows that the vertical location of the OD is identified as the unique location in the image at which the sliding window returns a maximum peak.

The horizontal and vertical edge images were generated from the convolution of the input image with a simple gradient mask [$1 \ 0 \ -1$] and its transpose for vertical and horizontal edges, respectively.

3. RESULTS

Two publicly available databases were used to evaluate the accuracy and the computation time of the proposed technique. The two databases are: (1) STARE database (605 × 700 pixels) [8], (2) Drive database (565 × 584 pixels) [9]. Accuracy and computation time results of evaluating the proposed method using these databases are summarized in Table 1. The number of images in each database is also included.

Table 1: Accuracy and computation time of the proposed OD localization technique.

<table>
<thead>
<tr>
<th>Database</th>
<th>STARE</th>
<th>DRIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Images</td>
<td>81</td>
<td>40</td>
</tr>
<tr>
<td>Success</td>
<td>71</td>
<td>40</td>
</tr>
<tr>
<td>Accuracy</td>
<td>87.7%</td>
<td>100%</td>
</tr>
<tr>
<td>Computation Time</td>
<td>0.8 sec.</td>
<td>0.8 sec.</td>
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</table>

The detected location of the OD is considered correct if it falls inside the OD area. The proposed method was able to correctly locate the OD in 71 images out of STARE’s 81 images (87.7%) in 0.8 seconds per image. In addition, it achieved a success rate of 100% when tested on DRIVE database images (i.e. the OD was correctly located in all 40 images) taking an average of 0.8 seconds per image.

Fig. 3 shows the results of applying the proposed method to selected retinal images from STARE databases.
4. DISCUSSION

Figures 3(a)-(d) show sample of successful localization results when applying the proposed method to STARE database. It is worth noting that the technique of vasculature convergence [5] failed to locate the OD correctly in the first three images, while the geometrical model-based technique [1] failed to correctly locate the OD in the fourth image. Fig. 3(e) shows an image from STARE in which the proposed method failed to locate the OD. It can be observed from the resulting location that the method determined the horizontal location of the OD correctly but failed to determine the vertical location. Fig 3(f) shows another image from STARE in which the proposed method failed to locate the OD because it is partially hidden. Convergence of vessels approach also failed to locate the OD in this image.

Table 2 shows the detailed results of applying the proposed method to STARE database. The accuracy of the technique to correctly determine the horizontal and vertical location of the OD is illustrated, separately.

Table 2: Accuracy results of determining the horizontal and vertical location of the OD in STARE database.

<table>
<thead>
<tr>
<th>Database</th>
<th>STARE</th>
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<tbody>
<tr>
<td>Successful Horizontal Localization</td>
<td>74</td>
</tr>
<tr>
<td>Horizontal Localization Accuracy</td>
<td>91.4%</td>
</tr>
<tr>
<td>Successful Vertical Localization</td>
<td>71</td>
</tr>
<tr>
<td>Vertical Localization Accuracy</td>
<td>95.6%</td>
</tr>
</tbody>
</table>

* Accuracy in determining the vertical location is calculated ONLY for the images where the horizontal location is successfully determined.

In the proposed method, hybrid appearance- and geometric-based features have been utilized to identify the OD. As shown above, even in the presence of retinal pathologies, these features were unique to the OD and thus allowed proper localization. In addition, the selected features allowed splitting the 2D problem of OD localization into two 1D problems. The latter reduced the computation time significantly (fraction of a second). As shown in the algorithms 1 and 2, the most computationally demanding operation is the image convolution with two 3x1 masks to calculate the horizontal and vertical edge maps. This operation is negligible when compared to the initial step of extracting the retinal vessels that is required in all geometric-based techniques. The latter is usually achieved by applying a 2D matched filter (typically $10 \times 15$ mask) with several orientations (typically at 12 different angles) [10]. Finally, the parameters of algorithms are maintained constant (except for linear scaling of the windows’ sizes according to image resolution). That is, there is no need to tailor the parameters for different databases.

5. CONCLUSION

A new method for OD localization in retinal fundus images is presented. The method is based on decomposing the two-dimensional problem of OD localization into two one-dimensional problems by projecting the image features onto two perpendicular axes. The proposed method achieves accurate results in a significantly short computation time relative to the currently available techniques.

6. ACKNOWLEDGMENTS

This work is supported by a grant from the Center for Informatics Science (CIS), Nile University (NU), Cairo, Egypt.

7. REFERENCES