PROBABILITY MAP BASED LOCALIZATION OF OPTIC DISK

Attila Budai$^{(1AB)}$, *Lenke Laurik*$^{(12)}$, *Joachim Hornegger*$^{(1A)}$, *Gábor M. Somfai*$^{(2)}$, *Georg Michelson*$^{(3)}$

$^{(1)}$ Pattern Recognition Lab
University of Erlangen-Nuremberg, Erlangen
$^{(2)}$ Department of Ophthalmology
Semmelweis University, Budapest
$^{(3)}$ Department of Ophthalmology
University of Erlangen-Nuremberg, Erlangen
$^{(A)}$ Erlangen Graduate School in Advanced Optical Technologies (SAOT), Erlangen
$^{(B)}$ International Max Planck Research School for Optics and Imaging (IMPRS-OPTIM), Erlangen

ABSTRACT

Fundus imaging is one of the most commonly used modalities for examining retinal structures. The images are mostly analyzed by physicians. These diagnoses are subjective with a high rate of inter-observer variability, therefore an automated or a computer aided diagnosis is needed to speed up the monotonous screening process and to provide objective measurements. In this article we present an automatic algorithm for localization of the optic disk center in fundus images. The application field of the algorithm is preprocessing for further algorithms such as segmentation of the optic disk boundary, vessel tracking etc. The algorithm is evaluated using the DRIVE database and our own public high resolution image database. The tests show a localization error less than 0.2 optic disk diameter (ODD) in case of the high resolution database, and less than 0.35 ODD in case of the lower resolution DRIVE database.

Index Terms— Fundus Imaging, Optic disk localization, Vessel segmentation

1. INTRODUCTION

Fundus imaging is one of the most commonly used modalities for examining retinal structures. The images are mostly analyzed by physicians. To be groomed for this work these experts go through a time-consuming and expensive training. Since different experts have different knowledge and different level of experience the diagnoses are subjective with a high rate of inter-observer variability. Therefore an automated or a computer aided diagnosis is needed to speed up the monotonous screening process and to provide objective measurements.

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Diagnostic and screening algorithms developed for processing fundus images must be able to distinguish retinal structures and tissues. In this article we present an automatic algorithm for localization of the optic disk center in fundus images which is partially based on an already published vessel segmentation technique [1]. The algorithm generates and combines probability maps based on the local density of vessels and the local brightness of the retina. The application field of such an algorithm is preprocessing for further algorithms such as segmentation of the optic disk boundary, vessel tracking, diagnosis of Glaucoma etc.

1.1. State of the art

The optic disk is an oval, optically insensitive region of the retina, where fibers of the optic nerve emerge from the eyeball. The blood vessels from within the optic nerve enter the disk centrally and then course nasally following the edge of the cup. A healthy optic disk has an orange or pink color, which is brighter than the other parts of the retina, as in this region can only be seen the axons of ganglion cells forming the optic nerve. On the other hand, all the thick vessels pass this region, which appear darker. Most of the authors use one of these facts to localize the optic disk.

Multiple approaches [2][3][4][5] propose different intensity thresholding methods on one of the color channels (usually the green or the red one), while Sinthanayothin [6] uses a calculated variation image. It is shown by Hoover et al. [7] that lesions of the same brightness as the nerve, and imaging artifacts around the corner of the image may mislead most of these algorithms.

Hoover and other authors [7][8] propose analyzing the vessels to localize the optic disk. These algorithms need a vessel segmentation, which makes them more complicated. However the aforementioned method has a great advantage, being more robust to the high illumination differences in the background. Most of the algorithms try to locate the optic disk by finding the region with the highest density of thick vessels. In some images especially where tortuosity is present, these algorithms may locate a vessel crossing within 1-2 optic disk diameter distance from the real optic disk location.

2. METHODS

Our approach combines the aforementioned ideas in one algorithm. The initial step in our framework is a vessel segmentation method to differentiate vessels from the background for further analysis. Afterwards, two probability maps are generated: the first one is generated from the brightness of the image and the second one is based on vessel segmentation results. We combine the advantageous properties of an intensity based and a vessel segmentation based approach to locate the optic disk. The algorithm allows us to estimate not the exact geometric center of the optic disk, but the point where the vessels enter the eye. Most of the cases these two are overlapping or are located very close to each other.

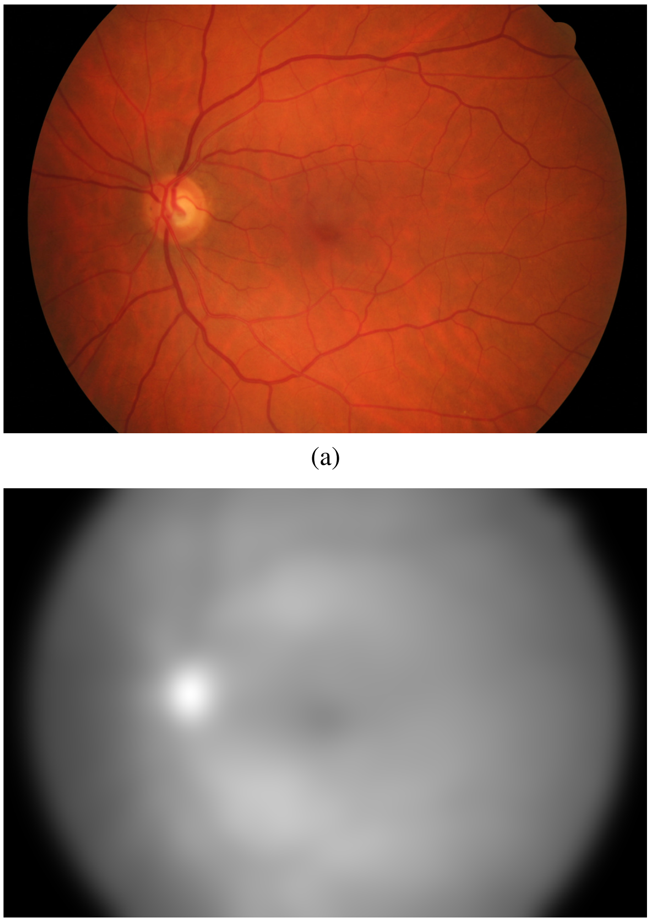
2.1. Brightness based probability map

To generate a probability map, the RGB (Red, Green, Blue) color image is converted into HSV (Hue, Saturation, Value) color space. Here the "V" channel shows the brightness of the pixels, which is used to generate the first probability map. For the localization we only need spatially large bright regions without thin or small structures like vessels and lesions, which could mislead the algorithm. To eliminate of these structures a Gaussian smooth with a large kernel size (in case of the high resolution images the variance is 100 pixels) is applied. As a result, the center of the circular optic disk stays relatively bright, while all other smaller or thinner bright structures and artifacts are blurred into the background. The smoothed image will be used as a first probability map. Figure 1 shows an example for a fundus image and the generated brightness map.

2.2. Vessel segmentation based probability map

The second probability map is based on vessel segmentation using the algorithm published by Budai et al.[1]. The algorithm uses the eigenvalue analysis of the Hessian matrix published by Frangi [9] in a multiscale framework. The images are binarized using hysteresis thresholding to segment a certain percentage of pixels with the highest value.

These binary images are smoothed by a large Gaussian kernel similar to the one used in case of the brightness probability map. The smoothing blurs the thin vessels and the thick vessels far from each other into the background, while the region of the optic disk stays bright because of the high density of thick vessels. Figure 2 shows an example of segmented vessels and the generated second probability map.



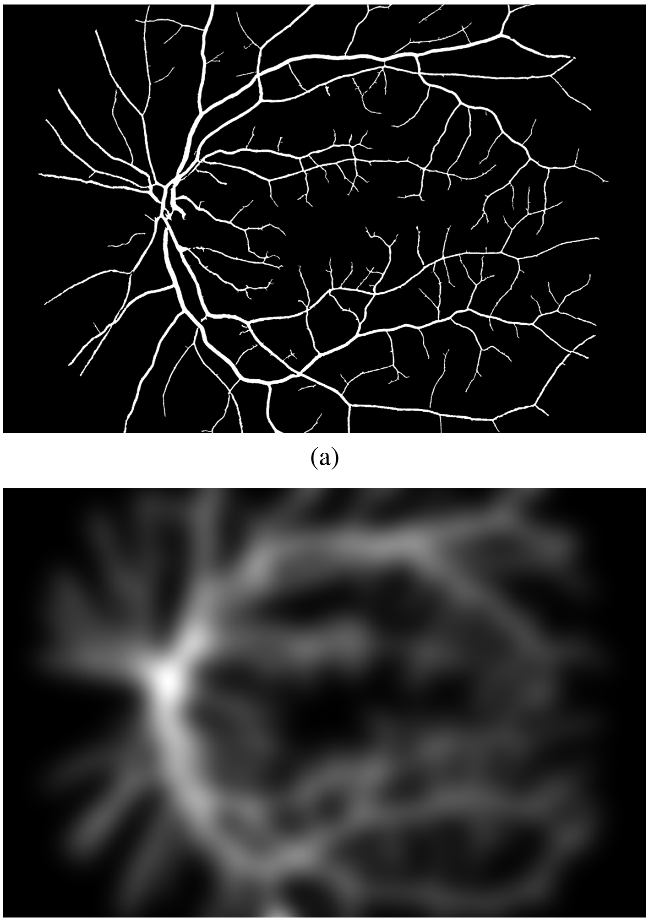
(a)

(b)

Fig. 1. Example of a fundus image (a) and the brightness probability map (b).

2.3. Combination of the probability maps

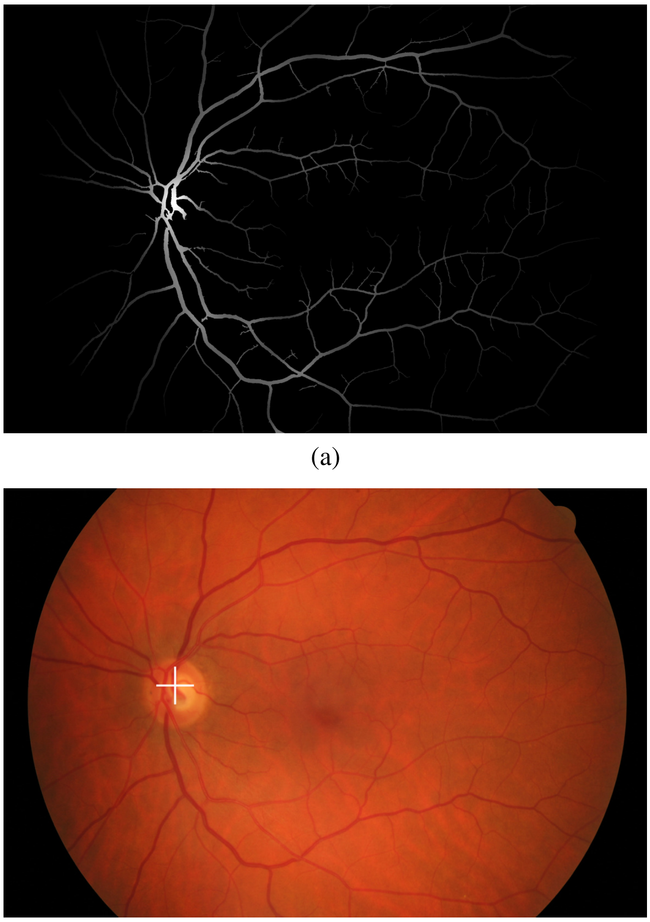
The two probability maps are multiplied to get a joint probability map. According to the gained map the bright regions have a reduced probability caused by the vessel segmentation based map, and the locations with high vessel density have reduced probability caused by the brightness map. Since we are searching for a point where the vessels leave and enter the eye, we can reduce our search space to the pixels which are actually segmented as vessels. Thus, multiplicating the joint probability map with the binary vessel map, we set all the non-vessel pixels probability to zero. Afterwards thresholding is used to segment 0.01% of the pixels with the highest intensity. This segments a region of thick vessels, which are close to each other with bright background. The geometric center of this region is the estimated center of the optic disk.



(a)

(b)

Fig. 2. Example of vessel segmentation (a) and the probability (b) map based on it.



(a)

(b)

Fig. 3. The combined probability map (a), and the estimated optic disk center marked with a white cross(b)

3. RESULTS

The algorithm was evaluated by using our public database of high resolution fundus images (HRF Database) [10], and 20 images of the well known DRIVE database[11]. Our database consists of fundus images of healthy, diabetic retinopathy affected, and glaucomatous eyes. 15 images are available for each group. The images have a high resolution of 3504×2336 pixels. The images of the DRIVE database have a much lower quality and a resolution of 565×584 pixels.

The results of the proposed algorithm were compared to gold standard data provided by two experts. These experts localized the geometric center of the optic disk, and measured the optic disk diameter (ODD) in each of the images. This data and the gold standard segmentation results are available for the HRF database [10]. This way we can express the distance between the real and estimated optic disk centers in ODD. Table 1 and Table 2 show the mean, the standard deviation, and the median of the localization errors.

In case of the DRIVE database, a single outlier (image 23) misleads the algorithm, because of a spot, which has a much higher vessel density than the optic disk. This spot is about 4 ODD distance from the real optic disk. Thus, this single outlier results a highly increased mean and standard deviation. Table 3 shows the same means and standard deviations using the DRIVE database without the outlier.

A preliminary evaluation with respect to severe diseases was done on two images (im0005 and im0044) of the STARE database[12]. Here the optic disk and the vessels are less visible, which could mislead the algorithm. The proposed algorithm reached an error of 0.26 and 0.94 ODD using these two images, which is promising if we consider the presence of diseases, and the quality and resolution of the images.

Database	Expert 1	Expert 2
HRF	0.188 ± 0.185	0.137 ± 0.178
DRIVE	0.340 ± 0.751	0.339 ± 0.724

Table 1. Mean $\pm$ standard deviation of the localization error in optic disk diameter compared to both gold standard data

Database	Expert 1	Expert 2
HRF	0.173	0.095
DRIVE	0.172	0.175

Table 2. Median of the localization error in optic disk diameter compared to both gold standard data

Database	Expert 1	Expert 2
DRIVE	0.176 ± 0.171	0.181 ± 0.169

Table 3. Mean $\pm$ standard deviation of the localization error in optic disk diameter using the DRIVE database without the outlier image

4. CONCLUSION

We presented an automatic method to localize the center of the optic disk based on probability maps. These maps were generated from a vessel segmentation result, and the local brightness of the image. The results were compared to gold standard data provided by two experts using two different databases. The databases contain images of significantly different quality and resolution. Thus, the algorithm is proven to be robust in different environments. In case of our HRF database[10], the gold standard data is available for research purposes.

The proposed algorithm yields less than 0.2 optic disk diameter distance error. Thus, it can be used as an initialization step for optic disk boundary segmentation and other methods. The approach has to be evaluated using images where the optic disk is not bright or the vessels are not visible due to pathological changes.

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