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Automatic Measurement of Cup to Disc Ratio Based on Line Profile Analysis in Retinal Images

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Abstract— **Retinal image examination is useful for early detection of glaucoma, which is a leading cause of permanent blindness. In order to evaluate the presence of glaucoma, ophthalmologists may determine the cup and disc areas and diagnose glaucoma using a vertical cup-to-disc ratio. However, determination of the cup area based on computation algorithm is very difficult, thus we propose a method to measure the cup-to-disc ratio using a vertical profile on the optic disc. The edge of optic disc was then detected by use of a Canny edge detection filter. The profile was then obtained around the center of the optic disc. Subsequently, the edges of the cup area were determined by classification of the profiles based on zero-crossing method. Lastly, the vertical cup-to-disc ratio was calculated. Using forty five images, including twenty three glaucoma images, the AUC of 0.947 was achieved with this method.**

I. Introduction

ONE in about 20 people over the age of 40 has been diagnosed with glaucoma in Japan [1, 2]. The number of people with visual handicap is also estimated to be 1.64 million, and 24% of these were affected with glaucoma in Japan, 2007 [3]. Glaucoma is the leading cause of blindness, and 50 thousand people were blinded by glaucoma in Japan [3]. Although it cannot be cured, glaucoma can be treated if diagnosed early. Mass screening for glaucoma using retinal images is simple and effective. In view of this, the retina is examined selectively in the diagnosis performed by physicians as part of a specific health checkup scheme initiated in Japan in April 2008. Although this has improved the ocular healthcare, the number of ophthalmologists has not increased, thus increasing their workload. Computer-aided diagnosis (CAD) systems, developed for analyzing retinal images, can assist in reducing the workload of ophthalmologists and improving the screening accuracy.

The purpose of this study is to analyze the optic disc on a retinal image, which is important for diagnosis of glaucoma. Three dimensional images captured on stereo retinal fundus camera [4-9] and HRT [10] were used in several studies. However, it is difficult to use such 3D retinal fundus camera in the screening. Thus, we attempted to measure vertical C/D ratio automatically using two dimensional retinal images.

First, as a basic study for analysis of the optic disc, we had to develop a method to extract the optic disc from a retinal image. A number of studies have reported on automated localization of optic discs; several studies have also reported on segmentation of optic discs [11-16]. Nakagawa et al. had previously proposed a disc detection scheme using the P-tile thresholding method [11]. Since this method was proposed for detecting rather than extracting the optic disc, a more precise method is required for analysis of the optic disc features. Muramatsu et al. compared three methods, active contour model, fuzzy c-mean clustering, and artificial neural network (ANN) for the segmentation of the optic disc regions [12]. They reported the performance of ANN was best, and its area under the curve (AUC) was 0.89. Wong et al. proposed the method based on the level-set technique followed by ellipse fitting in order to smooth the disc boundary [13]. We also developed a simple method by combining the P-tile method [11] with optic disc segmentation using Canny edge detector [17] and the spline interpolation method.

And then we had to develop a method for determination of the cup region. Wong, et al. proposed an automated C/D ratio measuring method by detecting kinks in the blood vessels on the optic disc [13], but it was very difficult. Thus, we developed a determination of cup edge by analyzing a color profile of the optic disc. That method can be effective in segmentation of the cup, without detecting kinks, by focusing on the profile of the optic disc on a retinal image.

II. Method

Retinal images were captured using a retinal fundus camera (Kowa VX-10i). The photographic angle of the fundus camera was set to 27 degrees, and the optic disc was set in the center of image. The retinal images were obtained with an array size of 1600 × 1200 pixels and 24-bit color. Our method consists of two steps; A) extraction of the optic disc, B) determination of C/D ratio. More details are given below.

A. Extraction of optic disc

The presence of blood vessels that run on the outline of the optic disc makes accurate extraction of its outline difficult. Thus, to reduce the effect of blood vessels, the method

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proposed by Nakagawa et al. was applied to create a "blood-vessel-erased" image [11]. The optic disc region tends to be comparatively brighter than the retina. Thus, the approximate region of the optic disc was extracted by using the P-tile thresholding method on each red, green, and blue component image, and the optic disc region was determined by using an image combining these three binary images. Then, the area of the 600×600 pixel image, centered on the optic disc was extracted as the region for analysis. The resulting extracted region is shown in Fig. 1 (a).

An RGB color image was converted to an intensity image, and the pixel values were normalized. The change in intensity (brightness) is usually high at the outline of the optic disc; thus, we applied a canny edge detector [17] to enhance the edge. We determined the outline using the spline interpolation method based on the locations of the outline suggested by edge detection. The results of these approaches are shown in Fig. 1.

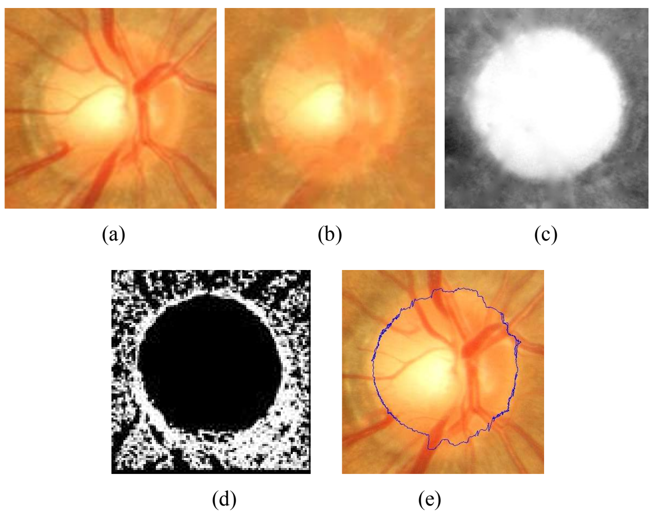

Fig. 1. Example of optic disc extraction. (a) Rectangular region surrounding the optic disc, (b) Blood-vessel-erased image, (c) a normalized intensity image, (d) Edge image by Canny edge detector, (e) Extracted outline of the optic disc.

B. Determination of cup-to-disc ratio

The vertical C/D ratio is most important factor for diagnosis of glaucoma, thus, we attempted to measure its ratio automatically. Glaucoma cases tend to have enlarged cup regions as against the normal cases. In other words, the bright region is extended in many cases. The contrast of the cup and the rim regions was also high. While comparing the optic disc profiles, the profile for normal cases tends to appear as a narrow mountain with long skirts, while that for glaucoma case appears as a broad mountain with short skirts, as shown in Fig. 2. Our present study focuses on this difference.

The images were preprocessed before obtaining the profile. A blood-vessel-erased image was first created using the method proposed by Nakagawa et al. [11]. Since there is high contrast between the cup and rim regions in the blue channel of a color image, a blue bit component was used for subsequent analysis. Thus, we classified the retinal images into the images of right and left eyes by comparing the pixel value in right and left side of an optic disc region, because the temporal side of an optic disc was brighter than that of the nasal side. A profile was then obtained around center of gravity of the disc region extracted automatically (described in section *A*). The blood vessel regions that were un-erased affected the profile. Moreover, the contrast of temporal side of the optic disc was high in the blue component image. Thus, ten profiles were obtained around the center of gravity of the disc region, and profiles were then averaged so that the result would not depend on the specific line selected. This profile was smoothed, and impulses, if there were any, were removed, in order to reduce the effect of noise and remaining blood vessels.

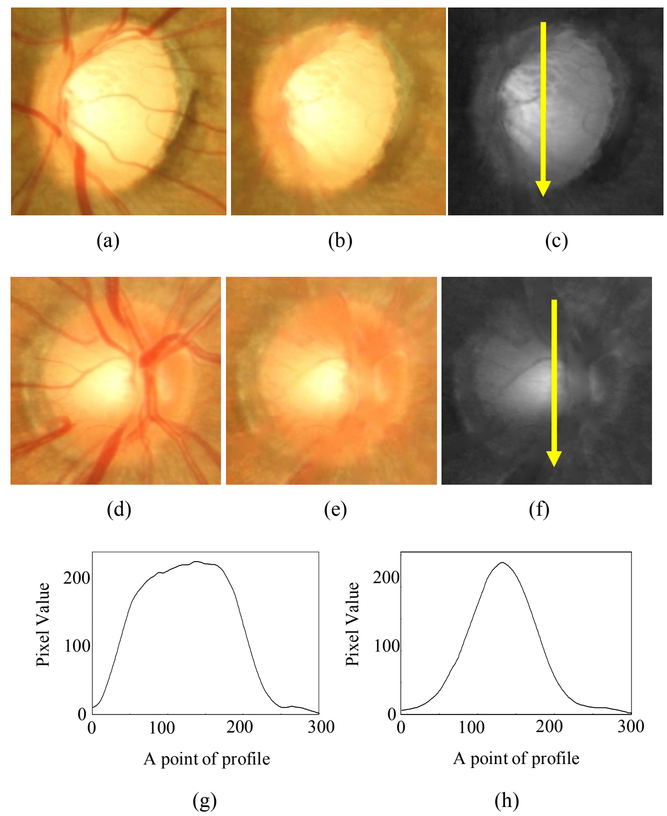

Fig. 2. The examples of profile lines. (a) Optic disc of a glaucoma case, (b) an image erased the blood vessels from (a), (c) a blue bit image of (b) and an arrow shows the location of the obtained profile, (d) to (f) show the images of a normal case. (g) profile of (c), and (h) profile of (f).

Subsequently, the profile was divided into two parts, i.e., upper and lower, or right and left, rim regions. The area under the average of pixel values on the profile was determined as the searching area for decision of the cup edge. The cup edge was then determined by using the zero-crossing method in the search area. The profiles were obtained in 10 degree intervals around the center of gravity of the disc region. In other words, thirty six points of cup edges were obtained by this process experimentally. The cup outline was finally determined by the spline interpolation method based on the 36 points.

The vertical C/D ratio *CDR* was determined by Gloster et al. method [18]:

$$CDR = C_v / D_v \quad (1)$$

where C_v is the vertical cup diameter, and D_v is the vertical disc diameter. C_v and D_v were determined by the distances between the top and bottom levels of them (as shown in Fig. 3). The higher the vertical C/D ratio is, the higher the glaucoma risk is.

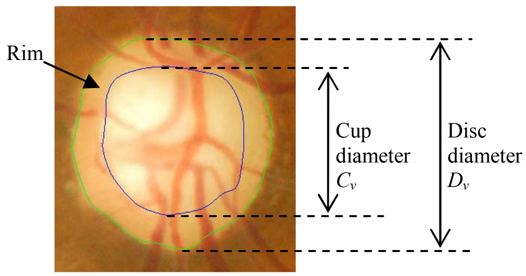

Fig. 3. Determination of cup and disc diameters, and C/D ratio. A green line shows an outline of a disc, a blue line shows an outline of a cup.

III. Results and Discussion

The proposed method for extracting the optic disc was evaluated on the basis of the manual outlines drawn by an ophthalmologist. Forty five retinal images, including twenty-three glaucoma images, were included in this test. The proposed method was useful in the extraction of disc regions with a concordance rate of 85%, which expresses the area of intersection as a percentage of the area of union. But, the concordance rate of the cup region was 67%, because the proposed method frequently tended to fail to erase the blood vessels in the nasal side. But, the cup edge in the top and bottom regions tended to be determined correctly. Thus, we do not discuss except the vertical C/D ratio in this paper, although Gloster et al. method [18] proposed the vertical C/D ratio, the horizontal C/D ratio, the ratio of areas of the cup and disc, and the ratio of the narrowest dimension of the rim divided by the diameter of the disc at that point.

The vertical C/D ratio of the gold standard was determined by equation (1) using the manual outlines of the ophthalmologist. We analyzed the results of the vertical C/D ratios using ROC (receiver operating characteristic) analysis, as shown in Fig. 4. The AUC by the vertical C/D ratios of proposed method and the ophthalmologist were 0.949 and 0.947, respectively, and the difference was not found to be statistically significant (p = 0.956). On the other hand, the average C/D ratios obtained by using the proposed method were 0.74 and 0.59 for abnormal and normal cases, respectively, while those by the ophthalmologist were 0.85 and 0.64, respectively. Also the average errors of abnormal and normal cases were 0.11 and 0.10, respectively.

The result of the comparison of C/D ratios by the ophthalmologist and the proposed method is shown in Fig. 5. The C/D ratios by the proposed method tended to be slightly lower than those of the ophthalmologist. Although standards for determination of the cup edge were different in the ophthalmologist's diagnosis and the proposed method, both C/D ratios tended to be high values in glaucoma cases.

The results of four images including 2 glaucoma cases are shown in Fig. 6, and their C/D ratio by the ophthalmologist and proposed method are shown in Table I. The proposed method could determine the approximate cup regions in case of (a) and (c). Determination of the cup edge of the nasal side failed in case (b). Because the blood-vessel-erasing failed in this case, thus the determination of the cup edge of the nasal side failed. In case (d), determination of the cup and disc edges was missed, thus the peripapillary chorioretinal atrophy (PPA) existed on temporal side of the optic disc. However, in cases (b) and (d), the cup edges on the top and bottom regions were determined approximately, thus the calculation of vertical C/D ratio was not affected.

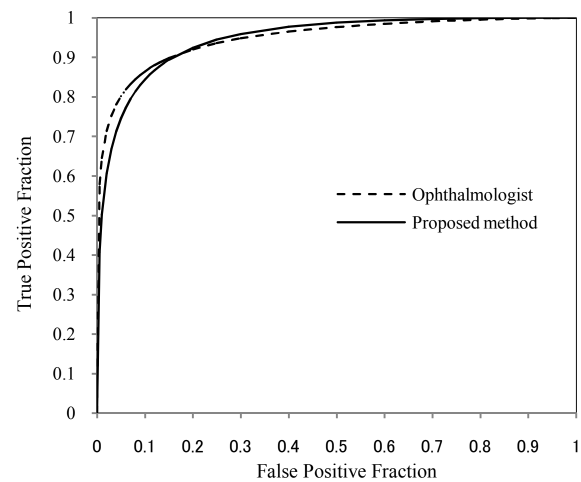

Fig. 4. Two ROC curves are shown. AUCs of the ophthalmologist and the proposed method were 0.949 and 0.947.

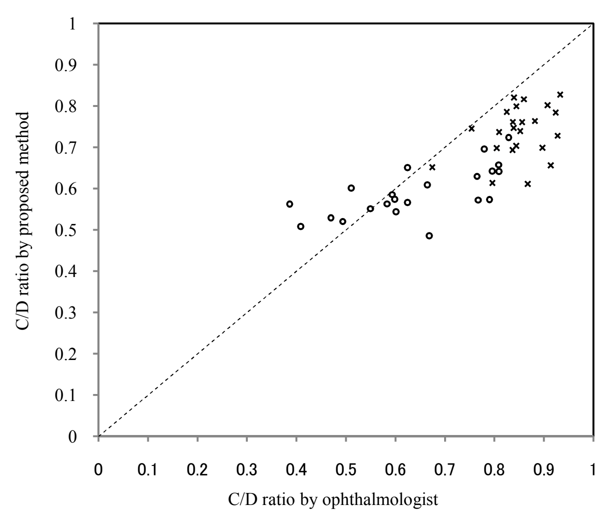

Fig. 5. Comparison of C/D ratios by the ophthalmologist and the proposed method. Circles show normal cases, cross marks show glaucoma cases, and the dashed line shows a diagonal. The marks exist so near the diagonal through the origin that both C/D ratios were similar.

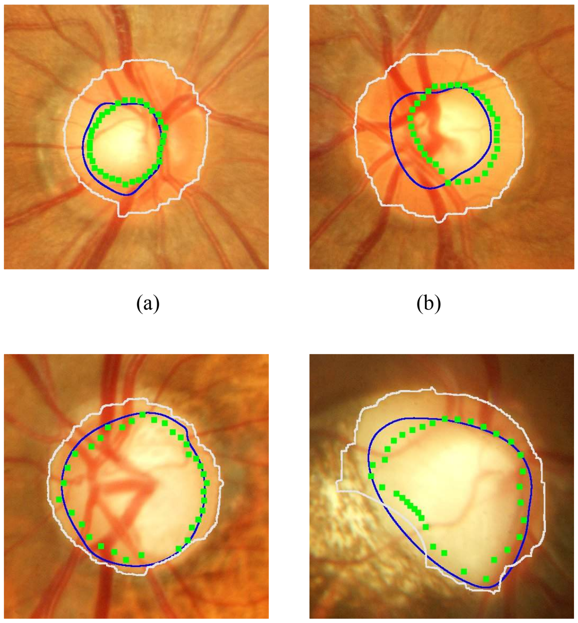

Fig. 6. Results of determination of cup and disc regions. White solid lines show the disc edge by proposed method. Blue solid lines show the cup edge by ophthalmologist. Dashed lines show the cup edge by proposed our method. (a) and (b) are normal cases. (c) and (d) are glaucoma cases.

TABLE I.
COMPARISON OF C/D RATIO BETWEEN OPHTHALMOLOGIST AND PROPOSED METHOD IN 4 CASES

	Case (a)	Case (b)	Case (c)	Case (d)
Ophthalmologist	0.60	0.60	0.93	0.82
Proposed method	0.54	0.57	0.83	0.79

IV. CONCLUSION

We proposed a method for determination of the optic disc edge in retinal images. The proposed method achieved a concordance rate of 85% relative to the disc areas determined by an ophthalmologist. Moreover, the cup edge was determined by the profile analysis based on zero-crossing method. The AUC of the proposed C/D ratio calculation method reached to 0.947. Although the proposed method is not error-free, the results indicated that it can be useful for the analysis of the optic disc in glaucoma examinations.

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