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Blood Vessel Contour Estimation in Eye Fundus Image Using Fuzzy Inference for Diagnosis of Arteriosclerosis

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***Abstract*—In this paper, we propose a method to estimate a contour of the vein in the eye fundus image for a diagnosis of arteriosclerosis. It is based on the fuzzy inference, and the membership functions of the fuzzy rules are allocated considering the edge intensity of the vein. The proposed method was applied to the real fundus images, and the effectiveness of the proposed method was verified.**

***Index Terms*—Eye fundus image, Blood vessel intersection. Arteriosclerosis, Fuzzy inference.**

I. Introduction

FUNDUSCOPY is one of the medical examinations carried out in a medical checkup. This image is taken from the eye fundus, and medical doctors can diagnose not only the eye disease but also the systemic illness by this examination.

The medical doctors have to diagnose many of those images one by one, and it takes a lot of time. Therefore, an automatic diagnosis system for the eye fundus image is strongly required [1].

In this funduscopy, a venous diameter ratio at the point of intersection with an artery is used as an indicator of arteriosclerosis (Fig. 1). The risk of arteriosclerosis becomes higher as this ratio becomes smaller [2].

The vein of concern goes under the artery, and thus the evaluation of the venous diameter becomes difficult. In this study, to solve this problem, we propose a method to estimate a contour of the vein by using a fuzzy inference [3], [4].

In the proposed method, a contour of the vein is piecewise estimated by the polynomial series inferred by the fuzzy rules. The effectiveness of the proposed method was verified by applying it to real fundus images.

II. Proposed Blood Vessel Contour Estimation in Eye Fundus Image

The proposed method consists of A. Seed points extraction of the venous wall, B. Extraction of the venous wall candidate regions, C. Venous wall estimation by the fuzzy inference, and D. Automatic allocation of the antecedent membership functions (MSFs) of the fuzzy rules.

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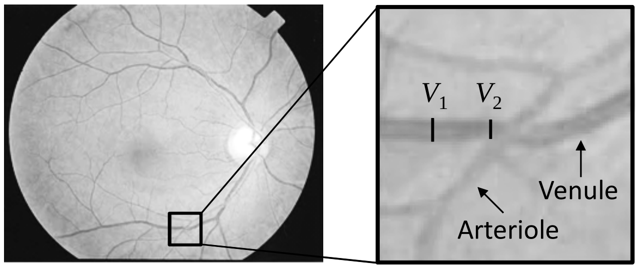

(a) (b)

Fig. 1. Eye fundus image. (a) Whole image. (b) Blood vessel intersection where a venous diameter ratio V_1/V_2 is evaluated.

A. Seed Points Extraction of the Venous Wall

In this study, the seed points, necessary to infer the contour of the venous wall, are extracted by the Takahashi *et al.* method [2].

First, a double ring filter is applied to the R-component (R in RGB) of the eye fundus image of Fig. 2 (a), and after binarizationi to get to Fig. 2 (b). Next, we set the circle of radius r around the point of intersection of blood vessel (Fig. 2 (b)). Then we get the central line of the vein [2]. Finally, the edge on the perpendicular line to the central line are detected by a Canny filter, and extracted as the seed points of the venous wall (Fig. 2 (c), (d)). At this time, the incorrect-extracted seed points are removed by the distance between the seed points.

B. Extraction of the Venous Wall Candidate Regions

The venous wall candidate regions are extracted by the first-order differential filter and the above-mentioned seed points.

First, the first-order differential filter is applied to the edge detection in order for the extraction of the venous wall candidate regions. The mask of the first-order differential filter has three directions that are vertical, horizontal, and diagonal in order to extract the lower and the upper venous walls (Fig. 3). The edge intensity images of the lower and the upper venous walls are obtained by the average of the three edge intensities calculated by the first-order differential filter.

Next, the regions around the seed points are defined as the window areas. In the window areas, a Gaussian filter is

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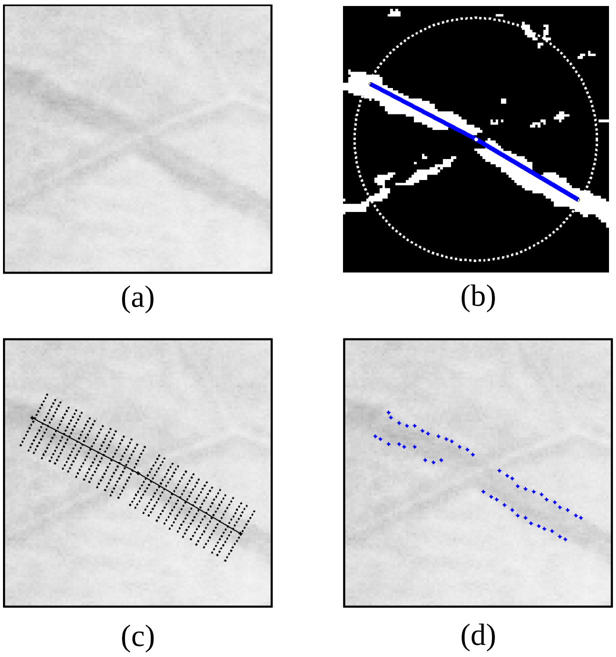

Fig. 2. Extraction of seed points for venular wall. (a) R-component image at the blood vessel intersection where a venous diameter ratio V_1/V_2 is evaluated. (b) Vessel region and central line. (c) Perpendicular lines to the central line. (d) Extracted seed points.

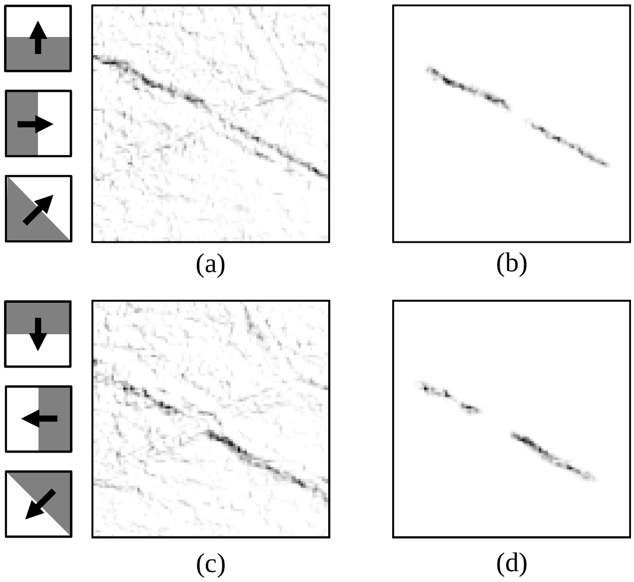

Fig. 3. Extraction of venular wall areas. (a) Extracted edges of upper contour of blood vessel. (b) Candidate area for upper contour of blood vessel. (c) Extracted edges of lower contour of blood vessel. (d) Candidate area for lower contour of blood vessel.

applied to the edge intensity. In other areas, the edge intensity is set to be 0. The degree of the venous wall is defined as the calculated edge intensity.

C. Venous Wall Estimation by the Fuzzy Inference

In this paper, the fuzzy inference is applied to estimate the contour of the venous wall. In this method, the venous wall is estimated by piecewise polynomials inferred by the Takagi-Sugeno (T-S) fuzzy model [3].

The objective true venous wall is inferred by the T-S fuzzy model, which is piecewise estimated by the polynomials in the Cartesian coordinates by a series of the following fuzzy if-then rules:

$$\text{IF } x_i \text{ is } A_l \text{ Then } f_l(x_i) = a_l x_l + b_l, \quad (1)$$

where A_l are fuzzy sets with membership functions μ_l shown in Fig.4. x_i corresponds to the angle index, and $f_l(x_i)$ is a linear function. The l-th rule thus stands for the piecewise approximation of the venous wall by a linear function in the interval $[t_l, t_{l+1}]$. The objective contour of the venous wall $\hat{y}(x_i)$ is inferred by [4]:

$$\hat{y}(x_i) = \mu_\ell(x_i) f_\ell(x_i) + \mu_{\ell+1}(x_i) f_{\ell+1}(x_i). \quad (2)$$

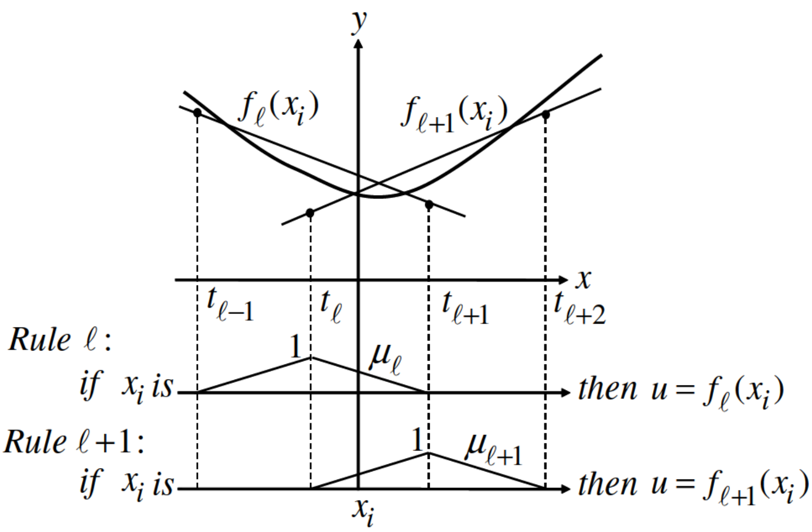

Fig. 4. Membership functions allocated to each $f_l(x_i)$ and $f_{l+1}(x_i)$, and the fuzzy rules for the interval of $[t_l, t_{l+1}]$

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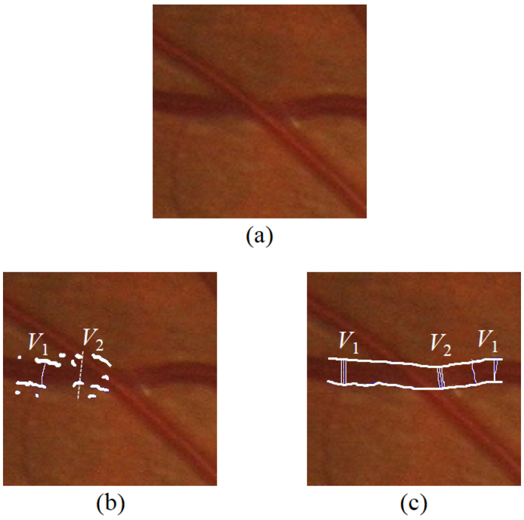

Fig. 5. Evaluation results of V_1 and V_2 for a normal eye fundus image. (a) Eye fundus image. (b) Estimated venous diameters by the conventional Takahashi *et al.* method. (c) Estimated venous diameters by the proposed method.

TABLE I
ESTIMATED VENOUS DIAMETERS AND RATIOS OF V_1/V_2. A NORMAL EYE FUNDUS IMAGE.

	Takahashi *et al.* Method	Proposed Method
V_1(pixel)	13.15	11.34
V_2(pixel)	(failure)	9.98
V_2/V_1	(failure)	0.88

The optimum coefficients a_l^* and b_l^* of the l-th fuzzy if-then rule are determined with use of the weighted least square method (WLSM) so as to minimize the following weighted error criterion:

$$E = \sum_{j=1}^{M}\sum_{i=1}^{N}\eta_{ij}^2(y_j - \hat{y}(x_i))^2, \quad (3)$$

where η_{ij} is an edge intensity of pixel (i, j). The lower and the upper venous walls are inferred by each different fuzzy model.

D. Automatic Allocation of Antecedent Membership Functions (MSFs) of the Fuzzy Rule

Let $\theta_k(k = 1, \ldots, K)$ be a specified angle at the k-th seed point. If all θ_k are obtuse angles, complementary triangular MSFs are uniformly allocated over the interval of concern.

A venous wall is then inferred by the T-S fuzzy model. In that case, a smooth venous wall is inferred along the obtuse seed points with a small number of MSFs.

In other cases, *i.e.*, the acute and obtuse angles coexist in the interval of concern, the two seed points on the either side of the seed point with an acute angle are excluded.

III. EXPERIMENTAL RESULTS

The proposed method is applied to three eye fundus images. One is a normal image ($V_2/V_1 \geq 1$), the ohter is a mildly abnormal image ($0.5 \leq V_2/V_1 < 1$), and the last is a severely abnormal image ($V_2/V_1 < 0.5$). The results are compared with those by the Takahashi *et al.* method.

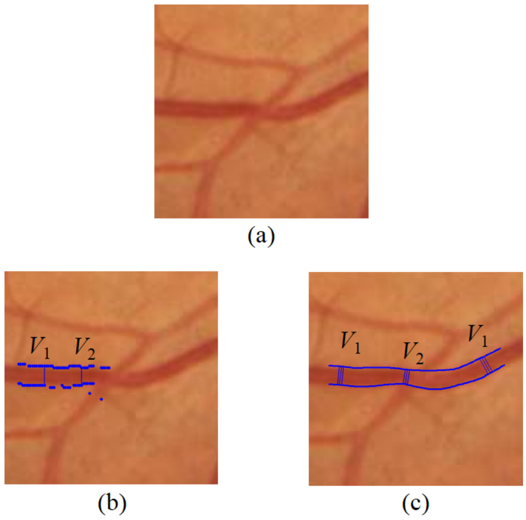

Fig. 6. Evaluation results of V_1 and V_2 for a mildly abnormal eye fundus image. (a) Eye fundus image. (b) Estimated venous diameters by the conventional Takahashi *et al.* method. (c) Estimated venous diameters by the proposed method.

TABLE II
ESTIMATED VENOUS DIAMETERS AND RATIOS OF V_1/V_2. A MILDLY ABNORMAL EYE FUNDUS IMAGE.

	Takahashi *et al.* Method	Proposed Method
V_1(pixel)	10.00	8.54
V_2(pixel)	9.00	6.93
V_2/V_1	0.90	0.81

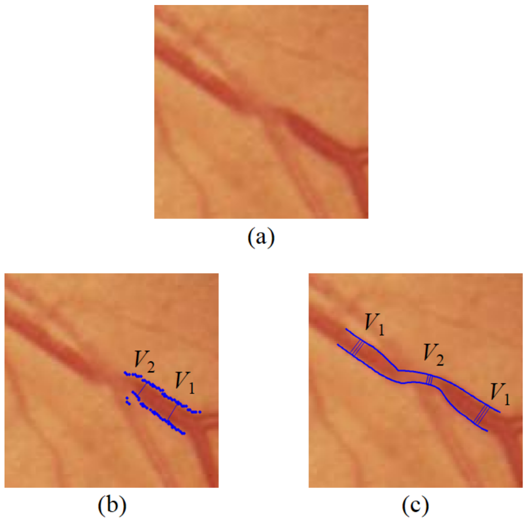

Fig. 7. Evaluation results of V_1 and V_2 for a severely abnormal eye fundus image. (a) Eye fundus image. (b) Estimated venous diameters by the conventional Takahashi *et al.* method. (c) Estimated venous diameters by the proposed method.

TABLE III
ESTIMATED VENOUS DIAMETERS AND RATIOS OF V_1/V_2. A SEVERELY ABNORMAL EYE FUNDUS IMAGE.

	Takahashi *et al.* Method	Proposed Method
V_1(pixel)	11.66	9.43
V_2(pixel)	8.60	4.51
V_2/V_1	0.74	0.48

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Fig. 5 shows the experimental results for the normal eye fundus image. Fig. 6 is for the mildly abnormal image, and Fig. 7 is for the severely abnormal image. Those results show that the proposed method works very well compared with the Takahashi $et\ al.$ method.

Tables I, II, and III show the numerical values of the estimated venous diameters by each method. The numerical results of the proposed method are generally consistent with the observation results by a medical doctor.

With those results the effectiveness of the proposed method has been verified.

IV. Conclusions

In this paper, we have proposed a fuzzy inference-based method to estimate the contours of the blood vessel in the eye fundus image. The effectiveness of the proposed method was verified by applying it to the real eye fundus images. The proposed method has given a better result than the Takahashi $et\ al.$ method.

Future work is to apply the proposed method to more of the eye fundus images, and further to confirm its effectiveness.

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