Extraction Method of Retinal Border Lines for Optical Coherence Tomography by Using One Directional Active Net

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Abstract— **In ophthalmology, the needs of retina diagnosis using optical coherence tomography (OCT) have been growing and the automatic measurement of a retinal thickness and its quantitative evaluation are desired for the diagnosis of retinal diseases. Previously, the automatic measurement methods of the retinal thickness have been reported for retinal OCT images. However, the conventional methods have a disadvantage that the methods extracted the retinal border lines intermittently for OCT images with any damages. In this paper, we propose a new automatic measurement method of a retinal thickness in OCT image. The method employs a new dynamic contour model ("One Directional Active Net (ODAN)") to extract two retinal border lines, and the thickness is defined from Inner Limiting Membrane (ILM) to Retinal Pigment Epithelium (RPE). ODAN employs a new energy function to extract the retinal border lines exactly and the energy function moves all nodes of ODAN to one direction only to minimize the total energy repeatedly. The energy function consists of the conformity characteristics energy of image to fit a border and the internal strain energy between the two dimensional nodes to arrange smoothly the position of each node. We confirmed the usefulness of the ODAN by the experimental results for normal and retinal disease OCT images. The proposed method is useful as the basic method for the detection of retinal diseases.**

Keywords— **inner limiting membrane, retinal pigment epithelium, optical coherence tomography, active net**

I. Introduction

Recently, tomographic images of retina have been obtained noncontactly and noninvasively by Optical Coherence Tomography (OCT). In a retina diagnosis using OCT devices, eye-grounds are irradiated with near infrared (NIR) laser first. Incident waves reflect on boundaries where the density of retina tissue changes and interference waves are generated by the incident and reflected waves. OCT devices observe the interference waves, as a result. The tomography image shown in Fig.1 and 2 is generated by the difference among these waves [1][2][3]. The generated OCT image can show the status of macular area and discus nervi optici as an image, therefore the needs of retina diagnosis using OCT images have been growing [4][5].

Meanwhile, there are many retinal diseases such as glaucoma, age-related macular degeneration and so on. Although most of these retinal diseases cause vision loss, their pathogenic mechanisms are not well understood and quantitative evaluation of the disease condition is so important in the treatment of retinal diseases. Currently the method that calculates the thickness between Inner Limiting Membrane (ILM) and Retinal Pigment Epithelium (RPE) [6] is mainly employed to evaluate the condition of retinal diseases quantitatively, the development of the extraction method for ILM and RPE has been required as a practical application.

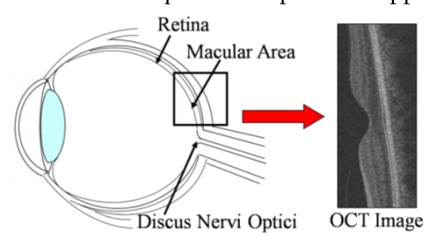


Fig. 1 Example of tomographic image of retina by OCT

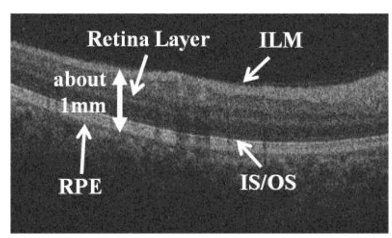


Fig. 2 Inner limiting membrane and retinal pigment epithelium

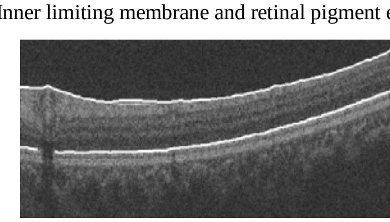


Fig. 3 Extraction result by conventional method

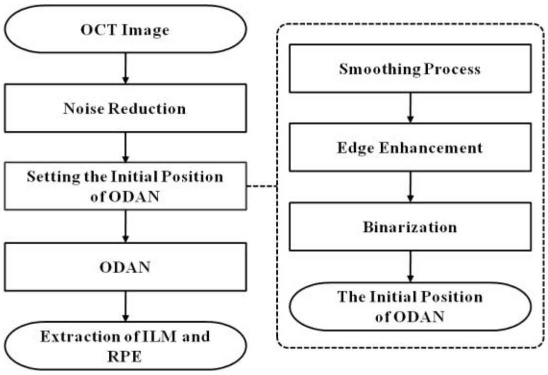


Fig. 4 Proposed method

To realize such request, the previous method without Active Net model [7] proposed the extraction method of ILM and RPE from OCT image using morphological operation and so on, and performed basic examinations. But this method has the problem that RPE line is intermittently extracted in retinal layer image with disappearance parts (Fig.3).

In this paper, we propose a new automatic extraction method using "One Directional Active Net (ODAN)", which is one of dynamic contour models. Active Net [8] is based on the energy minimization theory. We added a new constraint condition to the conventional Active net. The constraint condition is that all nodes of ODAN move vertically only. The method can extract the border lines using image texture information in the region en-closed with net model. By applying ODAN, we expect to extract ILM and RPE using neighbor information of damage part. In this paper, we propose the method to extract properly for retinal layer image with damage, and examined the extraction result of ILM and RPE.

II. EXTRACTION OF RETINAL PIGMENT EPITHELIUM BY ONE DIRECTIONAL ACTIVE NET (ODAN)

In this paper, OCT images of normal retina and retinal disease are used as the experimental materials. These OCT images are digitized to a pixel size of 0.006 mm × 0.006 mm, a 16-bit gray scale and resolution of 512 × 480 pixels. The size of interesting area is about 3mm × 3mm.

A. Preprocessing for OCT image

Fig.4 shows the outline of our proposed method. Generally OCT images often have speckle and spike noises due to multipath reflection and interference in the retina layer. In the proposed method, we employ a smoothing process to reduce these noises in the OCT image as preprocessing. The smoothing process employs the average filter of 5×5 pixels.

B. Setting the initial position of ODAN

ODAN processes by repetitive operation until extracting object. Therefore, it takes so long to set the initial net for full of OCT image. So, we reduce a processing time by confining the object of processing to neighborhood of retina. In this section, we describe the method to set the initial position of ODAN along the boundary. We extract neighborhood of ILM and IS/OS by using edge enhancement. The reason for applying the boundary of IS/OS is that IS/OS exist parallel to RPE and can be extracted a certain level of boundary by edge enhancement.

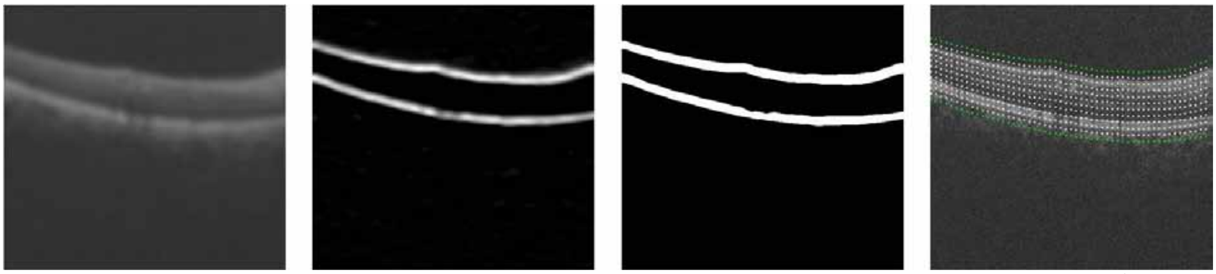
At first, we applied smoothing process for 20 times separately to noise reduction. This process can remove unneeded noises in edge enhancement (Fig. 6(a)). In the next step, we applied edge enhancement by the first derivative filter shown in Fig.5. We use the filter that used in conventional method [7] in this experiment. After the edge enhancement, we normalized intensity in 65535 values (16 bits) (Fig. 6(b)). After this, we applied Otsu's binarization method by a discriminant analysis (Fig.6(c)). Fig.6(c) shows that ILM and IS/OS could be extracted. Fig.6(c) is scanned from tops and bottoms, and finds two points that change white pixel from black one. We set the top nodes and the bottom nodes of ODAN from the two detected points with a margin. This process is done in a transverse direction, and Fig.6 (d) shows the extracted initial net. ODAN transforms the position of every node to minimize the total energy of every node. The number of nodes of ODAN is 660 (= height 12 × width 55). But sometimes this process would miss the position of edges in retinal diseases. To avoid this edge missing problem, we set the initial position of ODAN manually.

C. Extraction of ILM and RPE by ODAN

ODAN represents the behavior of dynamic contour model based on mechanics equation as energy, and is the method that extracts the object from image by finding stability state with energy minimization. Conformity characteristics energy of net and image is one of energy function of ODAN. The power reducing this energy corresponds with the power

-1	-4	-6	-4	-1
-2	-8	-12	-8	-2
0	0	0	0	0
2	8	12	8	2
1	4	6	4	1

Fig. 5 The first derivative filter



(a) Smoothed image (20 times) (b) Edge enhancement (c) Binary image (d) Initial position of nodes

Fig. 6 Setting the initial position of nodes in ODAN

drawing net to characteristic region in an image. It is possible to extract the selected region by defining energy function that represents remarkably characteristics of region hoping to extract for conformity characteristics energy of image.

In an OCT image, the intensity of a pixel in retinal layer is generally higher than the surrounding tissue because the NIR laser beams strongly reflect at the retinal border lines (ILM and RPE) and the strength of interference waves become high.

In this paper, the conformity characteristics energy of image is defined as the follow equation, because ILM and RPE can be extracted properly by the regional average and the degree in separation of intensity in the conformity characteristics energy of image.

$$E_{image}(p,q) = \omega_1 I_{nf}(p,q) + \omega_2 D_{nf}(p,q) \tag{1}$$

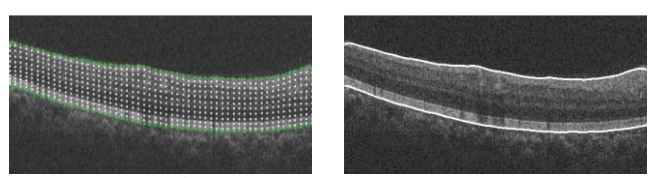
$$\begin{cases} I_{nf}(p,q) : \text{Average of intensity in neighborhood region at a node point}(p,q) \\ D_{nf}(p,q) : \text{Degree in separation of intensity in neighborhood region at a node point}(p,q) \\ \omega_1, \omega_2 : \text{Weight (on the inside nodes: } \omega_1 < 0,\ \omega_2 > 0 \text{ on the most outside nodes: } \omega_1 > 0,\ \omega_2 < 0\text{)} \end{cases}$$

For each node points, the method sets the neighborhood region (13×13pixels). The method calculates the average and the degree in separation of intensity in the neighborhood region. In this paper, if the average and the degree in separation of intensity are the smaller, then the value of conformity characteristics energy of image is the smaller. At retinal layer in OCT image, the average of intensity is high and the degree in separation is small. Therefore we gave weight (ω1 is negative weight and ω2 is positive weight) on the inside nodes of ODAN to lead to inner retinal layer. Also on the most outside nodes of ODAN were gave weight (ω1 is positive weight and ω2 is negative weight) to lead to boundary of the retinal layer. By defining conformity characteristics energy of image as Eq. (1), ODAN transforms to surround the retinal layer. ODAN can detect the retinal border lines (ILM and RPE).

III. Experimental results and discussion

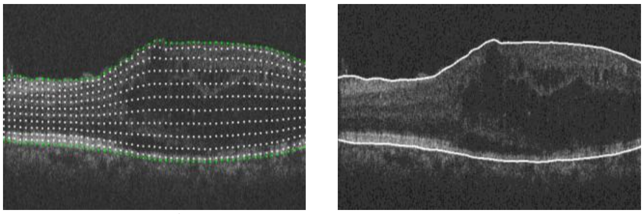
Fig.7 shows an experimental result by the proposed method. Fig.7 shows the extracted result that the retinal border lines (ILM and RPE) can be extracted by the proposed method. Also, this result shows that ODAN can resolve the intermitted problem by conventional method [7]. Processing time is about 12 seconds per one OCT image. Fig.8, 9, 10 and 11 show the experimental results for retinal diseases. Fig.8 and 9 could extract the retinal border lines properly, but Fig.10 and 11 could not extract the desired retinal borderlines.

As the reason of the Fig.10 and 11, ODAN has the problem that it depends on the initial position of nodes and parameters in Energy function. Actually, optimal parameter in Energy function could be varied for each OCT images. It could not desire the complete automatic extraction. For this problem, we will propose the method that extracts the retinal border lines by keeping the shape of initial position of ODAN. The curvature of each node would be calculated, and we would employ the energy function that lessening the error between the curvature of initial position and it of current net. By calculating the above curvature and energy function, we could realize the model-based extraction. We could employ this solution, and we could resolve the problem that ODAN depends on the initial position of the nodes and parameters of energy function.



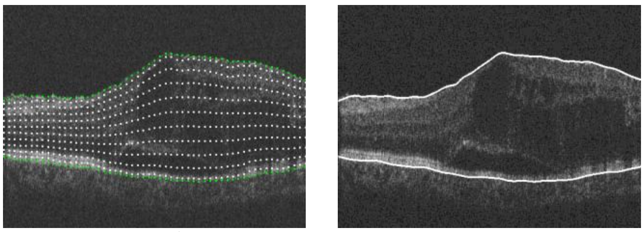
(a) Result of ODAN (b) Final result

Fig. 7 Experimental result



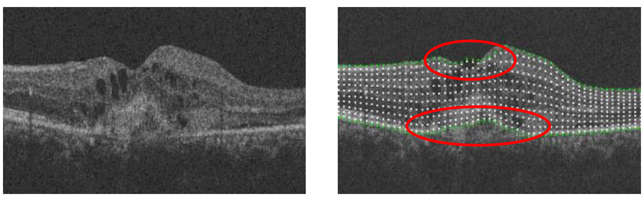
(a) Result of ODAN (b) Final result

Fig. 8 Experimental result for retinal disease (1)



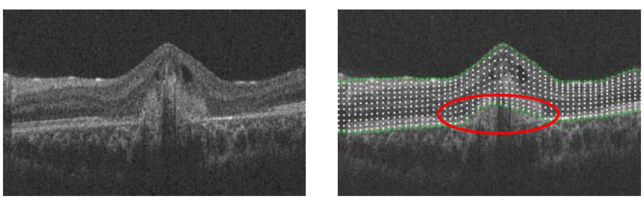
(a) Result of ODAN (b) Final result

Fig. 9 Experimental result for retinal disease (2)



(a) Original image (b) Result of ODAN

Fig. 10 Failure example (1)



(a) Original image (b) Result of ODAN

Fig. 11 Failure example (2)

IV. Conclusion and future works

In this paper, we propose a new automatic extraction method using “One Directional Active Net (ODAN)”, and we considered some basic examinations. Results of the experiment for normal and retinal disease OCT image suggest that our method can detect the retinal border lines (ILM and RPE). Also, ODAN has problem about dependence of initial net and parameter of energy function.

In the future, we will have to improve the modified energy function of ODAN used the curvature of the nodes and we will confirm the usefulness of ODAN using many more experimental materials.

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