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Automatic Extraction of Layer Structure for Retina in OCT Image Using Morphological Operation and Active Net

Ai Yamakawa, Shinji Tsuruoka,
Hiroharu Kawanaka
Graduate School of Engineering,
Mie University
1577 Kurima-machiya, Tsu, Mie 514-8507,
JAPAN
yamakawa@ip.elec.mie-u.ac.jp

Fumio Okuyama, Toshiki Yagi
Graduate School of Health Science, Suzuka
University of Medical Science
1001-1 Kishioka, Suzuka, Mie 510-0293,
JAPAN
fokuyama@suzuka-u.ac.jp

Abstract

In the field of ophthalmology, automatic measurement of retina and its quantitative evaluation are important for diagnosis of retinal diseases. Previously, automatic measurement methods of the thickness between Inner Limiting Membrane (ILM) and Retinal Pigment Epithelium (RPE) in the retina using Optical Coherence Tomography (OCT) images have been reported. These conventional methods employ basic image processing techniques and can extract ILM and RPE appropriately in most cases of normal OCT image. However these methods cannot be applied to some images with damages of retina. This paper proposes a new extraction method of ILM and RPE using morphological operations and two-dimensional dynamic net model (Active Net) for OCT images to improve extraction accuracy. In the proposed method, retina layer and ILM are determined by the morphological operations, and Active Net is employed to extract RPE in the retina. It is expected that layer structure of the retina can be extracted appropriately by the proposed method. Evaluation experiments using actual 30 normal OCT images were conducted to validate the effectiveness of the proposed method. The experimental results showed that the proposed method can extract ILM and RPE with damages appropriately, and correct extraction rate of 80% was obtained.

1. Introduction

Recently, tomographic images of retina have been obtained noncontactly and noninvasively by Optical Coherence Tomography (OCT). In a retina diagnosis using OCT devices, eyegrounds are irradiated with near infrared (NIR) laser first. Incident waves reflect on boundaries where the tissue density of retina 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 Figure 1 is generated by the difference among these waves [1][2]. 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 [3][4][5].

Meanwhile, there are many retinal diseases such as glaucoma, age-related macular degeneration, retinopathia diabetic and so on [6]. 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) [7] is mainly employed to evaluate the condition of retinal diseases quantitatively (Figure 2), the development of the extraction method for ILM and RPE has been required as a practical application.

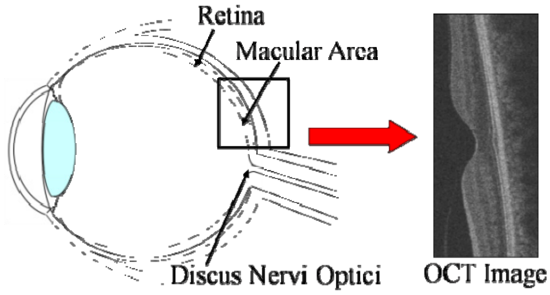


Figure1. Example of tomographic image of retina by OCT

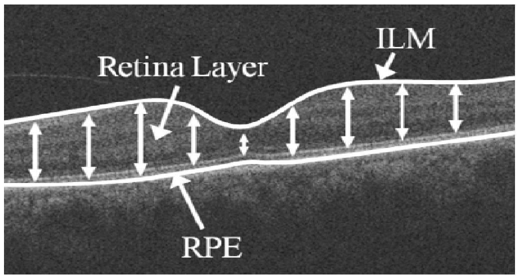


Figure2. Inner limiting membrane and retinal pigment epithelium

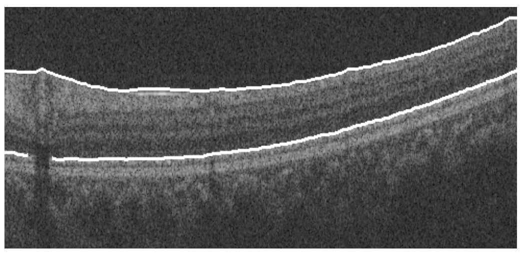


Figure3. Extraction result by Yagi's method

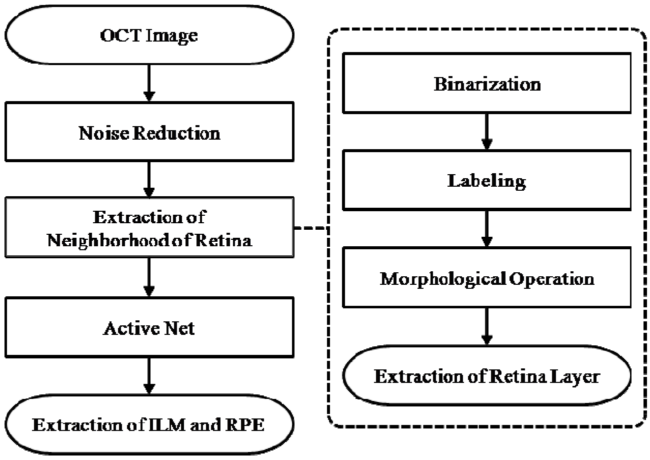


Figure4. Proposed extraction method of ILM and RPE

To comply with such request, Yagi at. el. [8] proposed the extraction method of ILM and RPE from OCT image using morphological operation and so on, and conducted basic examinations. But this method has the problem that RPE line is intermittently extracted in retinal layer image with disappearment parts (Figure 3).

In this paper, we propose a new automatic extraction method using Active Net, which is one of dynamic contour model. Active Net is based on the energy minimization theory and is widely used as extraction method of a two dimensional region [9]. The method can extract the contour using image texture information in the region enclosed with net model. By applying Active Net, we expect to extract 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.

2. Extraction of Neighborhood of Retina by Morphological Operation

2.1. Preprocessing for OCT image

In this paper, OCT images of 30 normal retina are used as the experimental material. These OCT images are digitized to a pixel size of 0.006 mm × 0.006 mm, an 8-bit gray scale and resolution of 512 × 480 pixels.

Figure 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 3×3 pixels.

The proposed method uses the morphological operations and the Active Net. The morphological operations can reduce the processing time of Active Net and improve the extraction accuracy, and the morphological operations can extract the neighborhood of retina. The Active Net can extract RPE precisely.

2.2. Segmentation of neighborhood of retina

In this paper, the initial position of nodes in Active Net is formed in a quadrangle. Active Net processes by repetitive operation until extracting object. Therefore, it takes so long to set the initial net for full of OCT image. So, we shorten processing time by confining the object of processing to neighborhood of retina. In this section, we describe the method to extract neighborhood of retina from OCT image as preprocessing to set the initial net of Active Net. As the first step of the extracting neighborhood of retina, binarization by a discriminant analysis method is applied to the smoothed image. Figure 5(a) shows the result of binarization. The Figure shows that the intensity of most pixels in the neighborhood of retina becomes white.

2.3. Removal of extra components

Some black connected components exist in Figure 5(a). These components are the elements of the retinal layer originally, however, not regarded as them in the following procedures. Therefore closing processing, which is one of morphological operations, is applied to the next step. In this step, a circular filter is employed and applied five times to the binarized image to remove the black connected components with small size. Black connected components in retinal layer can be removed by using closing operation. But white connected components upside ILM were existed. These white connected components are linked white components of ILM by dilation of closing operation, therefore it can't extract retinal layer effectually. So, labeling was applied so as to remove minimum white connected components existing upside ILM. White connected components upside large white connected components contained ILM were removed by labeling operation. Fig.5(b) shows the result of removal minimum white connected components. These minimum components could be removed by labeling operation. Closing operation was applied to the labeling processing image, and applied result was Fig.5(c). The figure shows that small black connected components were removed and most pixels in the retinal layer were changed to white pixels. As the result, only the processing region regarded as retinal layer is extracted (figure 5(c)). Also, ILM is distinguished by figure 5(c), we extract ILM using extraction processing of neighborhood of retina.

3. Extraction of Retinal Pigment Epithelium by Active Net

3.1. Setting the initial position of Active Net

We ease the upper area that is located at the top position of the white area in Figure 5(c) (neighborhood of retina) with a margin (20 pixels), and the lower are that is located at the bottom position of the white area with a margin (15 pixels).

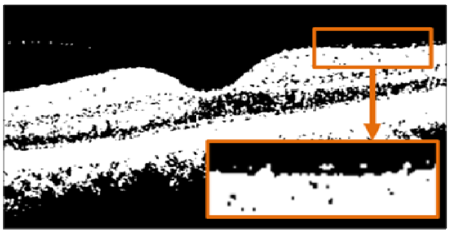
We set the node of Active Net for the above mentioned area (Figure 7(a)). Active Net transforms the position of every node to minimize the total energy of every node. The number of node of Active Net is 600 (= height 20 × width 30). The method extracts RPE using the initial position of Active Net.

3.2. Conformity characteristics energy of image

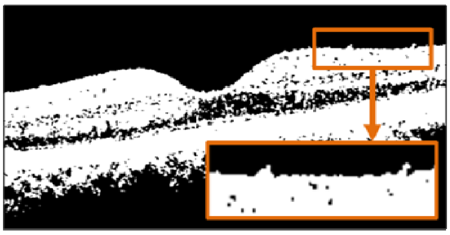
Active Net represents the behavior of dynamic contour model based on mechanics equation as energy, and is the method that extracts the object from image by finding stability state with energy minimization. Conformity characteristics energy of net and image is one of energy function of Active Net. The power lessening this energy corresponds with the power 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 OCT images, intensity in retinal layer are generally higher than the surrounding tissue because the NIR laser beams strongly reflect at the boundary of retina tissue and the strength of interference waves become high.

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



(a) Binarized image



(b) Labeling

(c) Closing operation

Figure5. Result of extracted neighborhood of retina

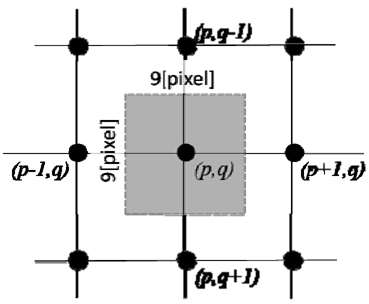
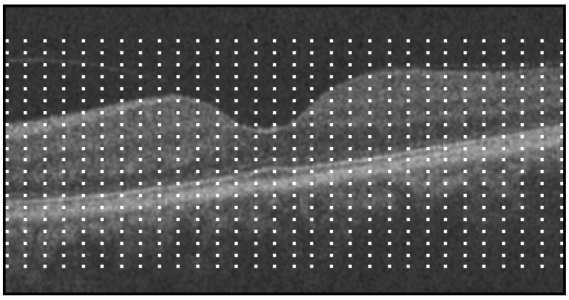


Figure 6. Node points of Active Net

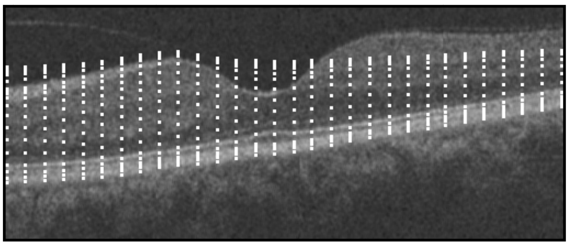
$$E_{image}(p,q) = \omega_1 I_{nf}(p,q) + \omega_2 V_{nf}(p,q) \quad (1)$$

$$\begin{cases} I_{nf}(p,q) : \text{Average of intensity in neighborhood region at a node point}(p,q) \\ V_{nf}(p,q) : \text{Variance of intensity in neighborhood region at a node point}(p,q) \\ \omega_1, \omega_2 : \text{Weight } (2.0, 2.0) \end{cases}$$

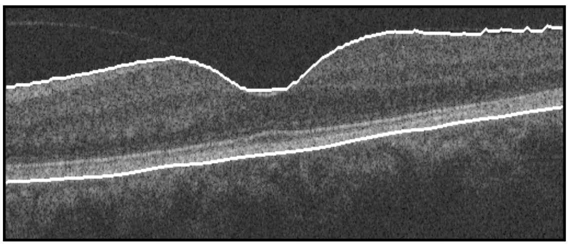
For each node points (Figure 6). The method sets the neighborhood region (9 pixels). The method calculates the average and the variance of intensity in the neighborhood region, and regularizes an obtained value in 256 steps. In this paper, if the average and variance of intensity are the smaller, then 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 variance is small. Therefore we gave weight (ω_1 is negative weight and ω_2 is positive weight) so that the inside node points of Active Net were led to inner retinal layer. Also the outside node points of Active Net were gave weight (ω_1 is positive weight and ω_2 is negative weight) so as to be let to boundary of retinal layer. By defining conformity characteristics energy of image as Eq. (1), Active Net transforms to surround the retinal layer. Also Active Net is not made to contract to horizontal direction, because Active Net can extract RPE only contraction to vertical direction.



(a) The initial position of nodes

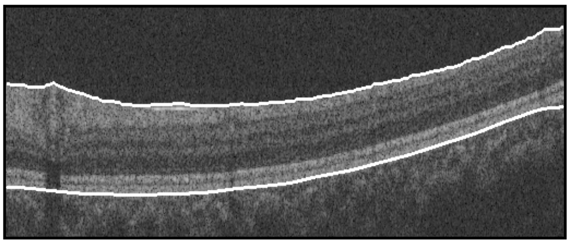


(b) Result of Active Net only

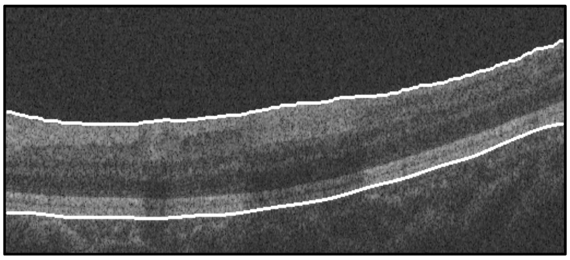


(c) Result of morphology and Active Net

Figure 7. Experimental result



(a) Example 1



(b) Example 2

Figure 8. Experimental result for retinal layer image that have damage

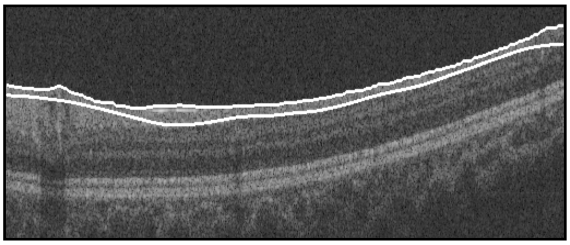


Figure 9. Failure example

3.3. The reservation of the end of Active Net

Active Net transforms to make the energy minimum by repetitive operation and extracts the object. When the energy of Active Net is the minimum value (or converges), it observes that Active Net extracts the object. So, the reservation of the end of Active Net is set to continue convergent condition of energy in this paper.

4. Experimental Results and Discussion

Figure 7 shows an experimental result by the proposed method. Figure 7(b) shows result by Active Net only, and Figure. 7(c) shows the result that put together ILM by morphological result of extracting neighborhood of retina and RPE by result of Active Net. Figure 7(c) shows the extracted result that ILM and RPE can be extracted by the proposed method. Figure 7(b) shows that the effective use of Active Net is depend on the initial position of nodes, and we propose a new method of setting the initial nodes automatically.

Figure 8 shows the experimental result for retinal layer image with damage. Figure 8 shows that Active Net can resolve the intermitted problem by Yagi's method[8].

However, Figure 9 shows a failure example. As the cause, Active Net in this paper has the problem that it depends on the initial net and node points. For that reason, we should consider the conformity characteristics energy of image as it does not depend on the initial net and node points.

As the result of the experiment, also, the extraction rate of 80% (24/30) was obtained. The extraction rate is defined as error of retinal thickness (differential between manual answer and experimental result) is smaller than 1/10 of retinal thickness by manual answer.

5. Conclusion and Future Works

In this paper, we propose an automatic extraction method using morphological operation and Active Net, and consider some basic examination. A result of the experiment for OCT image suggests that ILM and RPE can be extracted for retinal layer image with damage by our proposed method. The experimental result shows that our method can measure at the extracted rate of 80% for 30 normal images correctly.

In the future, conformity characteristics energy of image should be reconsidered, and we should experiment using many more experimental materials to improve the efficacy.

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