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Extraction of Disease Area from Retinal Optical Coherence Tomography Images Using Three Dimensional Regional Statistics

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Abstract

We propose a new extraction method of the macular disease area in the human retinal layer from OCT images using three dimensional regional statistics. In previous researches, we extracted disease area by using the mean and standard deviation of the two dimensional disease part pointed out by a clinical doctor. However, the previous method cannot extract disease area for some disease OCT images precisely. In this paper, we propose a new extraction method of the disease area using three dimensional regional statistics. We use a set of 128 images (3D-OCT image) consisted of 2 dimensional OCT retinal image about one retina of a patient. The regional mean and regional standard deviation of gray level are calculated in the three dimensional region of interest (ROI, 125 (=5 × 5 × 5) pixels) in the abnormal area pointed by a clinical doctor. These values are compared with every ROI in the abnormal area to extract the disease area, and the proposal system measures the volume of the disease area. We apply the proposed method to OCT images of 5 patients with retinal diseases. As a result, we can measure the volume of the abnormal area with 80.7% average accuracy.

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Keywords: *OCT,Age-related Macular Degeneration,computer aided diagnosis, REMURS-3D* ;

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1. Introduction

Optical coherence tomography (OCT) is an imaging technology performed non-invasive high resolution cross-sectional images of transparent and translucent structures [1]. In ophthalmology OCT can provides the structure imaging of retinal morphology at an intra-retinal level. The quantitative information of retinal thickness can be obtained in order to assess retinal diseases. The precise visualization of retinal structure morphology is the most critical in diagnosis retinal disease. Therefore the needs of retinal imaging using OCT devices have been growing [2].

Measurements of the retinal structure layers and thickness are performed by directing the light beam from optical source onto the retina. The back reflected light produced by the accident with the retinal layers contained interference beams. The OCT images are generated by scanning reflected beams, producing two-dimensional data set of gray scale images (Fig. 1) [2, 3].

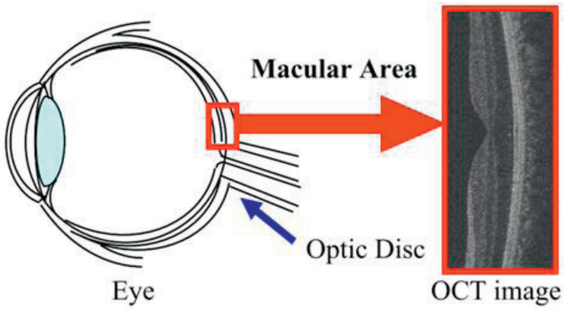


Fig. 1. Relationship between eye and OCT image

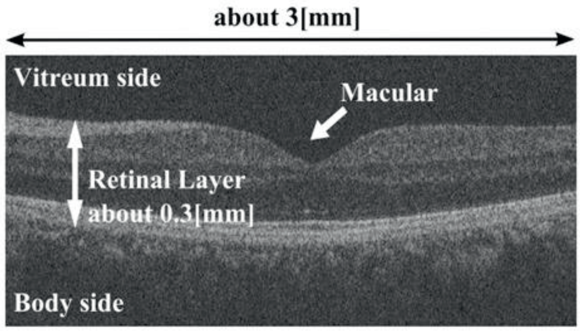


Fig. 2. OCT image of macular region

Retinal diseases have various kinds of abnormal and appear mainly at macular and optic disc. In this research, we focus on the macular OCT images. Fig. 2 shows examples of macular OCT images.

The thickness of retinal nerve fiber layer is important in early diagnosis of retinal disease. Quantitative information between inner limiting membrane (ILM) and retinal pigment epithelium (RPE), retinal layer structure and abnormal area in the retina can be used to access the retinal disease and monitoring the treatments process [4, 5].

Yagi et al. [6] proposed a method of extraction ILM and RPE using conventional image processing technique. However, his proposed method cannot extract the layer lines when the original OCT images having some disappearance points. To extract the boundaries of ILM and RPE, Yamakawa et al proposed one directional active net (ODAN) [7]. Kodama et al [8] proposed extraction method using statistical technique to measure the number of layer boundaries in retina in order to evaluate the size of retinal disease in horizontal direction. These methods have some problems. i) these method cannot extract the abnormal area in the image contained retinal layer damages, ii) these methods only can detect the black pixels in gray scale OCT images and iii) these methods cannot specify the abnormal area by a medical doctor.

To solve these problems, M. Fadzil et al. [9] proposed a region extraction method using two dimentional regional statistics (REMUS-2D) for an abnormal area. The method is one of 2 dimensional region growing method using the regional mean and regional standard deviation of gray level. However, the method has also some problem are i) the method cannot measure the volume of the disease for 3D-OCT, ii) the method can extract the abnormal area from only one slice, iii) the method is weak to noise on the input OCT image.

Therefore, to improve the border extraction of abnormal area, we propose a new extraction method using three dimensional regional statistics.

2. Three Dimensional (3D) OCT Image for Experiments

We use three-dimensional OCT images of retinal macular region as the experimental material. 3D OCT images are composed of 128 images per one eye. These images are acquired by using Topcon 3D-OCT 2000. The spatial resolution of OCT images is 6 μm or less in the vertical direction, 20 μm or less in the horizontal direction, and the slice gap is approximately 20 μm. In addition, the gray level is 16 bits, and the resolution is 512 × 480 pixels.

3. Extraction of Disease Part

Fig. 3 shows the outline of our proposed method. We used 128 OCT images as input images. Firstly, OCT

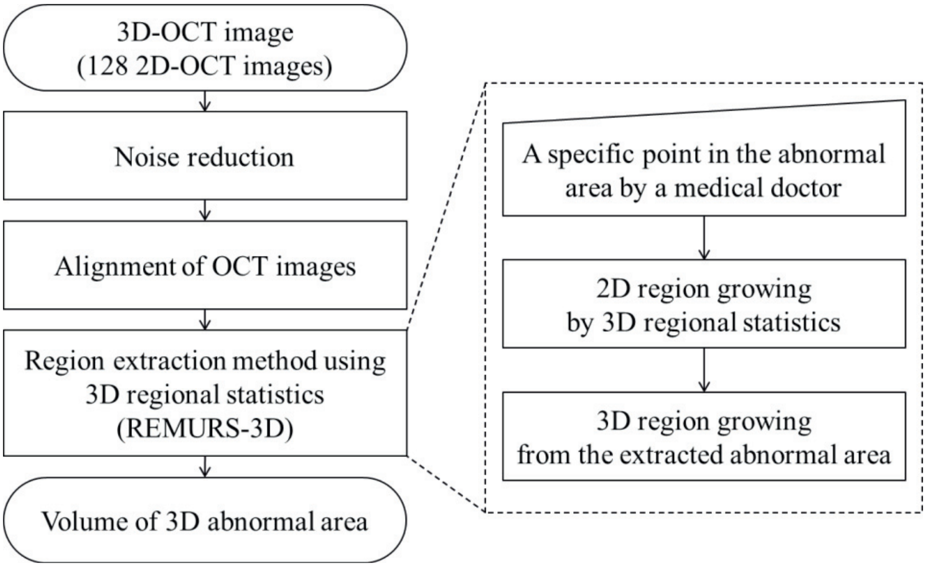
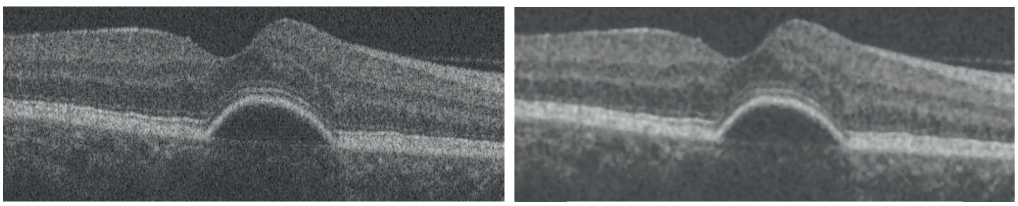


Fig. 3. Outline of proposed method



(a) Original image (b) After noise reduction

Fig. 4. Example of noise reduction

images are smoothed to reduce noise on OCT images. Secondly, we align the position of OCT images to reduce the difference of the position of retinal layers between the OCT images. Finally, we extract a disease area using three dimensional regional statistics.

3.1. Noise Reduction using Median Filter

OCT images include some speckle noises by light interference. Therefore, we eliminate the speckle noise by using median filter. In this paper, we use 5 × 5 median filter for gray level of the pixel, and we obtain the smoothed images (Fig. 4).

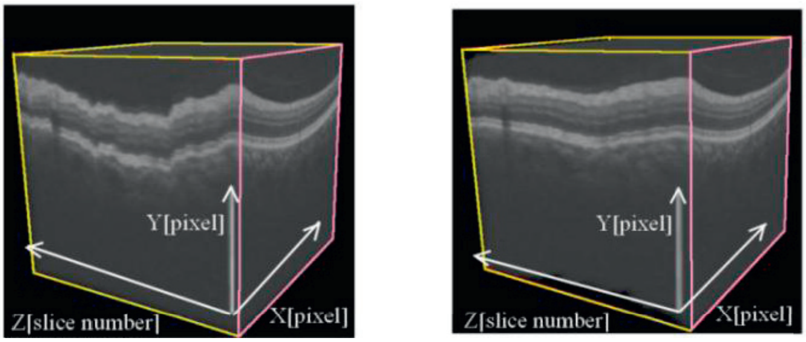
3.2. Reduction of the involuntary eye movement

Scanning speed of OCT is about one minute for128 slice images. The movement between images causes by involuntary eye movement. Moved OCT images have an improper contiguity and disrupt the analysis of the depth map below. Therefore, we reduce the movement of vertical direction by calculating the degree of similarity between adjacent images [10]. We use a normalized correlation method as a method of calculating the degree of similarity Eq. (1).

$$\frac{\frac{1}{N}\sum_{i=1}^{N} T(i)I(i)-\left(\frac{1}{N}\sum_{i=1}^{N} T(i)\right)\left(\frac{1}{N}\sum_{i=1}^{N} I(i)\right)}{\sqrt{\left(\frac{1}{N}\sum_{i=1}^{N} T^2(i)-\left(\frac{1}{N}\sum_{i=1}^{N} T(i)\right)^2\right)\left(\frac{1}{N}\sum_{i=1}^{N} I^2(i)-\left(\frac{1}{N}\sum_{i=1}^{N} I(i)\right)^2\right)}} \tag{1}$$

Here, $T(i)$ is gray value of template, $I(i)$ is the gray value of a input image, and N is the pixel size of sub image $T(i)$.

Fig. 5 (a) shows uncorrected 3D OCT image. Retinal layer are vibrating in the vertical direction, and there are gaps between the images. Then, Fig. 5(b) shows corrected 3D OCT image. It is smoother than before, and its adjacency between images is reformed.



(a)Uncorrected 3D OCT (b)Corrected 3D OCT

Fig. 5. Comparison before and after alignment

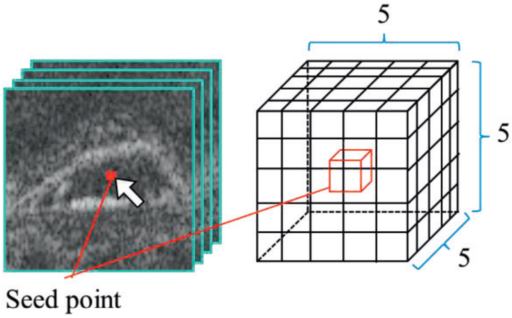


Fig. 6. Seed point and the 3D neighbor

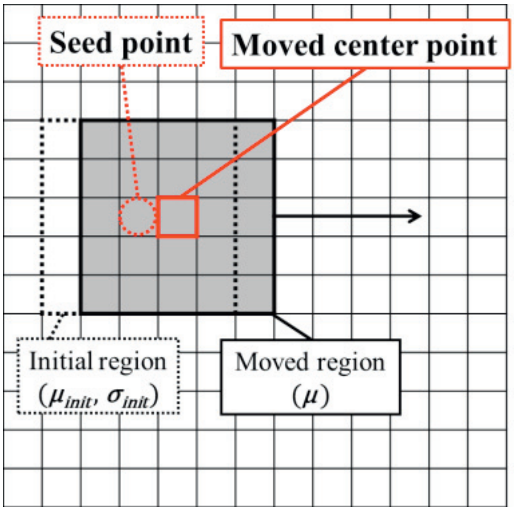


Fig. 7. Moving process the 3D neighbor

3.3. Region Extraction Method using REMURS-3D

We first choose one seed point on a OCT image manually in an interested disease part (Fig. 6) by a clinical doctor. Then we calculate the statistics in the seed's neighbor (5×5×5) to get the initial mean μ_{init} and the standard deviation σ_{init} for the intensity in the 3D neighbor of the seed point.

After the pointing the seed point, our system moves the center point from the seed point to the adjoining point of the seed point, and calculate the values of mean μ for the intensity in the 3D moved neighbor. If μ is in the following range, we regard the neighbor of seed as disease area.

$$(\mu_{init} - a\sigma_{init}) < \mu < (\mu_{init} + a\sigma_{init}) \quad (2)$$

Where a is the constant. If μ is not in the above Eq. (2), we regard the neighborhood as the normal area.

The above processes are repeated for each point on the same line of the seed point. The above moving process detects the boundary point. After the detection of boundary point, the above moving process is repeated for the lower lines and the upper lines, for the other OCT images, the above moving process is repeated from the position in the mean point of the abnormal area.

4. Evaluation Experiment of Extraction Method

4.1. Evaluation Criteria

We evaluated the extraction accuracy of our system for 3D-OCT images. We defined the false negative volume fraction (FNVF) as the fraction of tissue volume included in the true extraction to the volume missed by our method:

$$FNVF = \frac{|V_{true} \cap \bar{V}|}{|V_{true}|} \tag{3}$$

The false positive volume fraction (FPVF) which indicate the amount of tissue falsely identified by our method as a fraction of the total amount of tissue in the true extraction:

$$FPVF = \frac{|\overline{V_{true}} \cap V|}{|V_{true}|} \tag{4}$$

The true positive volume fraction (TPVF) describes the fraction of the overlapped amount of tissue in the true extraction result with our method:

$$TPVF = \frac{|V_{true} \cap V|}{|V_{true}|} \tag{5}$$

The DICE coefficient measures agreement between V_{true} and V:

$$DICE\ Coefficient = \frac{2 \times |V_{true} \cap V|}{|V_{true}| + |V|} \tag{6}$$

Here, V_{true} is manual extracted result in the image volume; V is the result of our proposed extraction. (Fig. 8)

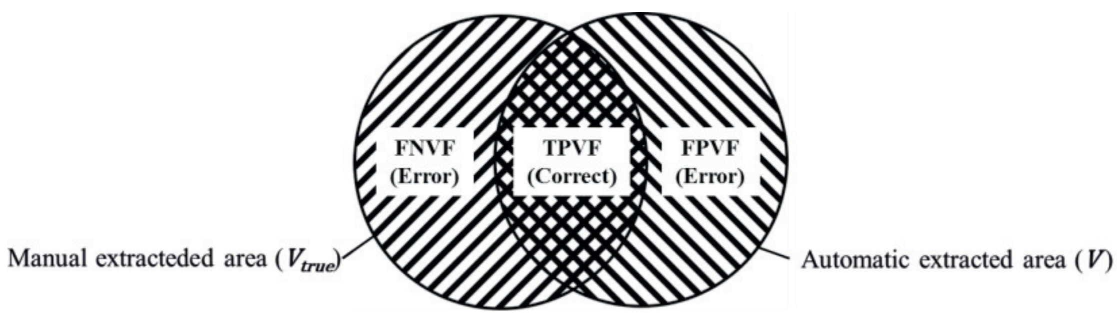


Fig. 8. Each evaluation index

4.2. Results and Consideration

We used OCT images of 5 eyes (5 x 128 images) to evaluate the performance, these OCT images consist of 2 eyes with age-related macular degeneration (AMD) and 3 eyes with drusen. Table 1 shows the result of evaluation experiment. Our system can extract with an average accuracy 80.7[%]. However, our system cannot extract 19.3[%] of disease area. Table 2 shows the comparison with the previous method (REMURS-2D) [9] and the proposed method (REMURS-3D). Fig. 9 and 10 show the examples of correct extraction result images in comparison with the previous method.

Fig. 11 shows Drusen #2 OCT image as the example of failed extraction. On this example, the region growing did not stop, because the bottom border of disease area is unclear by small difference between gray level of disease area and normal area.

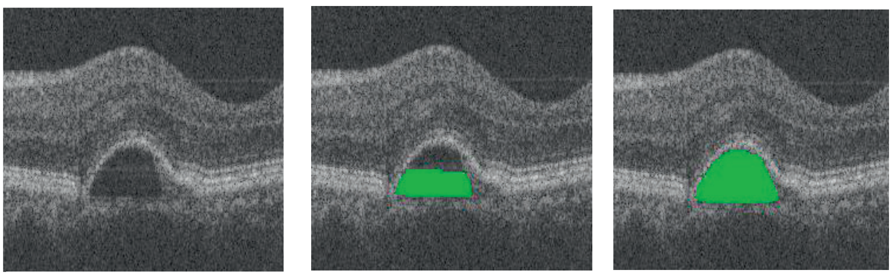
Fig. 12 shows AMD#1 transition of TPVF according to the change of coefficient a in Eq. (2). TPVF is increasing the coefficient a in increasing.

Table 1. Result of volume evaluation

	FNVF (Error) (%)	FPVF (Error) (%)	TPVF (Correct) (%)	DICE coefficient
AMD #1	8.1	11.4	91.9	0.904
AMD #2	7.7	15.5	92.3	0.888
Drusen #1	15.4	63.2	84.6	0.683
Drusen #2	41.6	30.8	58.3	0.617
Drusen #3	23.7	11.5	76.3	0.816
Average	19.3	26.5	80.7	0.781

Table 2. Comparison of proposed method with previous method

	FNVF (Error) (%)	FPVF (Error) (%)	TPVF (Correct) (%)	DICE coefficient
Proposed method (REMURS-3D)	19.3	26.5	80.7	0.781
Previous method (REMURS-2D)	26.8	54.2	74.8	0.653



(a)Original image (b) Previous method (c) Proposed method

Fig. 9. Example of extracted image (AMD #1)

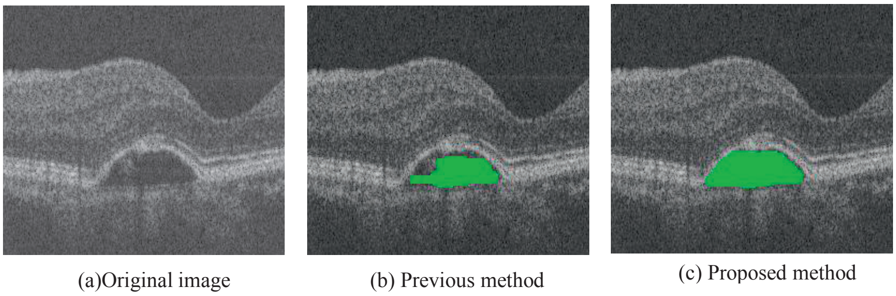


Fig. 10. Example of extracted image (AMD #2)

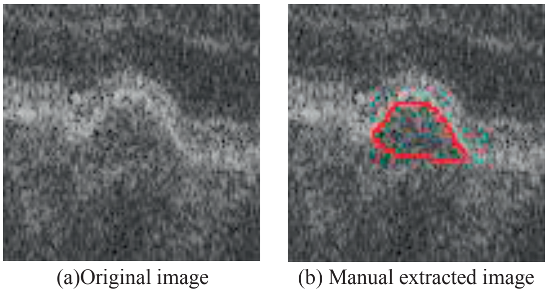


Fig. 11. Example of failed extraction (Drusen#2)

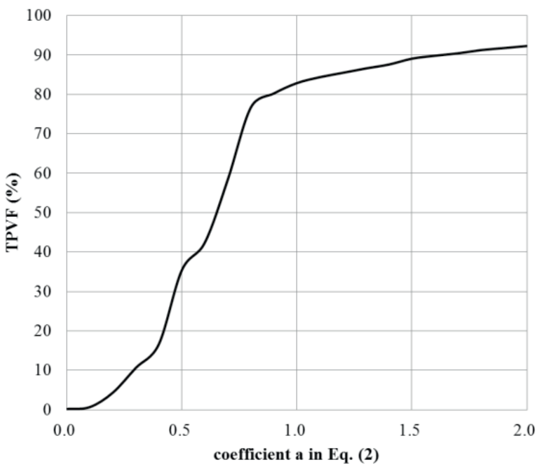


Fig. 12. Transition of TPVF when changes value a (AMD#1)

5. Conclusion

In this paper, we propose a new extraction method (REMURS-3D) for OCT image using three dimensional regional statistics. As a result, we can measure the volume of disease area with 80.7[%] accuracy, and we improved the accuracy 5.9% from the previous method (REMURS-2D).

This research will provide more useful information to medical doctor and patient for informed consent. We hope that this procedure may be added in the commercial OCT unit to evaluate the degree of disease and response to the treatment.

In future works, we will improve the proposed method using new criteria to further increase the accuracy using many OCT images. We are generating the surface model for three dimensional graphics.

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