AUTOMATED THREE-DIMENSIONAL SEGMENTATION OF RETINAL OCT IMAGES

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Abstract

Fourier Domain - Optical Coherence Tomography (FD-OCT) is a well-established imaging technique in ophthalmology. The segmentation of anatomical and pathological structures in ophthalmic images is essential for diagnosis and treatment of ocular diseases. However, FD-OCT gives large amount of data, which makes it infeasible to process manually. We propose an automatic segmentation algorithm to detect intra-retinal layers based on intensity and weighted gradient methods. The algorithm is tested upon the images of healthy volunteers obtained from Cirrus HD-OCT system.

Keywords— *Optical Coherence Tomography, image segmentation, retinal layers, Canny edge detection, axial gradient*

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1. INTRODUCTION

In ophthalmology, OCT has become a standard clinical approach for diagnosis and treatment of human retina. With advanced Fourier domain OCT (FD-OCT) systems, image acquisition has become faster producing huge amount of data. Various methods have been proposed to automate the retinal layer segmentation. Fabritius et al. used signal intensity variation based algorithm for retinal layer segmentation [1]. Zhang et al. proposed an automated segmentation of retinal layers using weighted gradient method and statistical error removing technique [2]. Yang et al. employed local and global gradient information for retinal layer segmentation [3]. Chiu et al. and other groups have proposed segmentation method for retinal layer segmentation of OCT image using graph theory technique [4, 5, 6]. Active countour approach has been employed by Yazdanpanah S et al. and Mishra et al. for retinal layer segmentation of OCT images [7, 8].

Here, we propose a simpler automated segmentation algorithm for retinal OCT scan of healthy human subjects, using intensity and gradient information from the image.

FD-OCT retinal scans are obtained from Cirrus HD-OCT system. Each A-scan contains 1024 pixels. Each B-scan has 512 A scans. And there are 128 B-scans in each retinal scan. Thus, 3D data cube is of dimension 1024x512x128. Depth resolution of FD-OCT system is 5μm (in tissue) and lateral resolution is 15μm (in tissue).

2. EXPERIMENTAL SETUP

The macular OCT images of healthy volunteers were obtained using Citrus HD-OCT system. Each three-dimensional scan covers macular volume of 2mm×6mm× 6mm and provides data of dimension 1024×512×128. At this specification, OCT system takes about 1.6 seconds to take one three dimensional scan. The axial resolution of OCT system is 2μm. The transverse resolution i.e. between two A-scans is about 12μm. Figure 2.1 shows a typical OCT image.

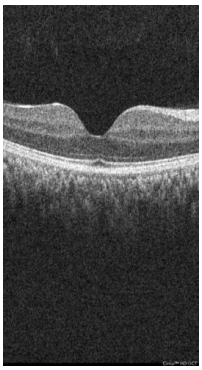

Fig 2.1: Sample OCT image

The segmentation algorithm was implemented on MATLAB (The MathWorks, Inc). Program runs on a personal computer (64-bit OS, Intel(R) Core(TM) i5-2400 CPU@3.10 GHz, 4 GB RAM).

3. TWO DIMENSIONAL SEGMENTATION OF RETINAL OCT IMAGE USING GRADIENT METHOD

The macular OCT image segmentation algorithm employed gradient information to detect layer boundaries. The change in intensity along A-scan is also utilized.

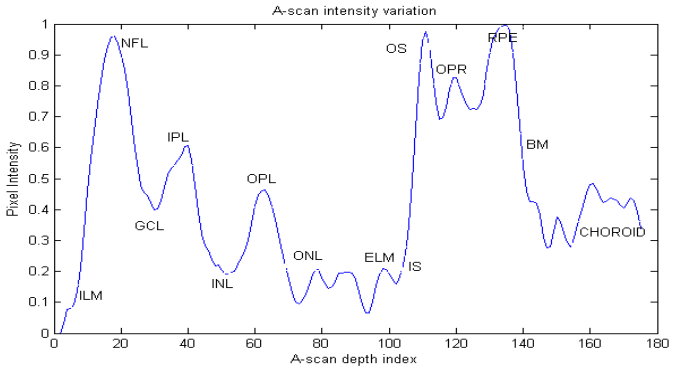

Fig 3.1: Intensity profile of A-scan used for marking various layers/boundaries.

3.1 Denoising and Finding Area of Interest

Image pre-processing is performed in three steps:

1) *2-D Gaussian filtering:*
   A Gaussian filter of size 5×7 and SD 2 is used for de-noising in order to remove speckle noise and smooth the intensity variation of image.
2) *DC component removal:*
   DC component in the image is estimated from the histogram. This dc component is subtracted from each A-scan. Then the A-scans are normalized.
3) *Image cropping:*
   The data cube dimensions decrease to (400×512×128) from (1024×512×128) after removing the vitreous and choroid regions.

3.2 Layer Detection Algorithm

This algorithm uses two techniques: Axial gradient and Canny edge detection.

1) *Axial gradient:*
   This is obtained by filtering the image with the matrix [1;1;1;0;-1;-1;-1];
2) *Canny edge detection:*
   At first, the image is smoothened to reduce noise. The gradient is obtained to highlight regions with high spatial derivatives. The algorithm then tracks along the gradient regions. It suppresses pixels that are not at maximum. Hysteresis then tracks the remaining pixels. Canny edge detector is implemented using '*edge'* function in MATLAB.

The function is first applied with the search limits from anterior boundary to posterior boundary with axial gradient threshold 0.5 and Canny thresholds 0 and 0.8. This gives the Inner Limiting Membrane (ILM) and the inner segment – outer segment (IS/OS) boundary. ILM and IS/OS are smoothed with a modified Gaussian filter. Then the image is considered as two regions: ILM to IS/OS, and IS/OS to posterior boundary (PB).

1) *ILM to IS/OS:*
   The layer detection algorithm is applied with axial gradient threshold 0.15 and Canny thresholds 0.1 and 0.15. This detects Nerve Fiber Layer – Ganglion Cell Layer (NFL-GCL), Inner Plexiform Layer – Inner Nuclear Layer (IPL-INL), and Outer Plexiform Layer – Outer Nuclear Layer (OPL-ONL).
2) *IS/OS to Posterior boundary:*
   The algorithm is applied with axial gradient threshold 0.4 and Canny thresholds 0.2 and 0.4. This detects the outer segment (OS), OPR (Outer-segment Photoreceptors), and Retinal Pigment Epithelium (RPE).

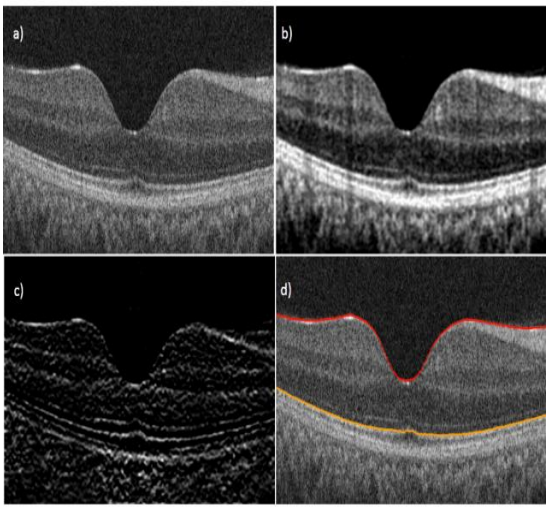

Fig 3.2: a) OCT image near fovea. b) Image after preprocessing. c) Axial gradient of image. d) ILM (red) and IS/OS (yellow) superimposed on original image

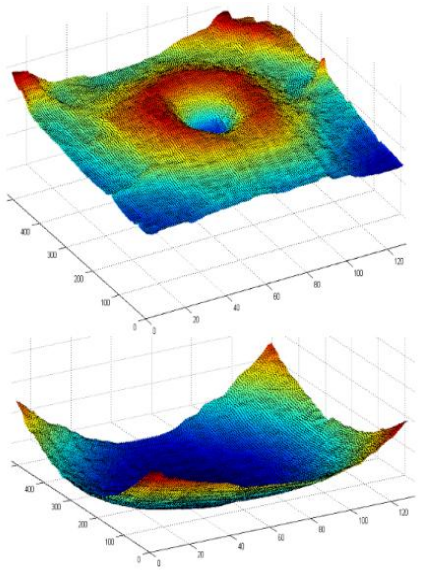

Fig 3.3: 3-D plot of ILM and RPE

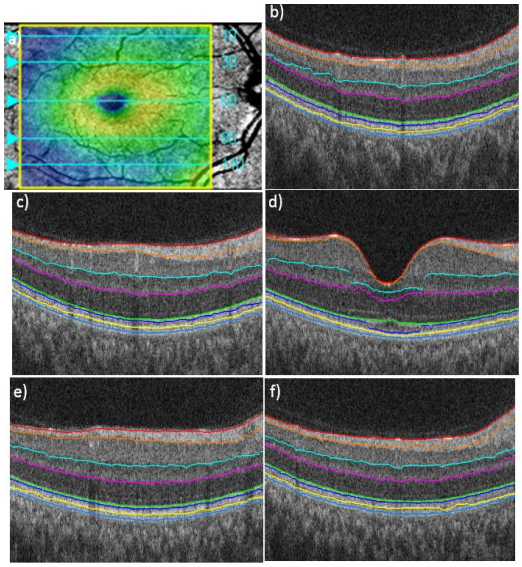

Fig 3.4: Segmentation result on various B-scans. The layers/boundaries marked are (from top): ILM, NFL-GCL, IPL-INL, OPL-ONL, IS/OS, OS, OPR and RPE

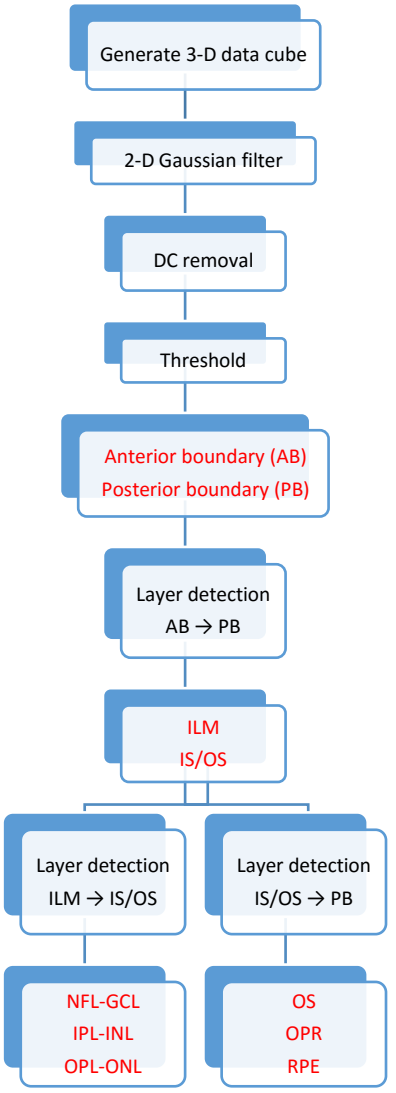

Fig 3.4: Flowchart of gradient based segmentation

4. THREE DIMENSIONAL IMAGE SEGMENTATION OF RETINAL OCT IMAGE USING INTENSITY/THRESHOLD INFORMATION

Three-dimensional macular OCT image provides better visualization of tissue structures by compensating for the error due to shadowed region caused by blood vessels or any other information loss. The macular scan is divided into three regions [Fig 2].

4.1 Denoising and Finding Area of Interest

A Gaussian filter of size 5×7 and SD 2 is used to filter each cross-sectional image. Each A-scan is then processed to remove DC component.

Anterior boundary is obtained by converting each cross-sectional image into binary form with threshold 0.1. The first white pixel in each A-scan is marked as anterior boundary.

To obtain posterior boundary, each cross-sectional image is converted to binary image with threshold 0.3 and first white pixel from choroid to vitreous direction is marked as posterior boundary.

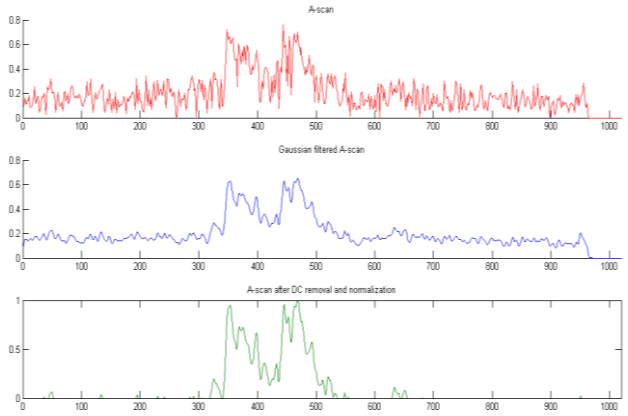

Fig Error! No text of specified style in document.**.1:** Intensity variation in a A-scan in original image (red), Gaussian filtered image (blue); and when DC part is removed and A-scan is normalized (green)

4.2 Separating Macular Image in Three Regions

This intensity characteristic is used to divide macular cube in three sections. Region 1 contains ILM, NFL, GCL, IPL, INL and OPL. Region 2 contains ONL, External Limiting Membrane (ELM) and IS. Region 3 contains OS, OPR, RPE and Bruch Membrane (BM). The data cube is multiplied with a three dimensional matrix of size 7×5×5 with each element of value one. The resultant is normalized and converted to binary form with threshold 0.3. In the resultant binary images, the upper and lower high intensity pixels in binary form are marked as Region 1 and Region 3

respectively, with Region 2 between them as shown in Fig Error! No text of specified style in document..2(c).

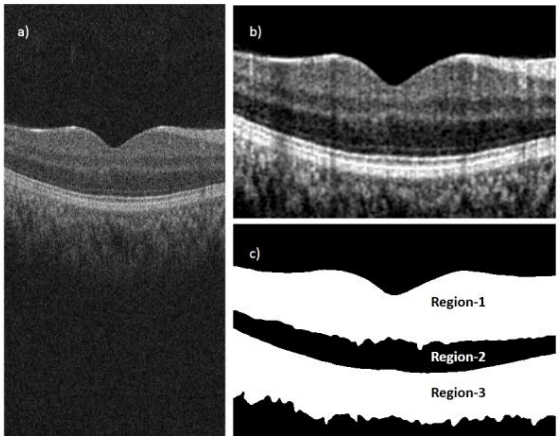

Fig Error! No text of specified style in document..**2:** a) one cross-sectional OCT scan of macula. b) Vitreous and choroid regions are removed from OCT image. c) OCT image divided into three regions.

4.3 Aligning A-Scans along IS/OS

In Region 3, the first intensity rise is detected and marked as IS/OS. All A-scans are aligned to make IS/OS a straight line. 3-D filtering of thus obtained data cube is performed using a Gaussian matrix of size 5×7×3 and SD 2. Each A-scan is normalized. After 3-D filtering and normalization, the error due to blood vessels is considerably minimized. This 3-D smoothened data cube will be used to find the different macular layers according to their intensity profile.

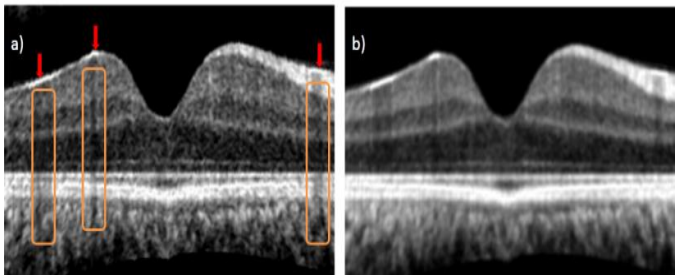

Fig Error! No text of specified style in document..**3:** a) OCT image flattened along IS/OS. b) Same image after 3-D filtering

4.4 Finding Macular Layers

The macular layers are detected by identifying peaks, changes in intensity, and thresholding.

The threshold-based search algorithm is run from anterior boundary to IS/OS with a threshold 0.2. This detects the ILM. Then the search continues from the ILM to posterior boundary, but with a threshold of 0.6. This detects NFL.

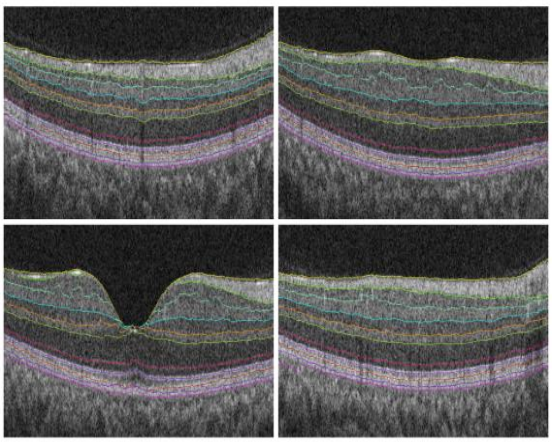

Fig Error! No text of specified style in document..**4:** The segmentation results showed on original OCT images. Segmentation result from top: ILM, NFL-GCL, GCL-IPL, IPL-INL, INL-OPL, OPL-ONL, ELM, IS/OS, OPR, RPE, Bruch's membrane.

The remaining layers are found by peak detection on the following regions:

Search Starting Row	**Search Ending Row**	**Layer Detected**
Region1-Region2 boundary	NFL	OPL
OPL	NFL	IPL
IS/OS	25 rows above IS/OS	ELM
IS/OS	Posterior boundary	OS
OS	Posterior boundary	OPR
OPR	Posterior boundary	RPE

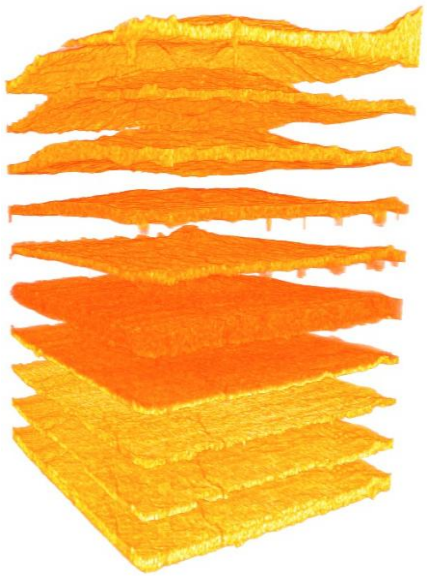

Fig Error! No text of specified style in document..**5** Shows the different layers of macula as obtained in segmentation.

From top: NFL, GCL, IPL, INL, OPL, ONL-ELM, ELM-IS/OS, OS, OPR, and RPE.

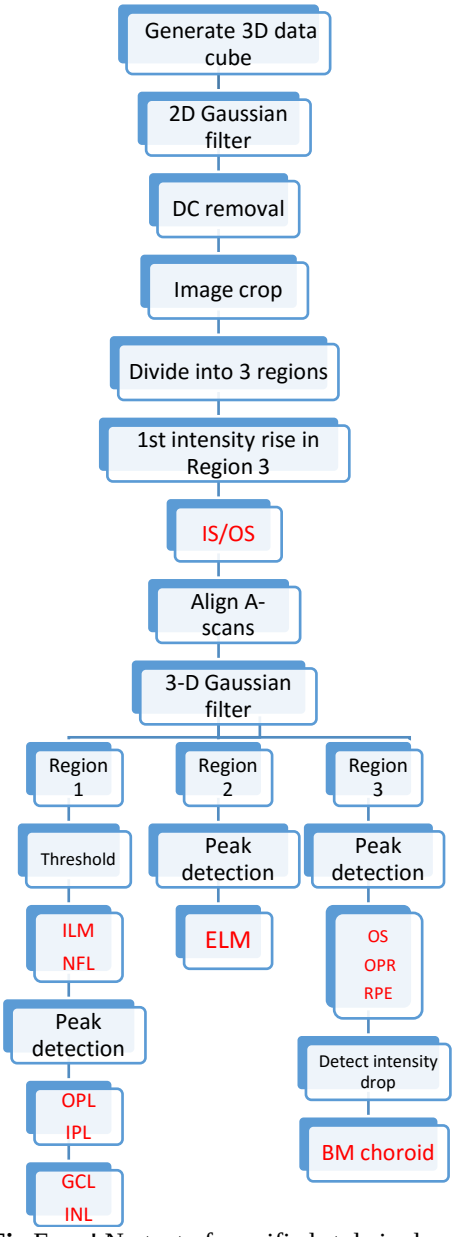

Fig Error! No text of specified style in document.**.6:** Flowchart of intensity based segmentation algorithm

5. MACULAR ANALYSIS

5.1 Fovea

At fovea, the A-scans have less total intensity i.e. addition of all pixels of A-scan. The normalized A-scan sum matrix is converted to binary form with threshold 0.5. In black region of this binary image, fovea location is obtained as the point of ILM and RPE difference. And the minimum ILM-RPE thickness at the center for the given image was 207µm.

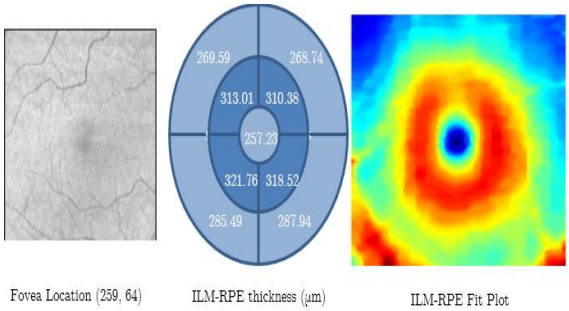

Fig 5.1: shows the ILM-RPE thickness variation on macular surface

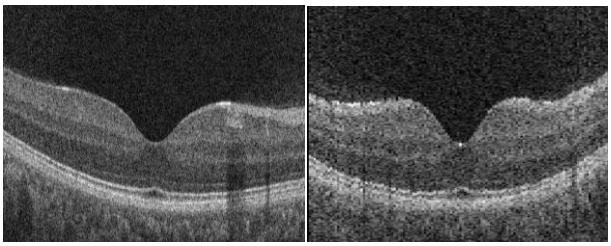

Fig 5.2: shows the two mutually cross-sectional images at center of fovea

5.2 Display ILM and RPE, and RPE Fit-Function

RPE fit function displays the ILM by making RPE a flat surface. So it is essentially the ILM-RPE thickness plot. Fig 5.3 shows the RPE-fit function plot.

Macular cube average thickness:

$$(\text{RPE-ILM}) \times (1024 \div 2000)\ \mu\text{m} = 285.16\mu\text{m}.$$

The macular cube volume measured as the macular volume between ILM and RPE for the ILM-RPE layer show above is:

(Average (ILM-RPE))$\div$ 1024 $\times$ 2 $\times$ 6 $\times$ 6 mm^3= 10.23mm^3

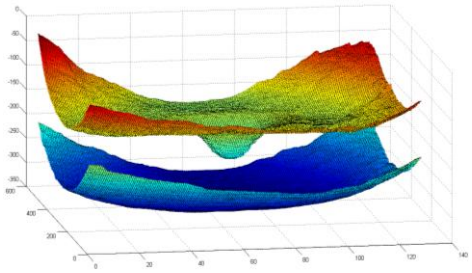

Fig 5.3: shows the ILM (top) and RPE (below) layers.

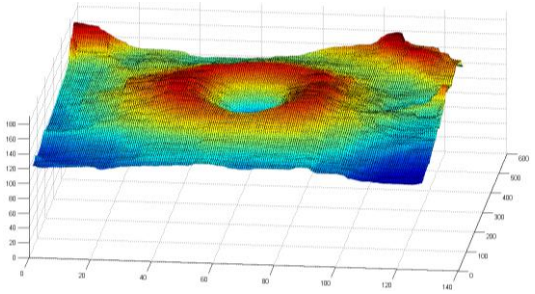

Fig 5.4: shows the RPE- fit function plot

Error! Reference source not found.: ILM-RPE analysis

	Central Subfield Thickness (μm)	Cube Volume (mm^3)	Cube Average Thickness (μm)
RPE	257.23	10.23	285.16

6. RESULT AND DISCUSSION

6.1 Result

In 2-D gradient-based segmentation, initially anterior boundary and posterior boundary are identified. The layer detection algorithm detects ILM, IS/OS, NFL-GCL, IPL-INL, OPL-ONL, OS, OPR, RPE.

In 3-D intensity-based segmentation, initially IS/OS is identified. Then the image is divided into 3 regions. ILM, NFL, OPL, IPL, GCL, INL, ELM, OS, OPR, RPE and BM choroid are identified.

6.2 Discussion

The segmentation algorithm does not use results from previous layers, so current segmentation is not affected by previous errors. Thick blood vessels create shadow due to high scattering by blood. In such shadowed region, current strategy to detect IS/OS is insufficient. Incorporation of global weighted gradient along with local gradient currently used can enhance the result. Moreover each boundary or layer has different scattering property and surroundings, which means there should be layer/boundary specific error removing algorithm.

7. CONCLUSION

We have demonstrated an automated segmentation technique using intensity and gradient information for retinal layer segmentation in FD-OCT images. Further work will be done to segment more retinal layers and to provide thickness of each layer automatically.

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