Automatic Segmentation of Layers in outer Retina by Model Selection

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Abstract: Extraction of image-based biomarkers, such as the presence, visibility or thickness of a certain layer, from 3D optical coherence tomography data provides relevant clinical information. We present a method to simultaneously determine the number of visible layers in the outer retina and segment them. The method is based on a model selection approach with special attention given to the balance between the quality of a fit and model complexity. This will ensure that a more complex model is selected only if this is sufficiently supported by the data. The performance of the method was evaluated on healthy and retinitis pigmentosa (RP) affected eyes. Additionally, the reproducibility of automatic method and manual annotations was evaluated on healthy eyes. A good agreement between the segmentation performed manually by a medical doctor and results obtained. From the automatic segmentation was found. The mean unsigned deviation for all outer retinal layers in healthy and RP affected eyes varied between 2.6 and 4.9 μm. The reproducibility of the automatic method was similar to the reproducibility of the manual segmentation. Overall, the method provides a flexible and accurate solution for determining the visibility and location of outer retinal layers and could be used as an aid for the disease diagnosis and monitoring.

Index Terms—Akaike information criteria, Attenuation coefficient, Bayesian information criteria, Information complexity, Maximum likelihood estimation, Model selection, Retinitis pigmentosa.

1. INTRODUCTION

1.1 Outer Retinal Layer Segmentation:

Several processing steps are performed to segment thelayers in the outer retina: pre-processing, fitting the candidatemodels, model selection and layer identification. First, the pre-processingstep detects the region of interest (the location ofthe outer retina). Second, the parameters of the various modelsfor the outer retina are calculated for every A-line by usingMLE. Third, the model selection procedure based on ICOMPRis applied to select the model best supported by the data. Fourth, the labels are assigned to the detected layers.

1.2 Pre-Processing:

The raw OCT data is converted to attenuation coefficientsafter which the loosely coupled level sets (LCLS) framework[4] is applied to the converted data to detect the location ofthe outer retina. Although the LCLS framework was not developedfor RP affected eyes, it performs well on RP data becauseRP data appears similar to that of healthy and glaucoma eyesfor which the original LCLS framework was developed. Thelayers affected in RP are the thin outer retinal layers, whichare not segmented by the LCLS framework. Next, each B-scanis filtered with an 1D Gaussian filter [5] steered alongthe orientation obtained by a 2D structure tensor [6] with agradient and tensor scale of $\sigma_g = 25$ μm and $\sigma_t = 120$ μm,respectively. The standard deviation of the Gaussian filters wasequal to the spacing between subsequent B-scans. Afterwards,each B-scan was sub-sampled such that the obtained spacingalong a B-scan matched the spacing between B-scans. Finally,the region of interest for the parameter estimation and modelselection procedure was set to be between the

posterior RPEboundary and the lower of the two following boundaries: theOPL-ONL interface or 40 µm above the anterior EZ boundary.

1.3 Representation of Layers And Models:

In case of a thin reflecting layer (i.e., thin in comparison tothe coherence length of the used light source), the response ofthe OCT system corresponds to a weighted and shifted versionof the system's point spread function (PSF), which can beapproximated by a Gaussian function. Since some of the outerretinal layers originate from structures thinner than the PSF ofan OCT system [3], we modeled each of the layers in the outerretina as a Gaussian function. Furthermore, we consideredseveral models of the outer retina, each with a differentnumber of layers and composed of different tissues.

$$M(\theta, z) = \sum_{i=1}^{k} a_i \exp\left(-\frac{(z - l_i)^2}{2\sigma_i^2}\right) + c$$

Where c is the signal offset (noise floor) and α_i, l_i, and σ_i are the model parameters corresponding to respectively theamplitude, location and standard deviation of the Gaussianfunction representing layer i. The variable k indicates thenumber of Gaussians in a certain model. In our framework, four models of the outer retina were considered, hence k variedfrom 1 to 4.

1.4 Model Fitting And Model Selection:

The location of ELM was restricted to the area between the OPLONLinterface and the anterior EZ boundary (as detected withthe LCLS method) and the other layers had to be within theregion bounded by the anterior EZ boundary and the posterior RPE boundary (also detected with the LCLS method). Thestandard deviation of the Gaussians, that represent the layers,was constrained to the range of 2-40 µm. An additional constraint was put on the amplitude of different layers, basedon prior knowledge of the attenuation coefficients of thedifferent layers as reported in Table I. This constraint wasdetermined experimentally by using data from healthy subjects(independent from those used for accuracy evaluation). Finally,the predefined order of the layers was enforced.

TABLE I: Amplitude constraint for different layers (mm^{-1}).

	Minimal	Maximal
ELM	0.01	0.2
EZ	0.5	10
IZ	0.1	2
RPE	3	80

1.5 Post-Processing Specific for Retinitis Pigmentosa:

To improve spatial consistency of the segmented layers, apost processing step specific for eyes affected by RP is proposed.For this, the number of visible layers for every A-line isprojected onto a 2D en face image on which further processingis performed. The en face image is decomposed into fourbinary images each showing area in which either one, two,three or four layers are visible. Each image is processed by twomorphological filtering steps: an morphological opening (toremove possible noise present as small and isolated structures)followed by a dilation operation (to connect discontinuitiesin layers smaller than the structuring element and create amore continuous result), both using a disk-shaped filter witha radius of 60 µm). The radius was based on the clinical need(as determined by the scan protocol for RP patient), whichindicates that information smaller that 120 µm are not relevant.The individual images are then summed together to create anupdated en face image. Finally, segmentation of retinal layersis extracted as the position parameter (l) of the fitted Gaussianmodel with the number of layers that corresponds to the valueobtained from the updated en face image.

2. LITERATURE SURVEY

D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, and et al., "Optical coherence tomography,"[1] This paper gives an

introduction to optical coherence tomography (OCT), explains its basic principles, and discusses the information content of OCT images. Various interferometric techniques used in OCT are reviewed and a short survey of results obtained so far in different fields of application and possible future developments are presented.OCT is an exciting, new, high-resolution imaging technique. Transversal and longitudinal resolution in the micrometer-range and dynamic ranges up to 140 dB has been obtained so far. OCT shows an extremely high potential as a noninvasive diagnostic tool in ophthalmology. Future developments might include new fields of application such as dermatology and include additional information like Doppler shift, birefringence, and tissue spectrometric data.

A. Hagiwara, Y. Mitamura, K. Kumagai, T. Baba, and S. Yamamoto, "Photoreceptor impairment on optical coherence tomographic images in patients with retinitis pigmentosa,"[2] with recent development of spectral-domain optical coherence tomography (SD-OCT), the pathological changes of retina can be observed in much greater detail. SD-OCT clearly delineates three highly reflective lines in the outer retina, which are external limiting membrane (ELM), photoreceptor inner and outer segment (IS/OS) junction, and cone outer segment tips (COST) in order from inside. These lines can serve as hallmarks for the evaluation of photoreceptor condition. In retinitis pigmentosa (RP) leading to photoreceptor degeneration, the ELM, IS/OS, and COST lines are shortened with the progression of the disease. In addition, shortening of the ELM, IS/OS and COST lines is significantly associated with each other. The line length is longest in the ELM, followed by the IS/OS, and COST, suggesting that retinal layer becomes disorganized first at the COST, followed by the IS/OS and finally the ELM. This finding is consistent with the previous report that the earliest histopathological change in RP is a shortening of the photoreceptor outer segments. On the other hand, retinal layer becomes restored first at the ELM, followed by the IS/OS and finally the COST after macular hole surgery. There may be a directionality of photoreceptor impairment or restoration on optical coherence tomographic image.

Three highly reflective lines in the outer retina, which are the ELM, IS/OS and COST, can serve as hallmarks for the evaluation of photoreceptor condition. In RP patients, the ELM, IS/OS, and COST lines are shortened with the progression of the disease. The shortening of the ELM, IS/OS, and COST lines is significantly associated with each other. In each eye, the line length was longest in the ELM, followed by the IS/OS, and COST, suggesting that retinal layer becomes disorganized first at the COST line, followed by the IS/OS line and finally the ELM line [9]. On the other hand, retinal layer becomes restored first at the ELM, followed by the IS/OS and finally the COST after MH surgery. Taken together, there may be a directionality of the photoreceptor impairment or restoration on OCT image. Further studies with the use of high-resolution images of OCT should lead to understanding a more precise process of the photoreceptor impairment or restoration in various retinal diseases.

Automatic segmentation of the layers in the outer retina can be challenging for the following two reasons. First, the layers are often indiscernible due to the limited resolution of the eye's optics and the OCT system [7]. Second, layers may deteriorate as a result of a disease

Developed a cluster based approach to detect the"proper number of layers to be segmented "in retinas of healthy and glaucoma subjects. Based on the detected visibility the data was placed into three groups with either 6, 7 or 12 interfaces between the retinal layers. In the first step, the pixels/voxels are grouped in rectangular/cubic sets to form a graph node. The weights of the graph are calculated based on geometric distance between pixels/voxels and differences of their mean intensity. The first diffusion map clusters the data into three parts, the second of which is the area of interest. The other two sections are eliminated from the remaining calculations. In the second step, the remaining area is subjected to another diffusion map assessment and the internal layers are localized based on their textural similarities. The method is based on the application of two sequential diffusion maps, first of which segments the ILM-to-RPE complex and reduces the data to the region between these two layers. The

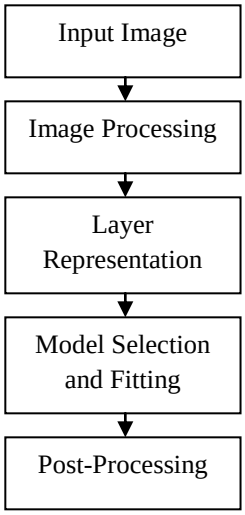
second map then localizes the internal layers between the ILM and the RPE complexes.

3 PROPOSED SYSTEM

Several processing steps are performed to segment the layers in the outer retina: pre-processing, fitting the candidate models, model selection and layer identification. First, the preprocessing step detects the region of interest (the location of the outer retina). Second, the parameters of the various models for the outer retina are calculated for every A-line by using MLE. Third, the model selection procedure based on ICOMPR is applied to select the model best supported by the data. Fourth, the labels are assigned to the detected layers.

The raw OCT data is converted to attenuation coefficients after which the loosely coupled level sets (LCLS) frame work is applied to the converted data to detect the location of the outer retina. Then each of the layers in the outer retina is modeled as a Gaussian function. The model parameters for each model were estimated by maximizing the likelihood function. To improve spatial consistency of the segmented layers, a post processing step specific for eyes affected by RP is applied.

Overall Flowchart:

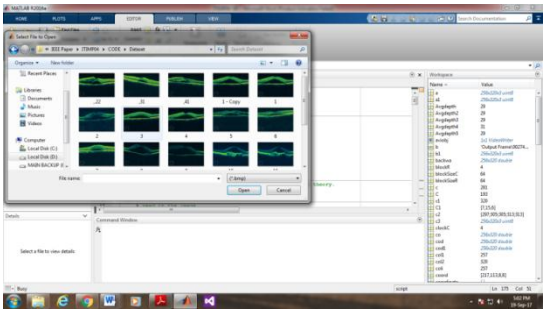


ADVANTAGE:

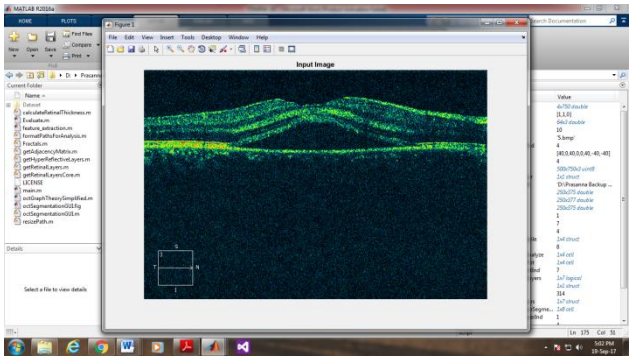
- Provides a flexible and accurate solution to the outer retinal layer segmentation.
- Provide accuracy nearer to manual segmentation.

4. RESULTS

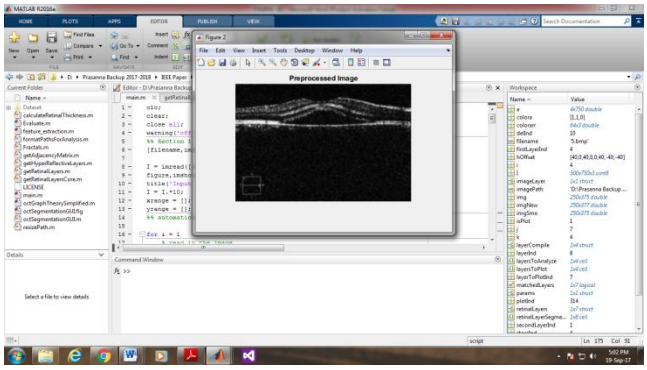
1. Selecting image:



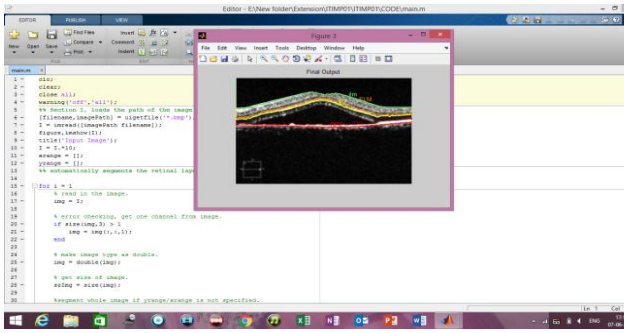
2. Input image:



3. Preprocessed image:



4. Output:



CONCLUSION

This paper presents a method to simultaneously determinethe number of visible layers in the outer retina and segmentsthem. The method is based on a model selection approachwith special attention given to balance the quality of a fit withmodel complexity. As such, the model selection procedure ensuresthat a more complex model is selected only if sufficientlysupported by the data. The approach is able to cope with layersthat may or may not be present within an image and providesnot only the number of visible layers, but also their positionand identification.

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