Retinal Layer Segmentation on OCT-Volume Scans of Normal and Glaucomatous Eyes

M.A. Mayer[1,2], J. Hornegger[1,2], C. Y. Mardin[3], R.P. Tornow[3]
[1]Pattern Recognition Lab, Department of Computer Science, [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), [3] Department of Ophthalmology
Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany
markus.mayer@informatik.uni-erlangen.de

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Friedrich-Alexander-Universität Erlangen-Nürnberg

Purpose

To segment the retinal layers, especially the retinal nerve fiber layer (RNFL), on OCT-volume scans of normal subjects and glaucoma patients.

Method: Data

- Optic nerve head (ONH) centered volume scans acquired by Spectralis OCT (Heidelberg Engineering).
- Volume scans consist of 49 to 97 B-Scans.
- B-Scan resolution is 384 to 512 pixels in transversal direction and 496 pixels in axial direction.
- Subjects: 3 healthy subjects, 7 glaucoma patients, one eye each.

Method: System

Preprocessing of the volume: The speckle noise of the volume data is reduced by weighted averaging in the 3D space. The subsequent segmentation steps are performed on the individual B-Scans.

Segmentation steps: 6 prominent layers are segmented in the order shown in Fig. 1. The search space for the boundaries is decreased by each step.

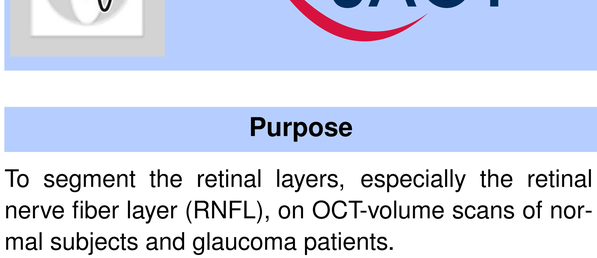

Figure 1: (a) Segmentation steps. (b) B-Scan to visualize the order and position of the boundaries. Blue: retinal pigment epithelium (RPE); red: inner limiting membrane (ILM); yellow: outer nuclear layer (ONL); green: outer plexiform layer (OPL); orange: inner plexiform layer (IPL); cyan: outer nerve fiber layer boundary (ONFL).

Segmentation of the layers: The retinal pigment epithelium (RPE), the outer nuclear layer (ONL), the outer plexiform layer (OPL), the inner plexiform layer (IPL), and the inner limiting membrane (ILM) are determined by the same algorithm (see Fig. 2):

- The B-Scan is denoised by median filtering.
- An edge detection that takes the second derivative into account generates a initial segmentation.
- Using RANSAC (a model fitting method), a polynomial of degree 5 is fitted through the initial segmentation.
- The error measurement used for optimizing the model fit in RANSAC is the L1 norm of the column wise distance between the initial segmentation and the polynomial.
- The points on the initial segmentation that exceed a certain distance from the polynomial are replaced by the points of the polynomial. The distance treshold is dependent on the currently segmented boundary.
- Blood vessel regions are linearly interpolated.

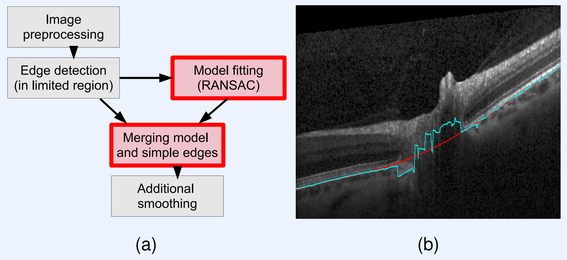

Figure 2: (a) Segmentation algorithm for the layers. (b) Example B-Scan: Edge detection result for the RPE (blue). RANSAC fitted polynom with L1 norm as error measurement (red).

Segmentation of the ONFL: The B-Scan is denoised by complex diffusion. The outer nerve fiber layer boundary (ONFL) is identified in between the IPL and the ILM using an energy minimization approach (see [1]) that takes the local gradient as well as local smoothness into account.

Postprocessing: A median filtering of the layer boundaries in the 3D space of the volume yields the final results.

Method: Evaluation

- **Manual correction** of all layer segmentations on all B-Scans of the 10 volume data sets.
- **RNFL thickness maps** were calculated from both the automated segmentations as well as the manually corrected ones.
- **Segmentation error**: The percentage of the scan area with an absolute thickness deviation of the two thickness maps of more than $10\mu m$.
- An area around the ONH center with a diameter of 1 mm was excluded from the evaluation.

Results

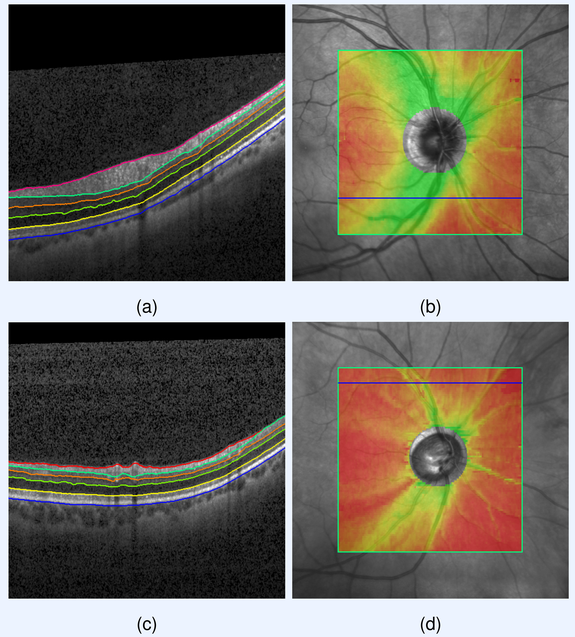

Figure 3: Example segmentation results: (a) B-Scan out of a volume scan of a normal subject. The automated layer segmentations are drawn. (b) Corresponding RNFL thickness map of the normal subject. The position of the B-Scan in a) is marked. (c) B-Scan out of a volume scan of a glaucoma patient. (d) Corresponding thickness map to (c). Color code of the thickness map: Pure green (thick RNFL $> 150\ \mu m$), pure yellow (RNFL $= 75\ \mu m$), red (thin RNFL).

The average segmentation error on glaucoma patients is 11.0% compared to 4.4% on normal subjects. Fig. 3 shows example segmentation results.

OCTSEG

The segmetations as well as the visualizations within this work were generated with OCTSEG (Optical Coherence Tomography Segmentation and Evaluation GUI). OCTSEG is a graphical user interface (GUI) written in Matlab to segment retinal OCT data. Its main features are:

- Segmentation of circular scans as well as ONH centered volume scans, acquired with a Spectralis OCT.
- Segmentation of 6 prominent retinal layers, the blood vessel positions, and the ONH position.
- An intuitive interface for a manual segmentation correction.
- Visualization of Spectralis RAW data (.vol ending) and the segmentation results. Various visualizations (en-face views, thickness maps) are available.
- Export of the results to the common CSV format.

A compiled version of OCTSEG for Windows can be downloaded at **www5.informatik.uni-erlangen.de** under the item 'Free Software'. The software is still under development and for research purposes only.

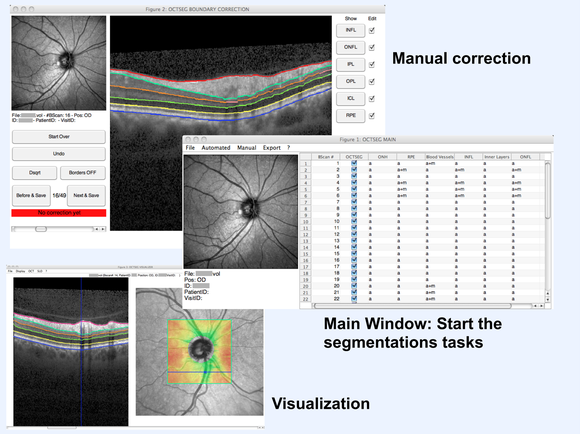

Figure 4: Screenshots of the OCTSEG GUI.

Conclusion

The proposed algorithm allows for an accurate segmentation of the retinal layers on OCT-volumes. Normal as well as pathologic data can be segmented with high accuracy.

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Commercial Relationship

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References

[1] M.A. Mayer, J Hornegger, C.Y. Mardin, R.P. Tornow: Retinal Nerve Fiber Layer Segmentation on FD-OCT Scans of Normal Subjects and Glaucoma Patients, Biomedical Optics Express, Vol. 1(5), pp. 1358-1383, 2010