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Visually Analyzing Parameter Influence on Optical Coherence Tomography Data in Ophthalmology

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Abstract

Optical coherence tomography (OCT) enables noninvasive high-resolution imaging of the human retina and therefore, plays a fundamental role in detecting a wide range of ocular diseases. Yet, OCT data often vary in quality and show strong parameter dependencies. We propose a visual analysis approach to support users in understanding the influence of parameters on different aspects of the data. First, we outline the problem scope and derive requirements for a visual parameter analysis of OCT data. Second, we devise matched visual designs that disclose the impact of specific parameter values and the relationships between multiple parameter settings. With our systematic approach we aim at helping users in choosing suitable parameter settings and finding a balance between acquisition effort and data quality.

Categories and Subject Descriptors (according to ACM CCS): Human-centered computing – Visualization – Visualization application domains – Visual analytics

1. Introduction

Optical coherence tomography (OCT) is a widely applied method to support the medical diagnosis of various ocular diseases. Based on high-resolution 3D imaging, ophthalmologists can search for subtle and localized retinal changes. For this purpose, they have to analyze three main aspects of OCT data: (i) the raw volume data, (ii) extracted retinal layers, and (iii) derived layer attributes. Yet, the ability to interpret those aspects and to identify inherent patterns is highly dependent on the data quality. Particularly in the acquisition process, different parameters do not only influence the OCT outcome but also affect the time and effort required to perform an OCT scan. So, to facilitate the assessment of abnormal conditions of the retina, it is vital to understand the influence of these parameters on the three main aspects and to be able to adjust the parameters to obtain OCT data of sufficient quality and with reasonable effort.

An open problem is the lacking support to choose suitable parametrizations. Due to the large range of parameter options, individually inspecting multiple parametrizations and related OCT data is cumbersome. Moreover, it does not allow for a comparison of parametrizations to explore parameters' influence. Existing works in the field of visual parameter space analysis [SHB*14] offer different approaches for specific data types. Examples are volume data [HBG11, BAAK*13], extracted geometry [vLBK*13, SPA*14], or attribute maps [PWB*09]. Our goal is to develop an integrated visual analysis approach that supports relating parameter influence to all three aspects of OCT data in combination.

2. Problem

OCT-based imaging captures the structure of the multi-layered retina and provides detail and contrast images with high spatial resolution. Typical OCT datasets contain one 3D tomogram composed of hundreds of 2D image slices, up to 11 extracted layers [EWF*14], various derived layer attributes (e.g., thickness maps), and one fundus image of the interior surface of the eye.

During image acquisition, the operator of the OCT device has to set several parameters that greatly influence the data quality. Examples are the scan area (position, size, orientation), the scan density (resolution and number of slice images), and on the fly noise reduction (number of averaged slice images). Yet, the influence of the parameters is often not known beforehand. This is because not only the raw volume data, but also the subsequently extracted layers, and the derived layer attributes are affected by parameter changes.

For ophthalmologists, datasets acquired with maximized parameter values, i.e., large scan area, high scan density, and good noise reduction, are preferable, as they increase the chance to detect local variations. However, such parametrizations significantly increase the time and effort required for conducting OCT scans. This causes strain for the scanned patient and the device operator, as the scan image has be continuously kept aligned and in focus to prevent image artifacts [YH14]. Hence, it is important to understand the parameters' influence on all three data aspects and in this way, help operators in setting parametrizations that offer a balance between image quality and acquisition effort in clinical practice.

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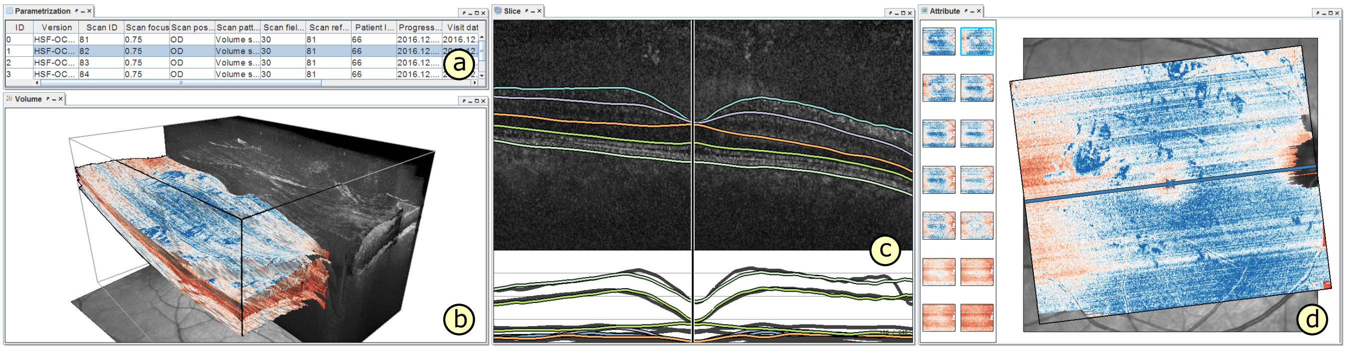

Figure 1: *Overview of our visualization tool. The user interface shows multiple linked views for analyzing parameter influence on OCT data: (a) a parametrization view, (b) a 3D tomogram view, (c) a 2D slice image view with extracted layers, and (d) a view for derived attributes.*

3. Approach

We aim at visually communicating the influence of acquisition parameters. Particularly, we want to identify parametrizations with suitable data quality and low scanning effort. To this end, our approach consists of two parts: (i) a systematic parameter sweep and (ii) a visual analysis of respectively acquired OCT datasets.

Parameter sweep: The parameter sweep includes three steps. First, we specify one parametrization as a reference. This reference represents OCT data of desired image quality but impractical acquisition effort, i.e., by maximizing all parameter values. Second, a set of alternative parametrizations is determined. These parametrizations represent OCT data of varied quality and reduced acquisition effort, i.e., by degrading the parameter values step by step. Third, one OCT dataset is acquired for the reference and for each alternative parametrizations.

According to these three steps, we analyzed the OCT manufacturer provided parameter options together with domain experts. Three acquisition parameters and 48 associated parametrizations were deemed immediately relevant. The respective OCT data are acquired in an ongoing experimental study with four subjects.

Visual analysis: For analyzing parameter influence on OCT data, we derived three requirements for the visualization design: (R_1) all three aspects of OCT data have to be visualized, (R_2) alternative and reference parametrizations have to be visually related, and (R_3) interactive exploration of multiple parametrizations has to be supported. To match these requirements, we propose a flexible visualization tool based on multiple coordinated views (Fig. 1).

To visualize the parametrizations together with the three aspects of OCT data, we support four types of views: (i) a parametrization view, (ii) a 3D tomogram view, (iii) a 2D slice image view, and (iv) a view for derived attribute maps (R_1). Each view encodes the deviations between alternative and reference parametrizations (R_2). Visually comparing these deviations is supported via a combination of juxtaposition, superposition, and explicit encoding [GAW*11].

The *parametrization view* shows an overview of the reference and all alternative parametrizations together with the respective parameter values in a table. The *3D tomogram view*, explicitly encodes deviations of the raw OCT data via direct volume rendering. Different composition modes help to find specific data characteristics, e.g., areas of low or high deviation via minimum or maximum intensity projection. Extracted retinal layers are shown as surfaces with deviations color-coded (positive: red, negative: blue [HB03]). The *2D slice image view* depicts deviations of the raw data for individual slice images. Extracted layers and derived layer attributes are encoded as superimposed lines on top of the slice images and in a detail chart. Grayscale lines represent the reference parametrization. The *attribute view* shows derived attribute maps as juxtaposed thumbnails on the side, ordered by their similarity. Deviations are color-coded. The thumbnails can be enlarged over a fundus image.

The visualization tool allows to dynamically add and arrange instances of the four views in the user interface. Using the parametrization view, listed parametrizations can be selected and assigned to any other view instance via drag and drop. Those view instances then either show the respective OCT data directly or deviations to a reference. This allows to quickly switch between parametrizations. To compare several parametrizations at once, multiple view instances for one data aspect can be created, juxtaposed, and accordingly assigned (R_3). Linking the view instances ensures that the same parts of the data are shown during navigation, e.g., zooming and panning. In the same way, equal parametrizations of different subjects can be compared. Relating the shown data back to the selected parametrizations is supported via special highlighting colors.

4. Conclusion

The presented visual analysis approach is a first step towards supporting the understanding of parameter influence on the three aspects of OCT data. Our tool is currently tested by domain experts. They were already able to judge up to what point a stronger noise reduction results in noticeable differences in the data, and in what way the layer extraction and the attribute derivation are affected.

So far, we focused on analyzing acquisition parameters. In future work, we will also consider parameter influence of the OCT data processing stages, e.g., layer extraction and attribute derivation. This entails integrating further suitable automated, visual, and interactive means to support larger numbers of parameters.

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