VU VRIJE UNIVERSITEIT AMSTERDAM

# VU Research Portal

## Imaging the structure and the movement of the retina with scanning light ophthalmoscopy

Vienola, K.V.

2018

***document version***
Publisher's PDF, also known as Version of record

**Link to publication in VU Research Portal**

***citation for published version (APA)***
Vienola, K. V. (2018). *Imaging the structure and the movement of the retina with scanning light ophthalmoscopy*. [PhD-Thesis - Research and graduation internal, Vrije Universiteit Amsterdam].

**General rights**
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

**Take down policy**
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

**E-mail address:**
**vuresearchportal.ub@vu.nl**

Download date: 17. Jun. 2025

# 7 Summary

## Imaging the structure and the movement of the retina with scanning light ophthalmoscopy

In this thesis the focus was to develop retinal imaging systems that were capable of imaging the posterior part of the eye fast enough to be able to detect the natural motion of the eye that occurs during fixation process. When these movements are detected fast enough with a scanning light ophthalmoscope (SLO), eye tracking capabilities can be achieved. Active eye tracking can be used as an auxiliary device in other imaging modalities that are vulnerable to eye motion artifacts due to long data acquisition times, such as optical coherence tomography (OCT). Especially OCT angiography (OCTA) is very sensitive to eye motion and in order to produce clinically relevant data to doctors, the data has to be reproducible and accurate in order to have a good diagnosis for the patient. However it is not just the clinical systems that can benefit from the eye tracking but also systems that cannot currently be used for retinal imaging due to extremely long acquisition times such as Raman spectroscopy and two-photon microscopy.

**Chapter 1** provides a general introduction to the topic at hand, starting from the structure of the human eye, and then explaining what the fixational eye movements

are and why do they occur. Lastly, a historical overview of the visualization of the retina is given, starting from the first fundus drawing to the modern fundus photos. The introductory part continues in **chapter 2**, where the principles of different SLO techniques and the theory of OCT are explained in detail. Additionally the reader is introduced to how the fixational eye movements can be detected from the two-dimensional (2D) images of the retina. And finally, as we are dealing with unnatural exposures of light to the eye, laser safety calculations are explained in detail to ensure the reader of the safety of the built devices. These two chapters will provide the necessary background for the science presented in rest of the chapters.

OCT imaging is known to have eye motion artifacts due to acquisition time of several seconds when considering volume scans. In **chapter 3** a tracking SLO (TSLO) was optically coupled with an optical frequency domain imaging (OFDI) system to simultaneously image the retina with two separate systems. The TSLO imaged the retina faster than the OFDI system, and was able to stabilize the OCT imaging in real-time. The TSLO detected the motion from the acquired 2D images and delivered a correction signal to the OCT's galvo mirrors up to a speed of 32 Hz. Residual motion artifacts in the OCT B-scans were reduced to 0.32 minutes of arc (1.6 µm) in an *in vivo* human eye and this made possible the acquisition of high quality images from the optic nerve head and lamina cribrosa pore structure.

To improve from the results obtained with the TSLO, a novel ophthalmoscope was built in **chapter 4** that was designed based on a digital micro-mirror device (DMD). By uploading parallel line patterns to the DMD, structured illumination was created. The retina was illuminated using up to seven parallel lines, which were projected at 100 Hz. The DMD offered a high degree of parallelism in illuminating the retina compared to traditional SLO systems utilizing scanning mirrors. To demonstrate the imaging capabilities of the system, the macula and the optic nerve head of a healthy volunteer were imaged. Confocal images show good contrast and lateral resolution with a $10^\circ \times 10^\circ$ field of view. This system was then improved and 2nd generation system was built using the same principle, with few exceptions. The illumination pattern was changed to concentric circles and the illumination scheme included an annulus to prevent strong illumination of the cornea which minimized the corneal back reflections causing the background signal decrease significantly.

By using the image data from the 2nd generation DMD-based ophthalmoscope, fixational eye movements were detected in **chapter 5**. First a full confocal image was acquired to serve as a reference frame for the motion. Then the subsampled frames were used to detect the retinal motion within the camera integration time. A model eye was built to test the performance of the motion detection algorithm and *in vivo* traces were shown from a healthy volunteer. Furthermore, it was possible to correct the subsampled frames for the motion and produce motion-corrected confocal im-

ages. This allowed easy averaging of images to produce high-quality image of the retina.

**Chapter 6** discusses the important elements for successful eye tracking and what can be done to improve it further in the future. Especial attention was given to the field programmable gate arrays (FPGAs) as they are the key to then decrease the system latency. By minimizing the calculation time of the motion trace, it is possible to increase the tracking bandwidth. Additionally, the chapter discusses the accuracy of the motion detection as it is also important to detect the motion accurately as it is detecting it fast. Finally, new opportunities for eye tracking is presented, which include technologies that can be brought to the ophthalmology and which would not be possible to do *in vivo* without eye tracking.