

VU Research Portal

Structural and spectroscopic in vivo imaging of the human retina with scanning light ophthalmoscopy

Damodaran, M.

2020

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Damodaran, M. (2020). *Structural and spectroscopic in vivo imaging of the human 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

Contents

1	General introduction	1
1.1	Human eye: anatomy and physiology	2
1.1.1	Blood supply to the retina	7
1.1.2	Common retinal pathologies	9
1.2	Retinal imaging techniques	12
1.2.1	Fundus photography	13
1.2.2	Scanning Laser Ophthalmoscope	15
1.2.3	Optical Coherence Tomography	15
1.3	Thesis aim and outline	16
	References	18
2	Principles of retinal imaging and retinal oximetry	23
2.1	Retinal imaging by scanning	24
2.1.1	Line scanning	26
2.1.2	Digital micromirror devices	28
2.2	Retinal imaging — optical considerations, laser safety and wavelength ranges	30
2.2.1	Optical considerations	30
2.2.2	Laser Safety considerations in retinal imaging	32
2.2.3	Light sources and signal to noise estimation	36
2.3	Retinal Oximetry	38
2.3.1	Retinal diseases and oxygenation	38
2.3.2	Evolution of retinal oximetry	39
2.3.3	Comparison of oximetry techniques	40
	References	44
3	Digital micromirror device based ophthalmoscope	49
3.1	Introduction	50
3.2	Methods	51
3.2.1	Optical system	52
3.2.2	Annular illumination on the pupil plane and retinal resolution	54
3.2.3	Parallel scanning method	55
3.2.4	Confocal image processing using virtual pinholes	56
3.2.5	Model eye measurements to evaluate SNR improvement	57
3.2.6	<i>In vivo</i> retinal imaging	60
3.3	Results	60
3.3.1	Model eye measurements to evaluate SNR improvement	60

3.3.2	<i>In vivo</i> retinal images	62
3.4	Discussion	66
3.5	Application: Fixational eye motion detection	67
3.6	Conclusion	69
	References	71
4	Optimal wavelengths for sub-diffuse scanning laser oximetry	75
4.1	Introduction	76
4.2	Theory of retinal oximetry and identifying optimum wavelengths	79
4.2.1	Theory of retinal oximetry	79
4.3	Experimental validation	93
4.3.1	Scanning Laser Ophthalmoscope - description of the system	93
4.3.2	Measurements in model eye using a retina mimicking phantom	93
4.3.3	Estimating vessel diameter from the images	96
4.3.4	Experimental Results with retinal phantoms	98
4.4	Discussion	101
4.5	Conclusions	105
	References	106
5	sub-diffuse scanning laser oximetry of the human retina <i>in vivo</i>	111
5.1	Introduction	112
5.2	Methods	113
5.2.1	Wavelength selection for dual wavelength retinal oximetry	113
5.2.2	System design	116
5.2.3	Balanced detection to increase the signal-to-noise ratio	120
5.2.4	Wavelength sweep hyperspectral imaging	121
5.2.5	<i>in vivo</i> human measurements	123
5.2.6	Retinal vessel segmentation and oxygenation map	123
5.3	Results and discussion	124
5.3.1	Technical aspects regarding multispectral SLO with an SC source	124
5.3.2	<i>in vivo</i> two wavelength oximetry	128
5.3.3	Wavelength sweep hyperspectral imaging	128
5.4	Conclusion	136
	References	138
6	Non-invasive optical measurement of haemoglobin concentration in the posterior eye of adult humans	143
6.1	Introduction	144
6.2	Methods	147
6.3	Results and discussion	151
6.4	Conclusion	153
	References	155
7	Discussion and outlook	157
7.1	Background	158
7.2	Digital micromirror based SLO	158
7.3	Quantitative retinal imaging	160
7.3.1	Retinal oximetry	160

7.3.2	Retinal haemoglobin concentration	162
7.4	Future directions	163
7.5	Thesis conclusion	165
	References	166
8	Summary	169
9	Curriculum Vitae	177
10	Acknowledgements	181