Whole anterior segment / retinal SS-OCT system for comprehensive imaging and biometry of the eye

Ana Rodríguez-Aramendía[1,2], Fernando Díaz-Doutón[2], Pol Falgueras[2], Jaume Pujol[2], José Luis Güell[1], Ireneusz Grulkowski[3].

[1]*Instituto de Microcirugía Ocular, Barcelona, Spain*
[2]*Center for Sensors, Instruments and Systems Development, Universitat Politècnica de Catalunya, Barcelona, Spain*
[3]*Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Torun, Torun, Poland*

Whole eye visualization and morphometry are of utmost importance and relevance in the clinical practice. Due to its noninvasiveness and ability to generate cross-sectional and volumetric data sets with micrometer resolution, OCT is a great candidate in the quest for whole eye imaging and biometry by using only one instrument. However, OCT imaging with wide field of view (FOV) of the anterior and posterior segments of the eye poses important challenges. Different strategies have been proposed to assess them. These include the use of tunable lens technology to dynamically change the focus position along the ocular structures [1], the use of extended coherence length VCSEL sources [2], the use of dual path configurations that avoid adapting the reference arm by using coherence revival [3] and can image both eye segments either simultaneously [4] (exploiting polarization multiplexing) or sequentially [5] (by mechanically flipping a set of mirrors) or interlaced detection schemes that require the use of two detectors [6].

In this paper, we describe a dual path SS-OCT instrument that sequentially images the whole anterior segment from corneal apex to posterior face of the lens and the retina using a single source and detector. The system is designed around a spectrally balanced interferometer using a short cavity swept laser (Axsun Technologies) sweeping at a rate of 50 kHz and centered at 1050 nm with 100 nm bandwidth. The sample arm features a dual path configuration that permits to change from the anterior segment to the retinal modality by means of a flip mirror in a novel configuration. A diagram of the system is shown in Fig. 1.

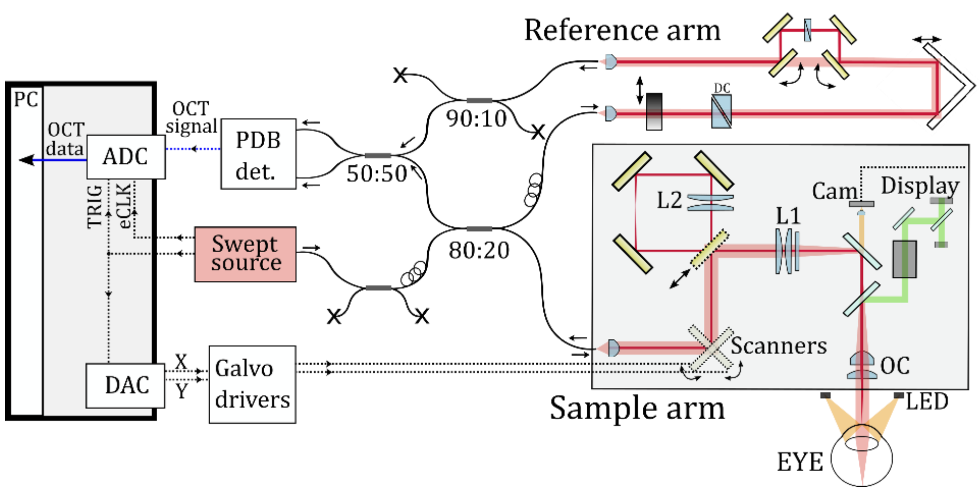

Figure 1. Schematic of the whole anterior segment / retina SS-OCT system.

The anterior segment modality exhibits a depth of focus of 4.10 mm, lateral resolution of 26 µm and 13 x 13 mm FOV. In the posterior segment imaging modality the diffraction-limited optical design yields a lateral resolution of 12 µm and a 21º FOV with respect to the nodal point of the eye. A high speed digitizer (Alazar Technologies) alternates between an externally clocked acquisition optimized for retinal imaging and a long image depth range acquisition with a fixed-interval sampling rate of 0.8 GS/s for whole anterior segment imaging. This high speed digitization combined with the extended coherence length of the source and the long depth of focus illumination permits to image the whole anterior segment, from corneal apex to posterior face of the lens. The measured axial resolution is ca. 8 µm. A wide-field pupil imaging system, composed by an illumination ring of LEDs and a CMOS camera, aids patient alignment. The optical interfaces have been designed and optimized with optical simulation software (Zemax, Radiant Zemax

LLC) using off-the-shelf components and keeping a compact size (See Fig. 2). The system is compliant with the European norm for laser safety EN 60825-1:2007. In a preliminary validation of the system, a group of 20 healthy volunteers were imaged. An example of the operation of the system is shown in Fig. 3.

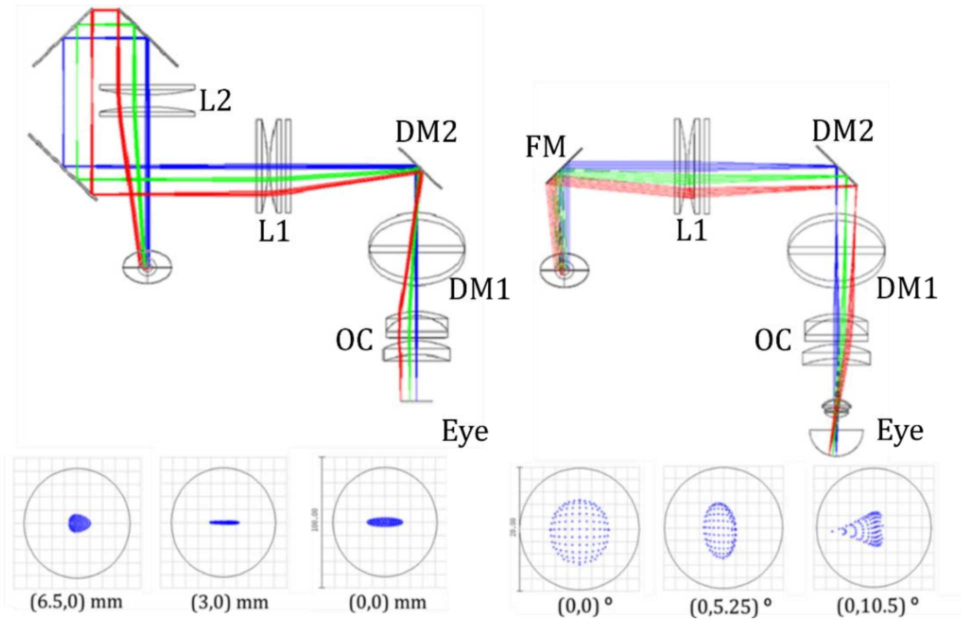

Figure 2. Anterior segment (left) and retinal (right) optical interfaces design. Spot diagrams for both interfaces, illustrating the diffraction-limited performance of the designs, are shown below. L1, L2, OC: lenses ensembles, DM1, DM2: dichroic mirrors, FM: flip mirror.

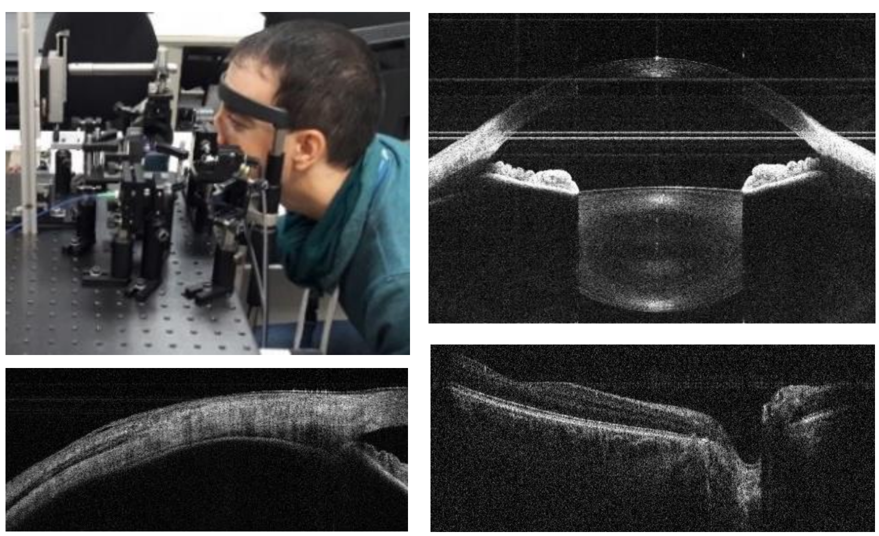

Figure 3. Healthy volunteer being imaged with the prototype. Single unaveraged images of the anterior segment (2000 Ascans/Bscan), retina (1500 Ascans/Bscan) and sclerocorneal limbus region (1500 Ascans/Bscan).

For the quantitative use of the OCT data sets acquired by the system, an image postprocessing algorithm has been developed. It allows for automatic segmentation of the corneal and lenticular anterior and posterior surfaces, which are subsequently corrected for optical distortion and fitted to aspheric curves. The iridocorneal region is also segmented and, after manual labelling of the scleral spurs, several parameters characterizing the amplitude of the angle can also be obtained. In this way, the developed algorithm permits to obtain a full set of biometric standard parameters of the anterior segment of the pacient, such as the corneal thickness, anterior chamber depth, lens thickness, radii of curvature, angle opening distance or the trabecular iris space area.

The prototype is currently undergoing a clinical study at an ophthalmic hospital (Instituto de Microcirugía Ocular, Barcelona). Subjects are imaged with the developed prototype and with other imaging modalities that have similar visualization capabilities and permit to obtain, partially, the same biometric parameters. The study's aim is to compare the developed system with standard commercial instruments and validate its performance.

ACKNOWLEDGEMENTS

The study is supported by the European Union's Horizon 2020 research and innovation programme through the project Advanced Biomedical Optical Imaging and Data Analysis (BE-OPTICAL) Marie Skłodowska-Curie grant agreement No. 675512.

REFERENCES

1 Grulkowski, I. *et al.* Swept source optical coherence tomography and tunable lens technology for comprehensive imaging and biometry of the whole eye. *Optica* **5**, 52-59, (2018).

2 Grulkowski, I. Liu J.J., Potsaid B, Jayaraman V., Lu C. *et al*. Retinal, anterior segment and full eye imaging using ultrahigh speed swept source OCT with vertical-cavity surface emitting lasers, *Biomed. Opt. Express* **3**, 2733-2751 (2012).

3 Dhalla A., Nankivil D., Izatt J.A., Complex conjugate resolved heterodyne swept source optical coherence tomography using coherence revival, *Biomed. Opt. Express* **3**, 633-649 (2012).

4 McNabb R.P., Polans J., Keller B., *et al.* Wide-field whole eye OCT system with demonstration of quantitative retinal curvature estimation. *Biomed. Opt. Express* 10(1):338–355 (2018).

5 Nankivil D., Waterman G., LaRocca F., Keller B., Kuo A.N., Izatt J.A. Handheld, rapidly switchable, anterior/posterior segment swept source optical coherence tomography probe. *Biomed. Opt. Express*. 6(11):4516–4528 (2015).

6 Kim H.J., Kim M., Hyeon M.G., Choi Y., Kim B.M. Full ocular biometry through dual-depth whole-eye optical coherence tomography. *Biomed Opt Express* 9(2):360–372. (2018).