UCM PhDay Físicas 2022

Development of a low-cost and versatile whole-eye optical beam scanner for OCT

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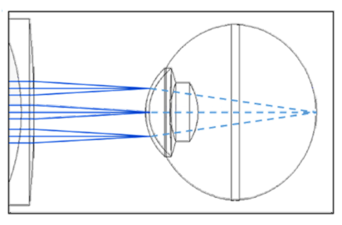
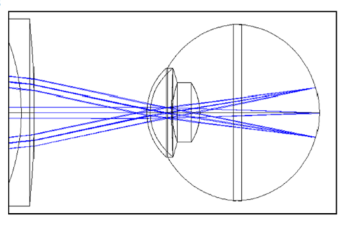
Background

- Conventional optical coherence tomography (OCT) systems have limited capability of performing a whole-eye scan. Different scanning configurations are required for imaging the anterior and posterior segment of the eye [1].
- Electrotuneable lenses (ETLs) are used for the design of non-mechanical and dynamically changing devices (beam expanders, steering systems, etc.)[2, 3, 4].

Anterior segment requires a telecentric scan



Posterior segment requires an angular scan



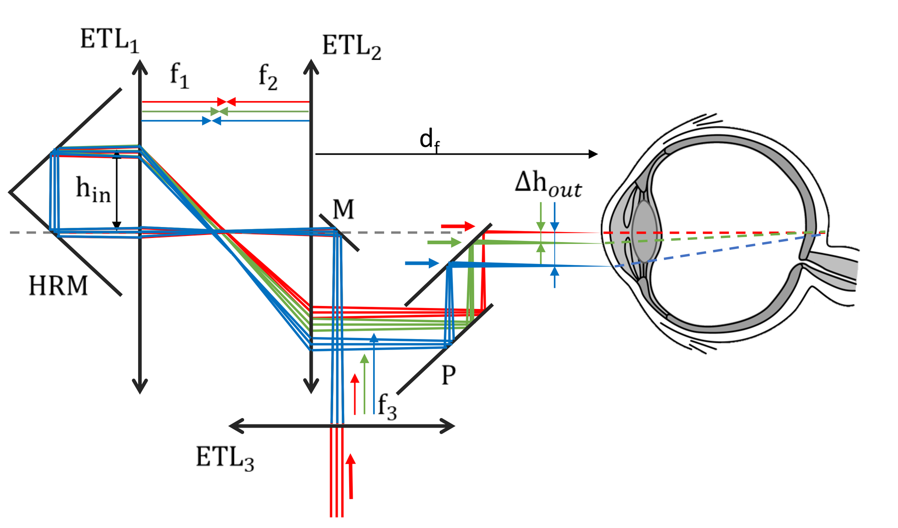
Purpose

Designing a novel whole-eye optical beam scanner:

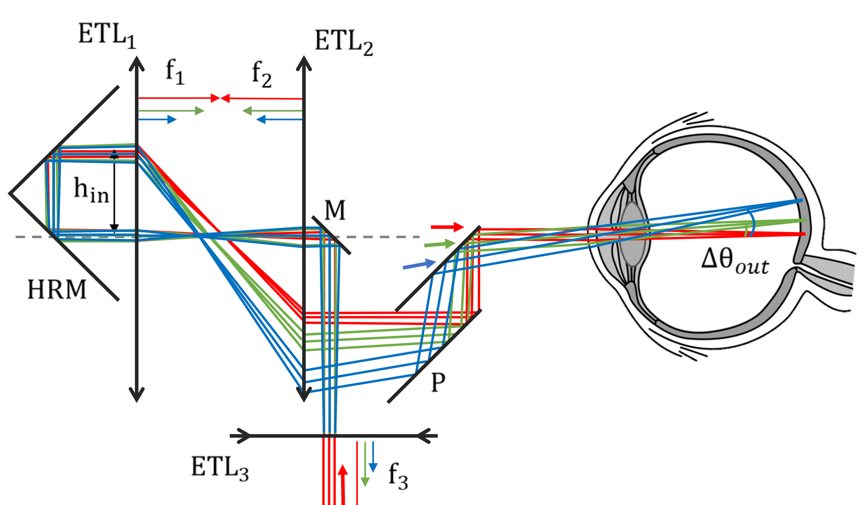
- Allowing for non-mechanical scanning the anterior and posterior eye segments.
- Allowing for non-mechanical switching between anterior and posterior eye imaging configurations.
- Reducing cost of standard beam scanners used in OCT.

Working principle

1. To select the direction of the output beam:
   - The input light beam must be at an offset h_{in} with respect to the optical axis of two collinear lenses ETL_1 and ETL_2.
   - f_1 and f_2 are set as a function of the desired transversal displacement h_{out} or the tilted angle θ_{out} using analytical equations deduced from the ABCD formalism.
2. To select the vergence of the output beam:
   - f_3 is set as a function of f_1 and f_2 and the desired focusing distance d_f to focus or collimate the output beam.
3. To minimize the transversal resolution variation during the scan:
   - A double pass configuration through ETL_1 and ETL_2 is implemented using a hollow-roof mirror (HRM).



Anterior Segment case → Telecentric scan
- Focused output beam
- h_{out} is varied
- θ_{out} is 0



Posterior Segment case → Angular scan
- Collimated output beam
- θ_{out} is varied
- h_{out} is varied as a f(θ_{out})

Scanner design and characterization

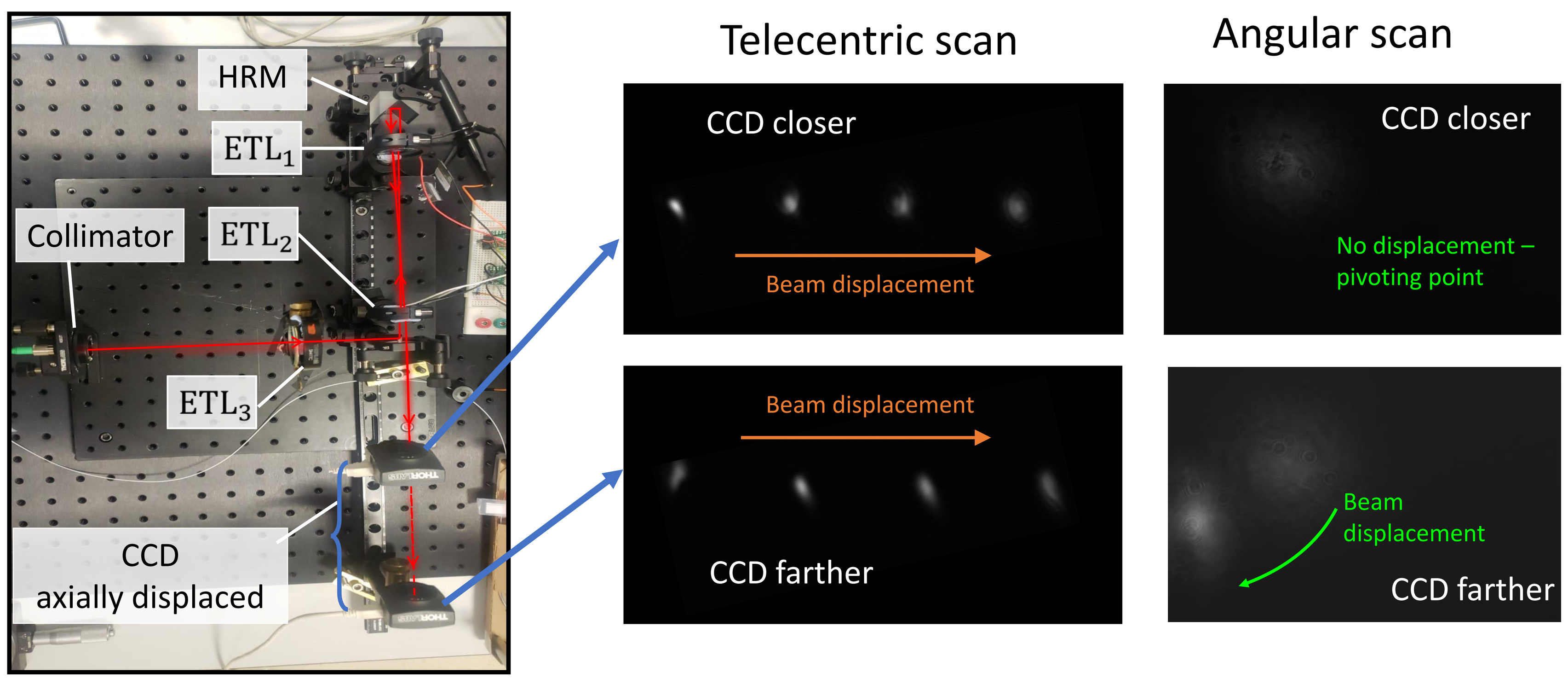
- Optical design: it was experimentally built with commercial components available on the market.

Optical beam scanner range	
Anterior segment scan	1.8 mm
Posterior segment scan	1.9º

List of components	Specifications
ETL_1, ETL_2	ϕ = 10mm Lens power: 8 to 20D
ETL_3	ϕ = 3mm Lens power: -13 to 10D
HRM	1"x1" prism mirror at 90º

Restricting parameters:
- Clear aperture of ETL_2
- Focal range of ETL_1

- Scanner characterization: a CCD was aligned in the sample plane and was axially displaced to analyze the telecentric and angular scan.



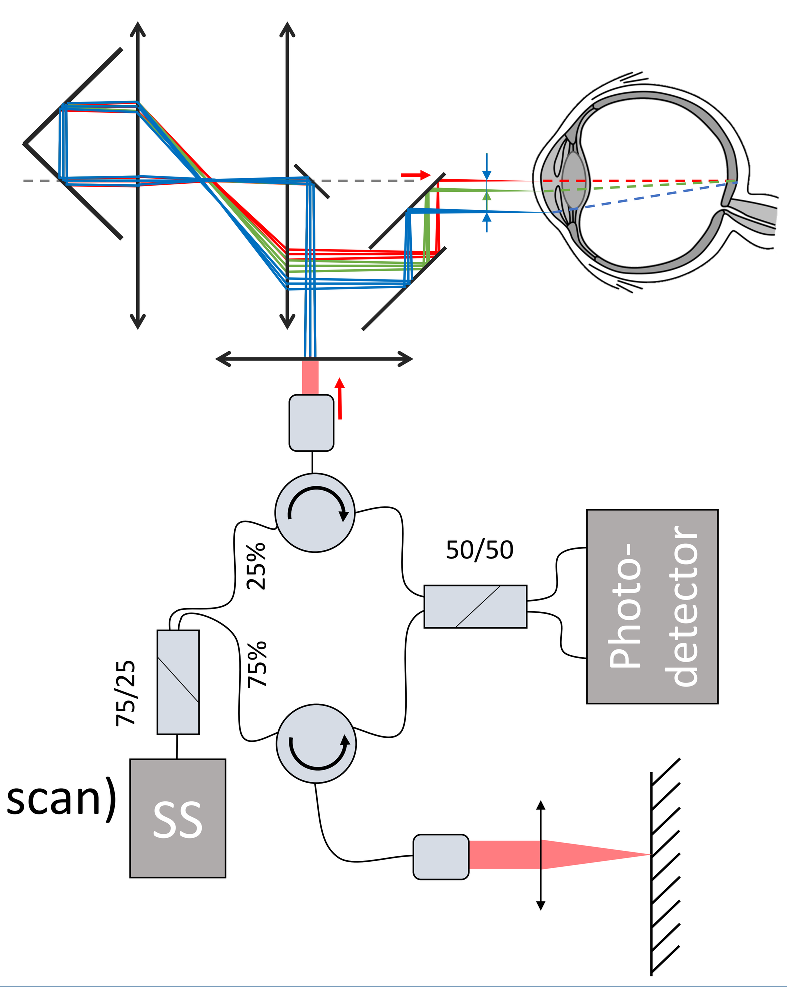
Setup: Custom SS-OCT

OCT System specifications:

- Swept source (SS): λ_c = 1060 nm
- Sweeping rate: 60 kHz
- A-scan period: 10 ms
- Axial resolution: 5 µm
- Axial pixel size: 6.8 µm

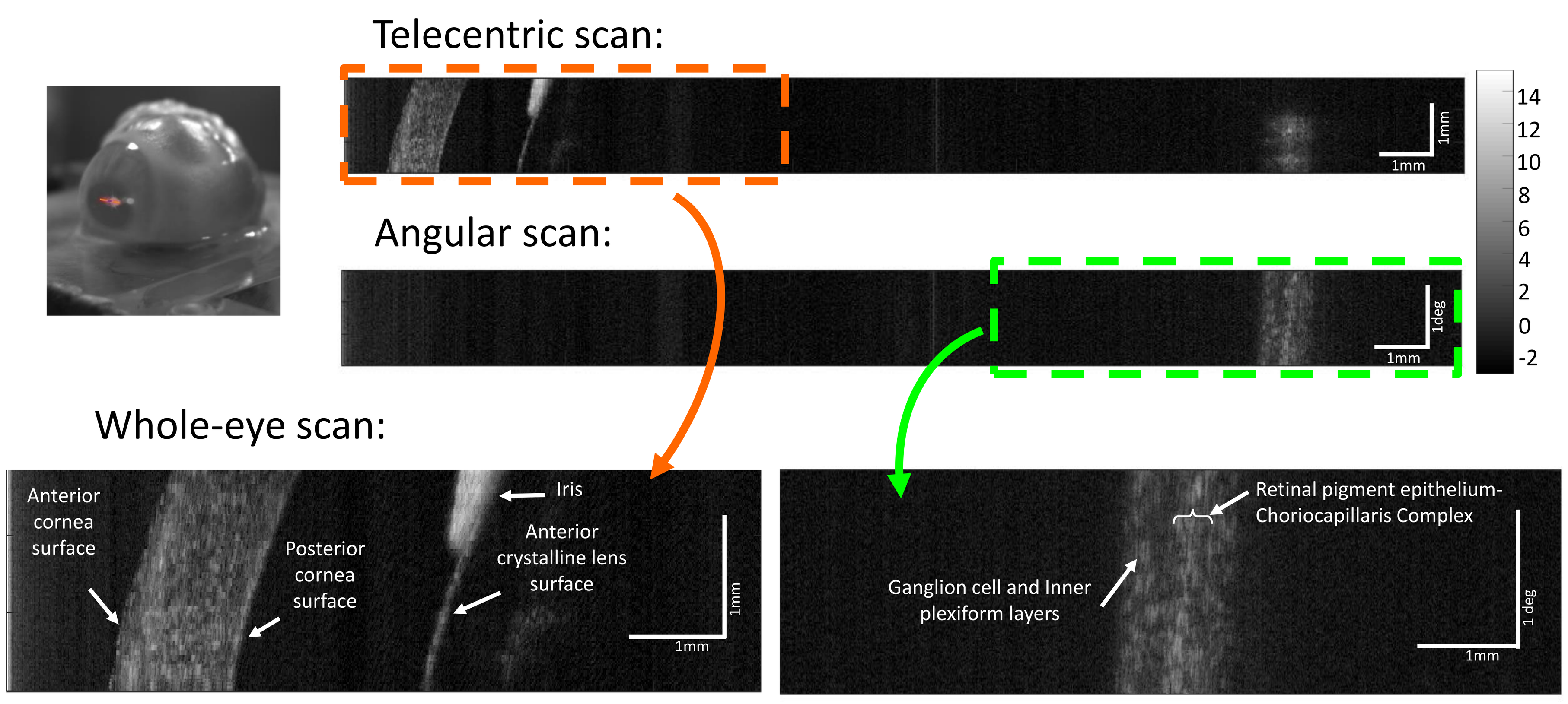
Imaging parameters:

- 120 A-scan x 100 B-scan (in place)
- B-scan period: 1.2 s
- Lateral resolution (theo.): 12µm (telec. scan)
- Lateral pixel size: 15 µm (telec. scan)



Experimental Results

Sample: ex-vivo rabbit eye



Conclusions

1. We designed an **optical beam scanner**, based on three electrotuneable lenses, that controls the **direction and vergence** of an output light beam **without employing any mechanically scanning component**.
2. We experimentally demonstrated the capability of **the optical beam scanner to perform whole-eye scans by non-mechanically switching the scanning configuration in sequence** for the anterior and posterior ocular segments.
3. Despite the **limited lateral range**, the OCT images show the potential of a software-reconfigurable optical beam scanner to perform **low-cost whole-eye scanning**.

References

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Commercial relationship:

Patent pending (EP22382246, AC MPU SM EG)

Funding: Comunidad de Madrid (IND2019/BMD-17262), Spanish Government PID2020-115191RB, International Research Agendas program MAB/2019/12