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Subject title

Patient-Specific 3D Eye Modeling and Tool Path Simulation for Ophthalmic Vitreoretinal Surgery Planning

Sections where the subject must be presented.

- EM - Robotics and Mechatronics
- Biomedical engineering

Subject longer description.

Patient-Specific 3D Eye Modeling and Tool Path Simulation for Vitreoretinal Surgery Planning

In ophthalmic surgeries such as vitrectomy or intravitreal injections, tool maneuvering inside the eye must be extremely precise to avoid damage to delicate structures like the retina. While robotic systems offer tremor elimination and sub-millimeter accuracy, surgeons lack clear feedback about where the tool tip is inside the eye, Figure 1. This problem becomes more complex as visualization during these procedures is limited to a narrow microscopic 2D field. This thesis proposes the development of a simulation-based solution that provides surgeons and researchers with a visual estimation of the tool path inside the eye. By combining pre-operative data such as OCT scans (cross section images of retina) and IOL Master biometry (axial length, white-to-white, anterior chamber depth), a patient-specific 3D model of the eye can be generated. Once the trocar is inserted and its position is tracked on the eye, this entry point becomes the pivot for simulating the internal trajectory of the surgical tool. This enables estimation of the tool tip location in real time and supports safer, more informed operations, Figure 2.

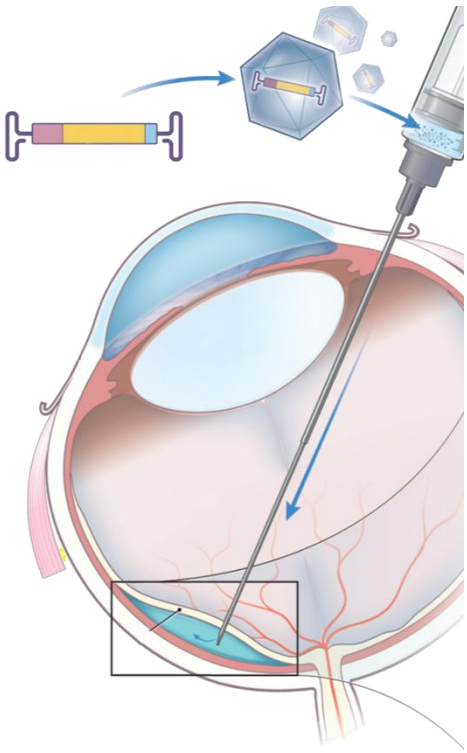

Figure 1: Sub-retinal injection. [Ref: nejm.org]

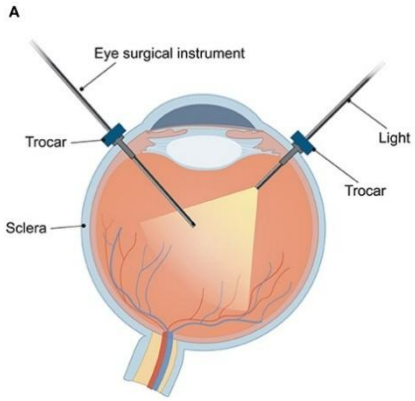

Figure 2: Vitrectomy surgery simplified workflow. [Ref: frontiersin.org]

Objectives:

3D Eye Model Generation: Develop an algorithm to generate a geometrically realistic 3D eye model from patient-specific inputs (image processing of OCT slices, IOL Master data).

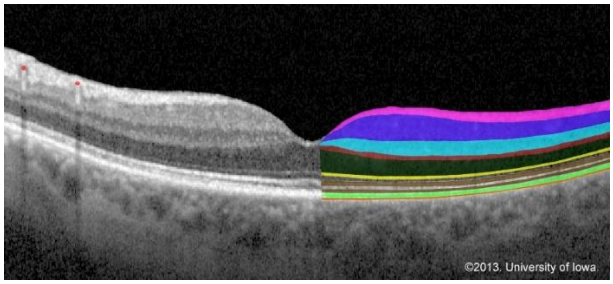

Figure 3: Oct image of retina. [Ref: Lowa University]

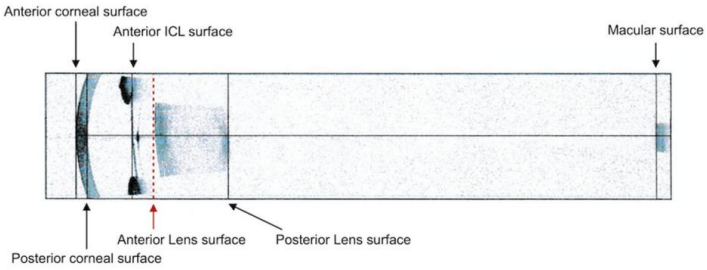

Figure 4: IOL image of eye biometrics. [Ref: Nature.com]

Tool Path Simulation: Implement a method to simulate the internal path of a surgical instrument inserted through a trocar, assuming pivoting around the scleral entry point.

Visualization & Surgeon Feedback: Build a user-friendly visualization layer that maps tool movement onto the virtual eye model. Validate clarity and usability with input from ophthalmic surgeons.

Research Phases:

Phase 1 (25%): Background study on eye anatomy, biometric measurements, and surgical workflow.

Phase 2 (45%): Development of the 3D eye model (Integration of biometric measurements and oct images) and simulation of tool motion around the trocar.

Phase 3 (30%): Visualization interface design and scenario simulation based on realistic clinical inputs.

Learning Outcomes:

The student will gain knowledge in image processing, 3D modeling, anatomical interpretation, and constrained tool kinematics. They will also build skills in Python programming, visualization libraries (e.g., VTK or PyVista), and simulation of minimally invasive tool motion. This project provides foundational insights into pre-operative planning tools for ophthalmic surgery and helps bridge the gap between clinical imaging and digital simulation.

This project will be conducted in collaboration with UZ Brussel hospital.

Interest and Contact:

Are you interested in contributing to this cutting-edge research in robotic assisted surgery, image processing, and 3D modeling?

Contact me at Amin.khorasani@vub.be for more information.