

STOC-T: From Early Concept to Prototype of New-Generation Noninvasive Volumetric Retinal and Corneal Imaging

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1. Introduction

Spatiotemporal optical coherence tomography (STOC-T) represents a groundbreaking modality designed for high-speed, volumetric imaging of biological tissues, enabling visualization without crosstalk and geometrical aberrations. STOC-T builds upon Fourier-domain holographic Optical Coherence Tomography by introducing spatial phase modulation, significantly reducing the spatial coherence of the tunable laser. This coherence reduction effectively suppresses coherent noise and enhances imaging depth, allowing detailed, previously inaccessible views of retinal and corneal structures such as photoreceptors, nerve fiber layers (NFL), and corneal endothelial cells.

STOC-T has been successfully utilized for high-resolution, noninvasive imaging of human eyes, demonstrating remarkable capabilities including rapid volumetric renderings of the retina, functional assessments of photoreceptors through optoretinography using targeted light stimulation, and visualization of blood flow via Doppler analysis and dynamic scattered light intensity measurements. Importantly, STOC-T allows comprehensive, full-thickness imaging of the retina.

These advancements trace back to the early conceptualization of manipulating spatial coherence through spatiotemporal modulation of light. Initially, full-field swept-source OCT (FF-SS-OCT), despite enabling high-speed imaging, faced significant limitations from crosstalk noise caused by spatially coherent laser sources, severely restricting transversal resolution and clinical applicability. To address this, we introduced a novel approach—spatiotemporal optical coherence (STOC)—using dynamically adjustable inhomogeneous phase masks to modulate spatial coherence. Later developments revealed that an active modulator could be effectively replaced by passive multimode fibers. These fibers naturally produce numerous unique interference patterns due to modal dispersion, which average out upon detection, greatly diminishing crosstalk.

In this presentation, I will outline our journey from the original idea of STOC manipulation to the development and realization of the STOC-T prototype, highlighting its current role in efficient, high-speed, and clinically relevant retinal and corneal imaging.

2. Methods and results

Fig. 1 illustrates the transition from an initial large, benchtop laboratory setup to our current compact and user-friendly STOC-T prototype. Initially, imaging required participants to be seated in uncomfortable positions due to the bulky equipment. The developed compact prototype now allows easy, comfortable imaging on a regular desk. Furthermore, an automated software interface simplifies the procedure, enabling individuals without specialized training to effectively perform imaging measurements.

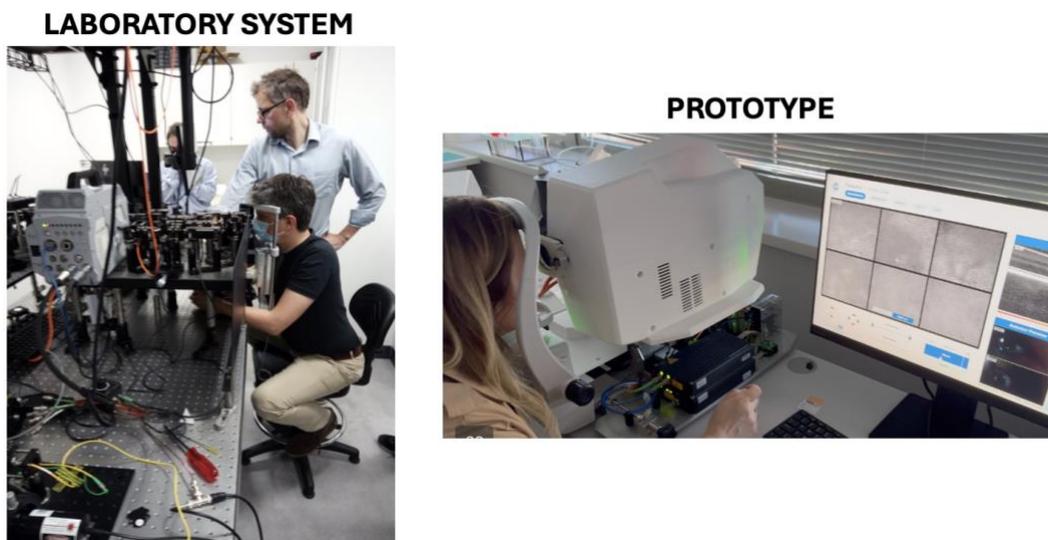


Fig. 1. From laboratory to a prototype system

Figure 2 presents retinal images acquired using the laboratory system, illustrating its capability for detailed ophthalmic imaging. The figure demonstrates wide-field en face views of the human retina, clearly capturing subtle anatomical features across different depths. Specifically, the images reveal intricate details within the inner limiting membrane (ILM) and nerve fiber layer (NFL), highlighting the clarity and contrast achievable with this approach. Additionally, photoreceptors in the inner segment/outer segment (IS/OS) junction are distinctly visualized, underscoring the system's sensitivity and high spatial resolution necessary for clinical analysis and diagnostics.

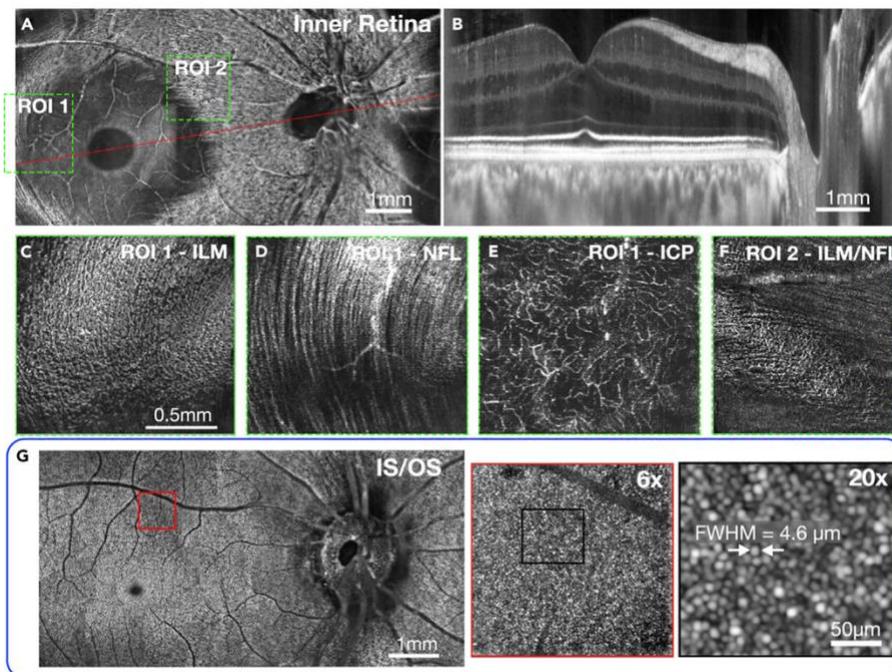


Fig. 2. Representational retinal images

Figure 3 depicts volumetric renderings of retinal images acquired using the prototype software. These renderings showcase the capability of the compact prototype to efficiently reconstruct detailed retinal structures in three dimensions. The images highlight the software's ability to clearly visualize retinal layers and anatomical features, facilitating intuitive interpretation and analysis. This advancement significantly simplifies the imaging workflow, making high-quality retinal imaging more accessible and practical for clinical settings.

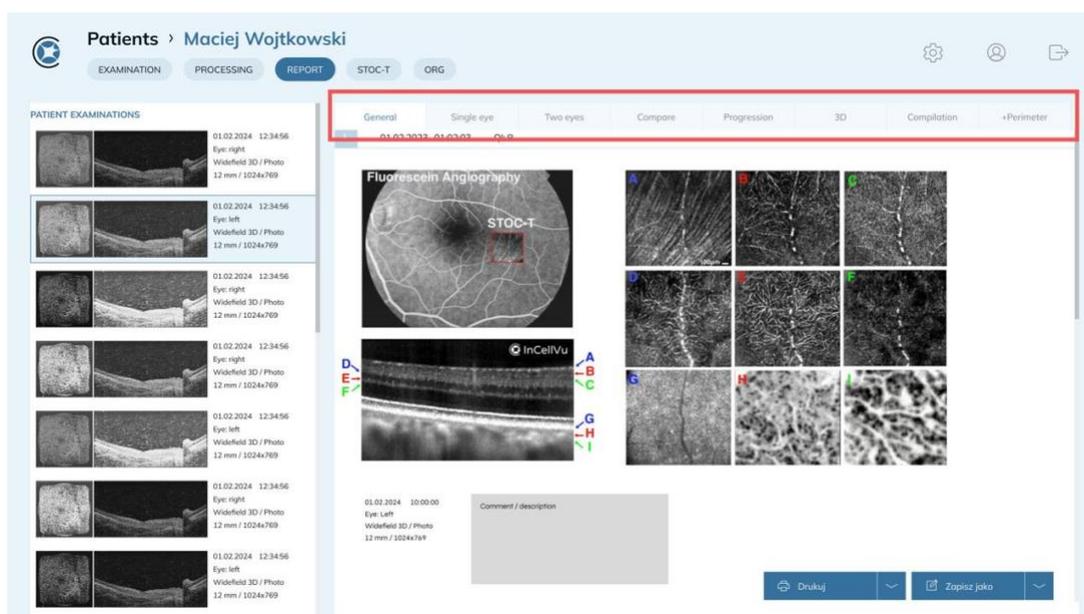


Fig. 3. Representational retinal images from the STOC-T prototype