

**Project number:** IPD12020

**Project name:** i-OCT (integrated smart optics for low-cost, super-resolution OCT)

**Goal:** to develop a prototype of a low-cost, high-resolution OCT system for use in ophthalmology

An OCT system extended with an adaptive optics system that compensates for aberrations in the lens and cornea of the eye

## Integrated smart optics technology in ophthalmology

Optical coherence tomography (OCT) is an imaging modality that produces high-resolution images of tissue up to a few millimetres in depth.

Although the axial (depth) resolution of OCT imaging is sufficient for use in ophthalmology, the lateral resolution is hampered by aberrations in the lens and cornea of the eye. While adaptive optics can compensate such irregularities, integrating that with OCT is complex and costly. To overcome these problems, the IOP project 'i-OCT' will develop integrated smart optics technology.

Optical coherence tomography is based on the principle that tissue reflects light. When a light beam is aimed at tissue, OCT provides cross-sectional images in which the contrast is based on differences in the backscattered light. “Compared to other non-invasive, in vivo, contactless imaging modalities such as ultrasound, high-resolution computed tomography (CT) and magnetic resonance imaging (MRI), optical coherence tomography (OCT) has a much better axial resolution: from 2 to 10 microns,” says Michel Verhaegen, Professor of Systems and Control at the Delft University of Technology and project leader of i-OCT. As a result, OCT is commonly used to visualise the many thin, functional layers in the top millimetre of retina tissue. “That makes OCT very effective for diagnosing and screening eye diseases such as glaucoma, age-related macular degeneration and diabetic retinopathy. But it is also useful for imaging coronary vessels.” In the latter context, a probe is used to introduce the light beam into an artery to check locally for arteriosclerotic plaque. In urology and gynaecology, OCT is used to improve cancer diagnostics, for instance at the Academic Medical Center (AMC) in Amsterdam.

#### Adaptive optics

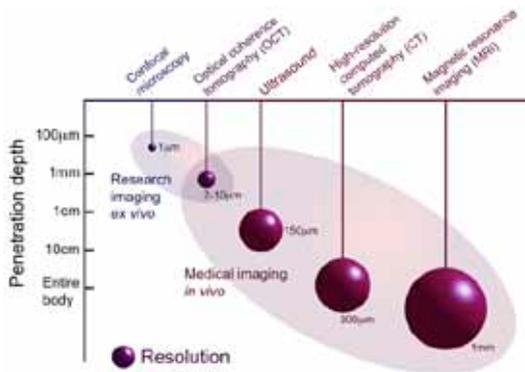
In ophthalmic use, the lateral resolution of OCT is determined by the spot size of the light source on the retina, which is approximately 20 microns. “The problem, however, is that organic materials such as an eye’s lens and cornea are not homogeneous. Different layers have different refractive indices, and aberrations present in the

lens and cornea will influence how the light is focused on the retina. That means that the lateral resolution of the OCT images is not good enough to facilitate the imaging of the most important part of the retina: the cones,” explains Verhaegen. “By correcting those aberrations with adaptive optics, it is possible to enhance the lateral resolution. This technology has already been in use for a decade in astronomical telescopes and microscopy.” While adaptive optics has also demonstrated its usefulness in ophthalmology, commercial OCT systems have yet to include this technology. “Not only would the necessary add-on hardware double the volume of the OCT system – you would need to include bulky optical components such as light sources, lenses, deformable mirrors and interferometers – but it would also double the cost. Besides that, the use of adaptive optics would require substantial maintenance: you would need specialists for regular calibration of the optical hardware. And on top of all that, you would have to deal with a loss of information, since the Shack-Hartmann wavefront sensors classically used to measure the wavefront aberrations will ‘steal’ photons from the optical path.” To overcome these issues, the IOP project ‘i-OCT’ will greatly simplify the necessary hardware. It will also integrate active image-resolution enhancement into the OCT system, reducing costs while preserving high-performance resolution.

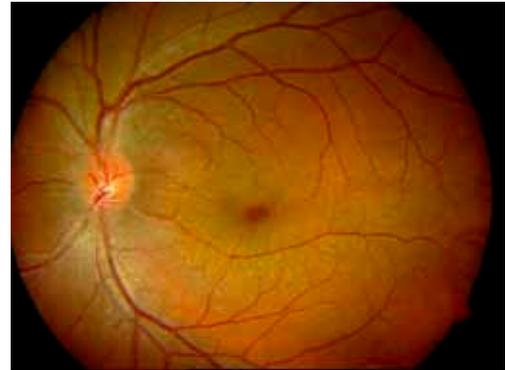
#### Algorithms

In order to reduce the hardware complexity, the aberrations will be corrected with software instead of using an expen-

*“Apart from its applications in healthcare, integrated smart optics technology will also be useful in other inspection domains”*



A comparison between the imaging depth and resolution of OCT and those of several other in vivo imaging modalities (Source: University of Illinois)



A retinal image taken with the current low-cost fundus camera of Focal Optical Systems (Photo: Focal Optical Systems)

sive, deformable mirror, which is currently a key element in systems for adaptive optics. Verhaegen: “We know that, in principle, it is possible to make the necessary corrections with model-based algorithms, but this method needs to be improved and accelerated. We need to be able to correct the aberrations in real time. Above all, it is a problem of mathematical optimisation that will be tackled at the Delft University of Technology.” Project partner TNO, which has extensive experience and knowledge of adaptive optics, especially in astronomy, lithography and microscopy, is responsible for the system engineering of the new concept. TNO will also develop a technical and commercial roadmap for the i-OCT system. “Apart from its applications in healthcare, integrated smart optics technology will also be useful in other inspection domains, including vegetables and non-organic materials. Hence, TNO will be exploring commercialisation in non-medical markets as well.”

### Prototype

Another project partner is Focal Optical Systems, a company that designs and develops optical precision-measurement systems, including diagnostic instruments for ophthalmol-

ogy. Focal has developed vision-software-enhanced eye-diagnostic devices for pre-screening eye-related diseases in developing countries. “In this project, Focal will develop pre-diagnostic software tools to automate the use of the i-OCT system in clinical environments. It will also develop a prototype of the i-OCT module that will incorporate the designs from TNO and the algorithms developed by the Delft University of Technology. At the end of this project, Focal envisions having put another smart diagnostic retinal-screening device on the market. The Department of Biomedical Engineering and Physics at the AMC will work on several theoretical and experimental aspects of the interaction between light and tissue to find out more about image formation of the retina. With the i-OCT technology developed in this project, it will be possible, for the first time, to quantitatively measure the light-absorption and light-scattering properties of the very thin retinal layers – something that has been a major challenge until now. This will allow doctors access to important physiological parameters such as perfusion, blood-oxygen saturation and the way in which cells are organised – all factors describing the state of health (or disease) of the imaged tissue.

### Participants:

- Academic Medical Center (AMC), Amsterdam
- Delft University of Technology
- Focal Optical Systems
- TNO

### Contact:

Prof Dr Ir M. Verhaegen  
 T: +31 (0)15 278 5204  
 E: m.verhaegen@tudelft.nl