Quantum Opportunities in Optometry

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Health Motivation

Macula's health with aging is an important clinical concern. Macular degeneration is the global leading cause of blindness among people over the age of 60, and it accounts for 90% of new cases of legal blindness in Canada [Cos-sco.ca. (2019)].

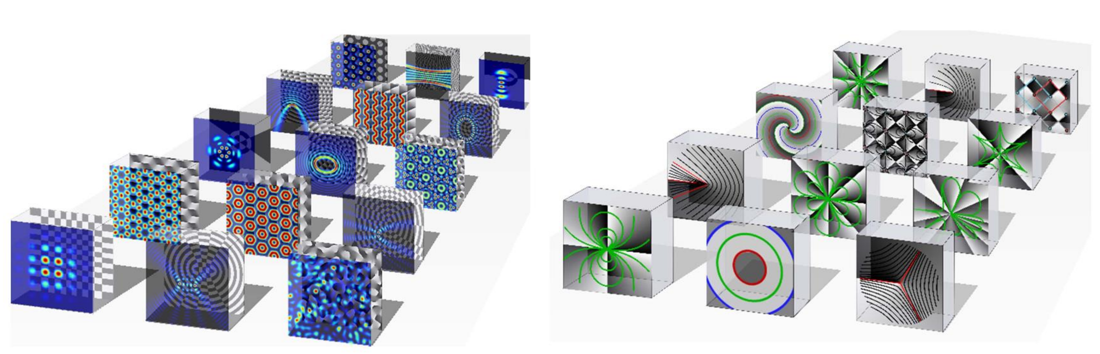
Partnership and goals

This project is a collaborative effort between the Institute for Quantum Computing, UW School of Optometry and Vision Science, and the Center for Eye and Vision Research in Hong Kong.

We are developing a programmable structured light interferometer to explore the power of quantum states and structured wavefronts for studying disorders and diseases of the human eye.

Quantum Optics

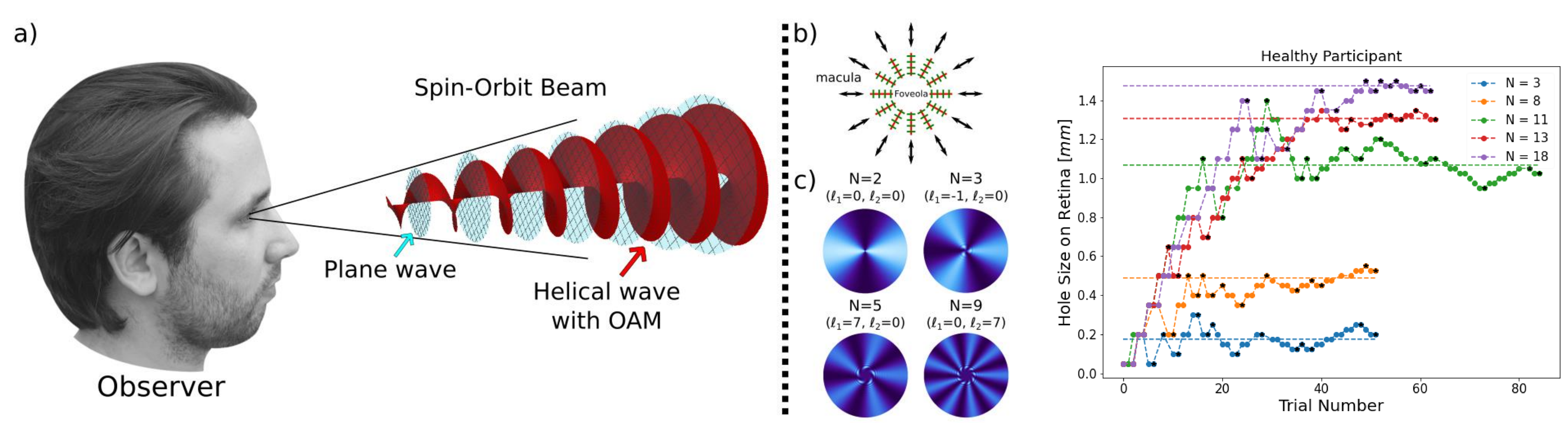
Quantum optics enables the control and structuring of light towards specific biological interactions. Recently there has been tremendous progress in generation and detection of structured light which possesses highly useful propagation characteristics such as orbital angular momentum, non-diffraction, and self-healing. These special beams have demonstrated a number of applications in microscopy, encoding and multiplexing of communications, and manipulation of matter. Here we extend the control of structured light to visual science applications.



Overview of exemplary structured light fields with corresponding amplitude and phase distributions. [Journal of Optics 19.1 (2016): 013001]

Shaping light for optometry applications

A major advantage of quantum technology for imaging biological tissue is that quantum probes can be engineered to be selective for a specific type of structural organization. For example, the macula in the human eye, the health of which is a major clinical concern in older adults, possesses azimuthally ordered birefringent fibers over 100 µm length scales. This structure is very well suited to quantum probing via structured light beams.

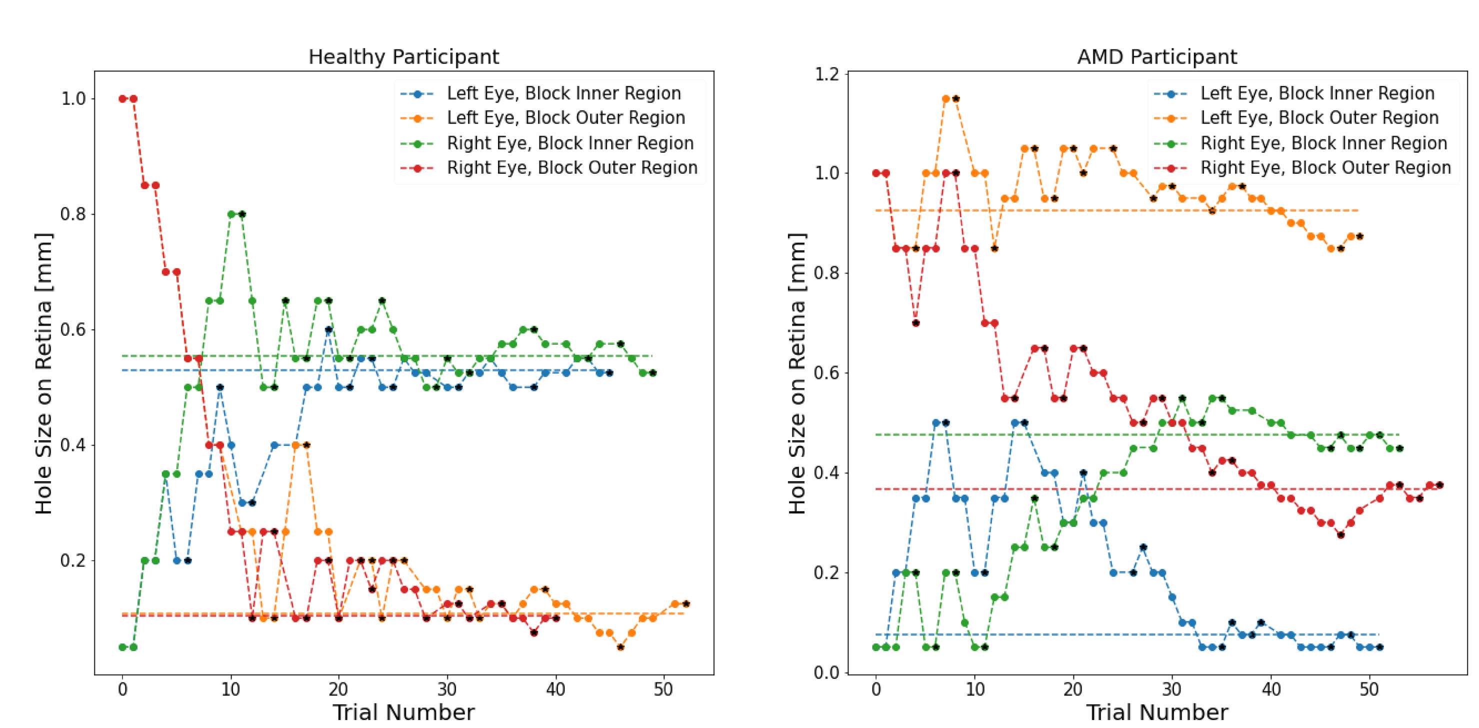


The above is a pictorial representation of structured light, composed of a coherent superposition of a planar right-circularly polarized state and a helical left-circularly polarized state, being directed onto the retina. The helical state carries quantized orbital angular momentum (OAM) and its phase varies along the azimuthal coordinate φ. b) In the macula of the human eye the macular pigment molecules (red) are bound to the radially oriented Henle fibers (orange) that surround the foveola. The radial symmetry of these dichroic elements (polarization filter direction shown by black arrows) coincides with the symmetry of the polarization coupled OAM beams shown in a). c) Depending on the OAM of the helical beam the participant observes a different unique signature when looking in the vicinity of the beam's origin.

Our initial study verified the entoptic phenomenon through which humans are able to perceive and discriminate structured light [PNAS 117 (26), 14682-14687]. We followed this up with a more intricate study that examined the limits of human vision in terms of azimuthal line density (N), rotation speed, and peripheral vision. An example of the employed staircase method testing the extension of peripheral vision is shown above on the right. Using these measurements we can determine the profile of the macular density pigment and infer on the health of the macula.

Tests with AMD Participants

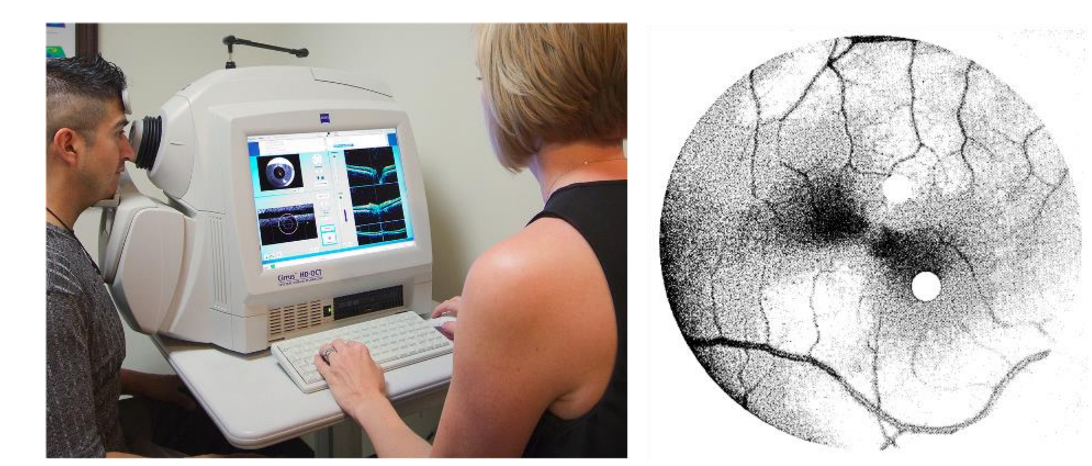
The performance between a healthy participant (left) and a participant with age related macular degeneration (right) is shown on the right. AMD is shown to cause a large variance in performance between the two eye, and the data indicates the loss of ability to perceive entoptic phenomena in the central point of vision.



Improved Retinal imaging

Common methods of retinal imaging:

- Fundus photography: intricate microscope attached to a flash enabled camera are used to photograph the rear of an eye.
- Optical coherence tomography (OCT): 2D imaging of the retina using low coherence light. Shown in Figure below (left).



(left) Optical Coherence Tomography is the current standard for eye imaging. [taylorsoptometrists.co.uk/.] (right) Retinal imaging with polarized light reveals the macula's structure. [Applied optics, 21(21), pp.3811-3818].

With quantum tools we can engineer a probe that is sensitive to the presence of specific structures in their entirety. For example, we can tailor spatial profiles of light's polarization to match a biological feature of interest. The addition of structured light to retinal imaging techniques promises to improve selectivity towards the structure of the macula and enable new methods of diagnosing macular degeneration. Once we demonstrate this in a clean system such as macula we can apply related techniques to other biological features, and re-explore biology with these new capabilities.

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