Alignment and validation of an AOSLO for imaging the human cone mosaic in the central fovea

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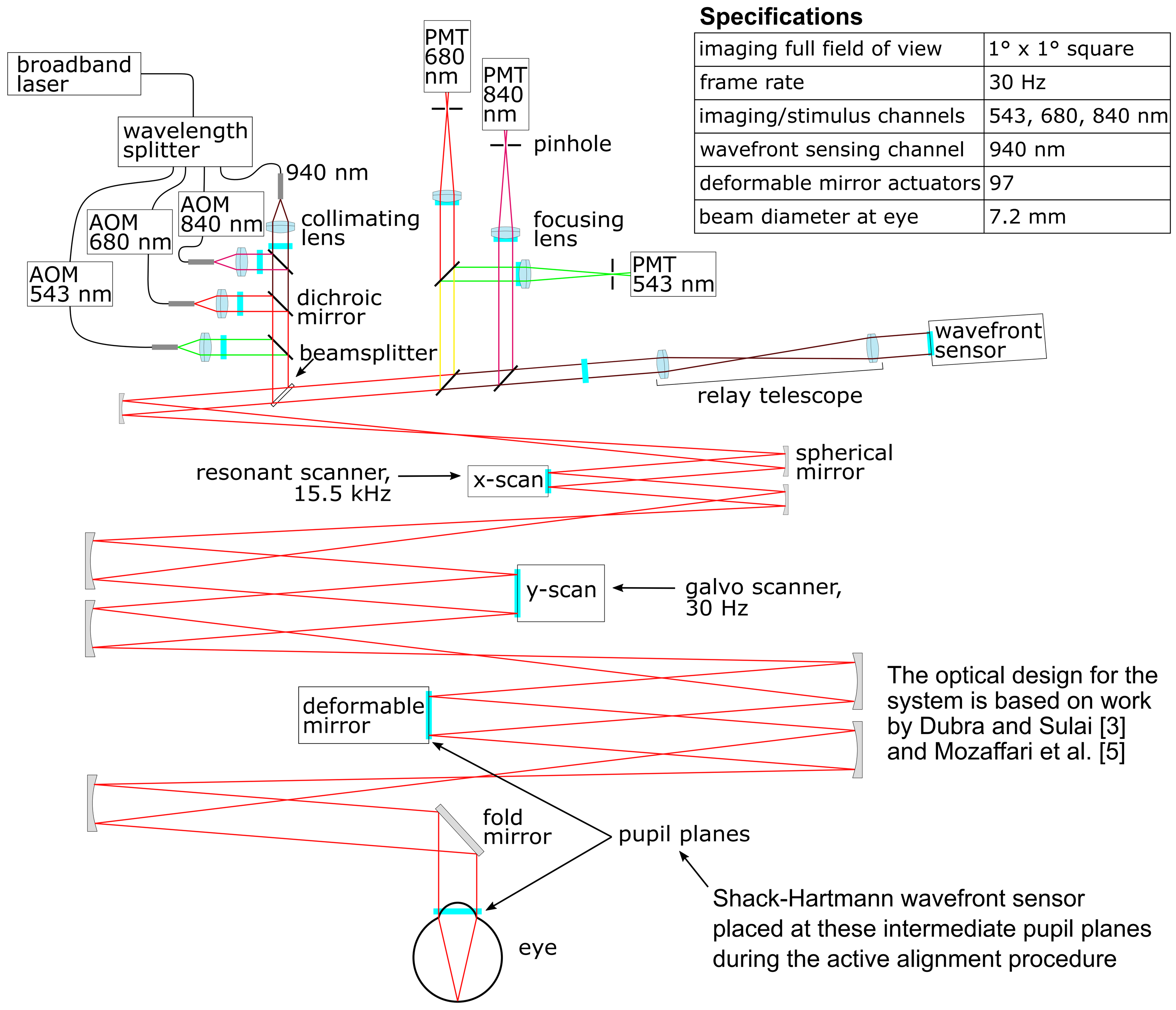
Introduction

- Recent research indicates that high-acuity vision is a sensorimotor process based on the interaction between foveal stimulation and eye movements [1-2].
- Advances in adaptive optics scanning laser ophthalmoscopes (AOSLOs) now enable individual human cones in the central fovea to be resolved, where the cones are smallest and most densely packed [3-7].
- Simultaneous examination of both foveal anatomy and fixational eye movements provides a powerful tool for advancing understanding of the mechanisms that underlie high-acuity vision.
- This AOSLO has been optimized for imaging the human central fovea in vivo.

System schematic and optical alignment techniques

Specifications

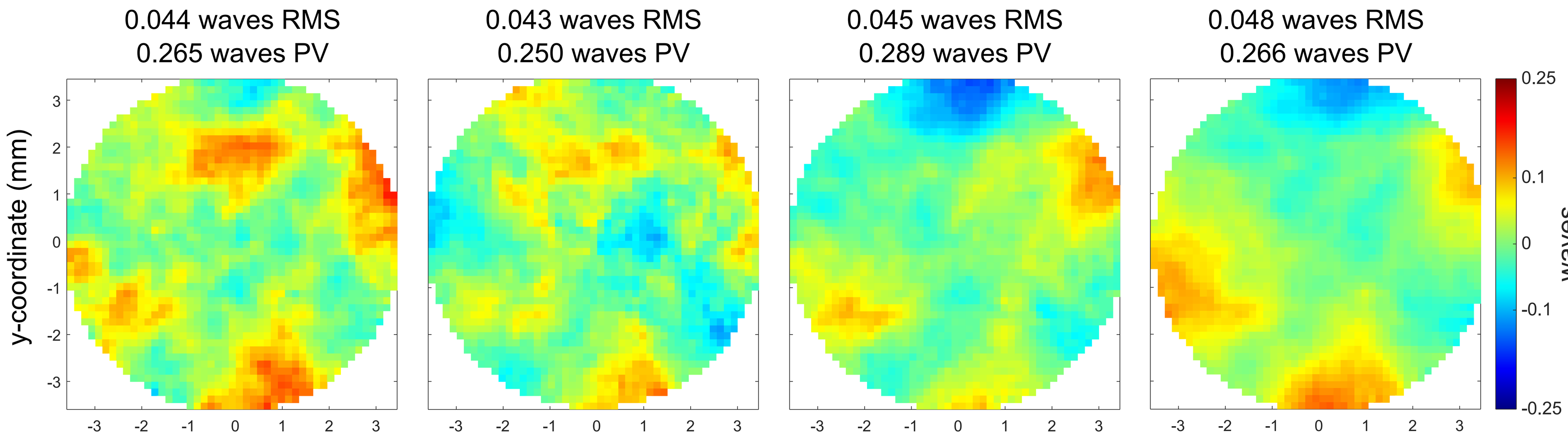
imaging full field of view	1° x 1° square
frame rate	30 Hz
imaging/stimulus channels	543, 680, 840 nm
wavefront sensing channel	940 nm
deformable mirror actuators	97
beam diameter at eye	7.2 mm



The optical design for the system is based on work by Dubra and Sulai [3] and Mozaffari et al. [5]

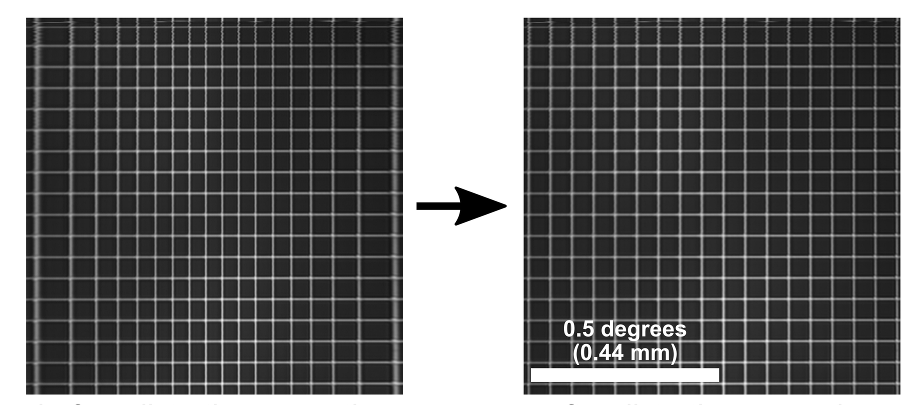
- Achieving cellular resolution in the central fovea requires a well-aligned and optimized imaging system due to the resolution limit imposed by the human eye.
- For coarse optical alignment, a laser-cut stencil was used to transfer the coordinates of each component onto the optical table with +/- 1 mm position uncertainty.
- An active alignment strategy was employed to optimize the alignment of each relay telescope in the AOSLO, resulting in a diffraction-limited imaging system.
- A portable Shack-Hartmann wavefront sensor was positioned at each intermediate pupil plane, and the spacing between each pair of mirrors was adjusted until each relay telescope had less than 0.01 Diopters of residual defocus.

Wavefront measurements of the light delivery system



- Once the system was fully aligned, the Shack-Hartmann wavefront sensor was placed at the eye pupil plane and the wavefront was measured for each channel.
- The RMS wavefront error is less than 0.05 waves for all channels, which is diffraction-limited by the Maréchal criterion (< 0.07 waves). This demonstrates that the optical system is well aligned and optimized for resolving human foveal cones.

Distortion correction and resolution target imaging

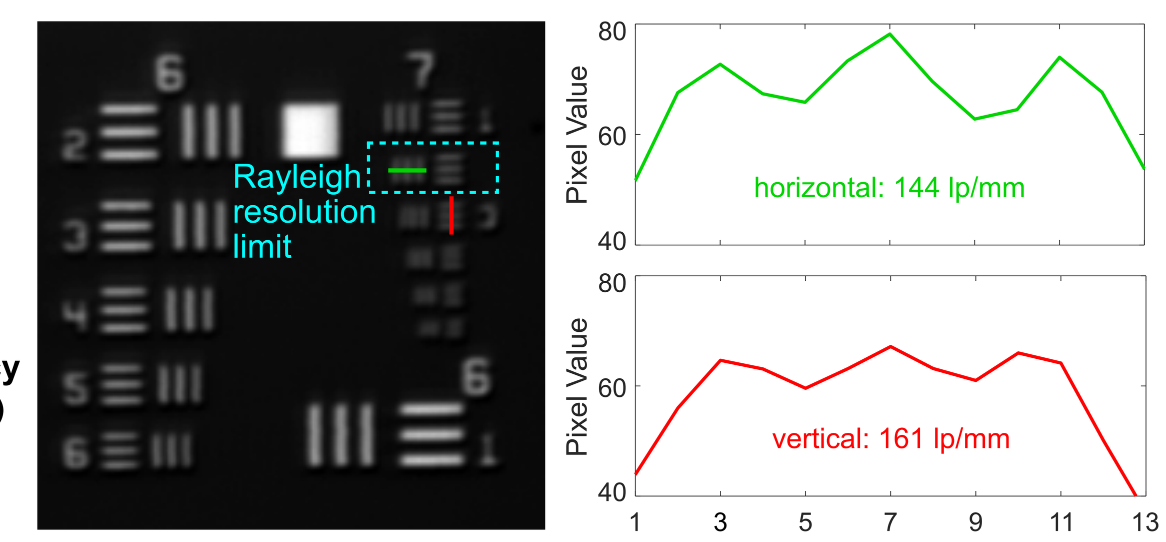


before distortion correction → after distortion correction

- Horizontal scanning is achieved with a resonant scanner that follows a sinusoidal motion profile.
- This sinusoidal motion causes the image to be stretched at the edges and compressed in the center.
- This distortion is corrected by digitally resampling the image in real time.
- A resolution target was imaged at the back focal plane of a model eye lens.
- Bars are resolved up to (and slightly beyond) the Rayleigh resolution limit.

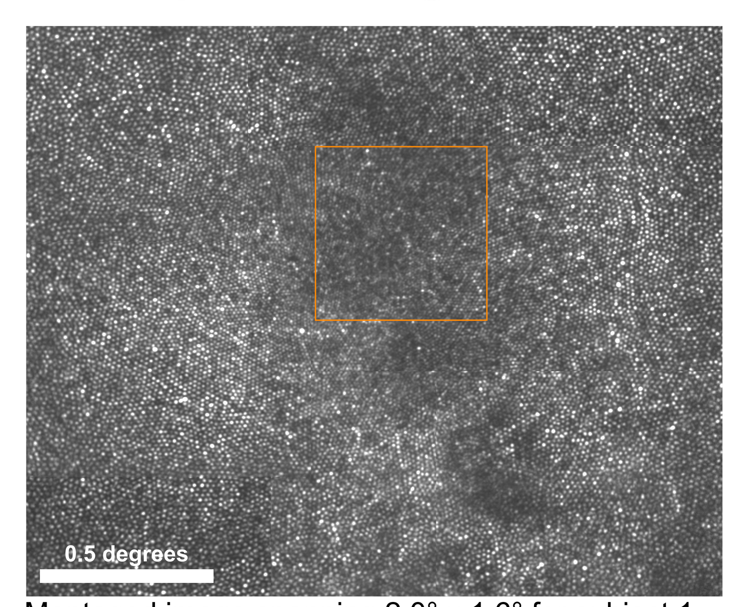
Maximum resolved spatial frequency (lp/mm)

wavelength	horizontal	vertical
543 nm	161	144
680 nm	203	144
840 nm	144	161

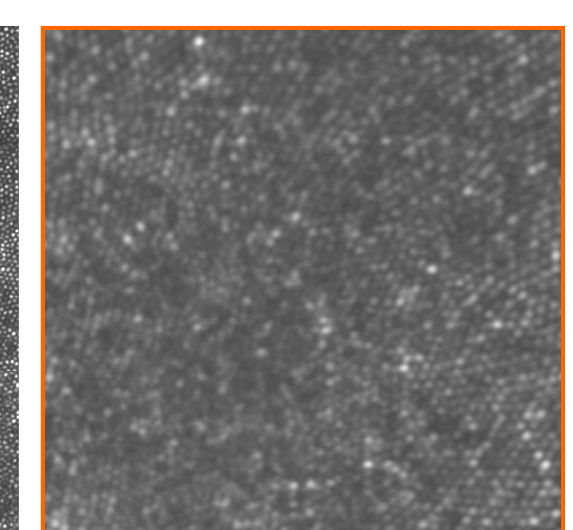


183 x 183 pixels (0.36° x 0.36°), 840 nm light

Example images from the system

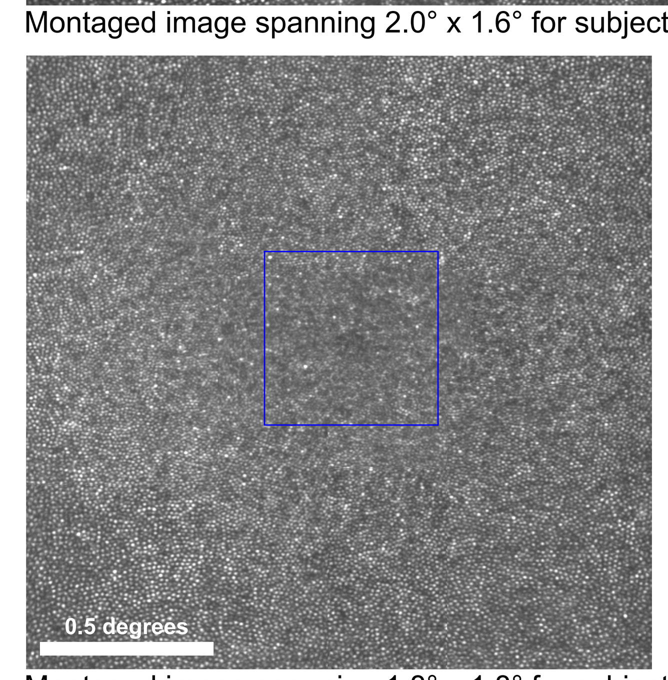


Montaged image spanning 2.0° x 1.6° for subject 1

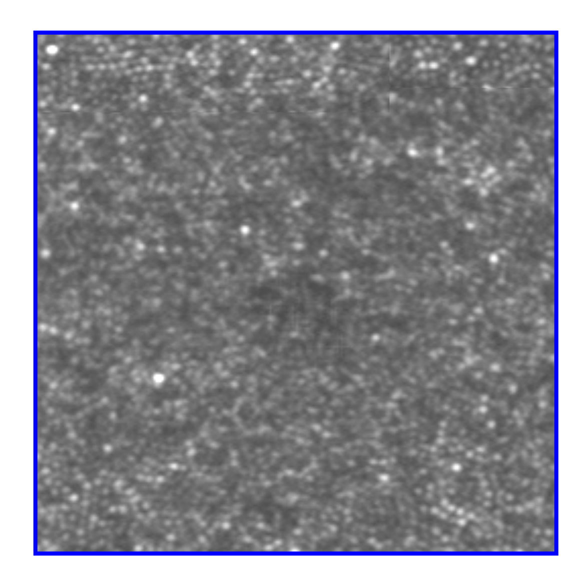


Central 0.5 degree region with highest cone density, enlarged by a factor of 3.

Subject 1
- right eye
- SR: -2.0 D
- 7.2 mm pupil diameter
- 840 nm imaging light
- 9 fixation points
- 1° x 1° scanning field of view



Montaged image spanning 1.8° x 1.8° for subject 2



Central 0.5 degree region with highest cone density, enlarged by a factor of 3.

Subject 2
- right eye
- SR: -3.5 D
- 6.5 mm pupil diameter
- 840 nm imaging light
- 9 fixation points
- 1° x 1° scanning field of view

- Images collected with the system demonstrate cellular-resolved performance, with the smallest foveal cones being resolved in two human subjects.
- All imaging was conducted with the 840 nm channel while subjects fixated on a small marker (4.7 x 4.7 arcmin) presented with the 680 nm channel.

Discussion and future directions

The AOSLO has been successfully implemented and can achieve cellular resolution in the central fovea. Using an active alignment procedure enabled the optical system to achieve diffraction-limited performance, as demonstrated by wavefront measurements and resolution target images. Real-time distortion correction was also implemented.

Next steps:
1. Finalize the image processing pipeline and montaging procedures
2. Run semi-automated cone detection algorithms on these images
3. Compute the cone density and determine the preferred retinal locus of fixation
4. Collect more human retinal images

Acknowledgments

We are grateful for Austin Roorda, Pavan Tiruveedhula, and the Roorda Lab at UC Berkeley for providing design blueprints, technical documentation, software, and expertise for implementing and using this AOSLO system. Funding for this research was provided by two NIH grants: EY029788 and EY018363.

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