Adaptive optics scanning laser ophthalmoscope for high-resolution imaging of the foveal cone mosaic

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Background

Cone density in the 1° foveola begins decreasing a few arcminutes from the point of peak density [1-2]

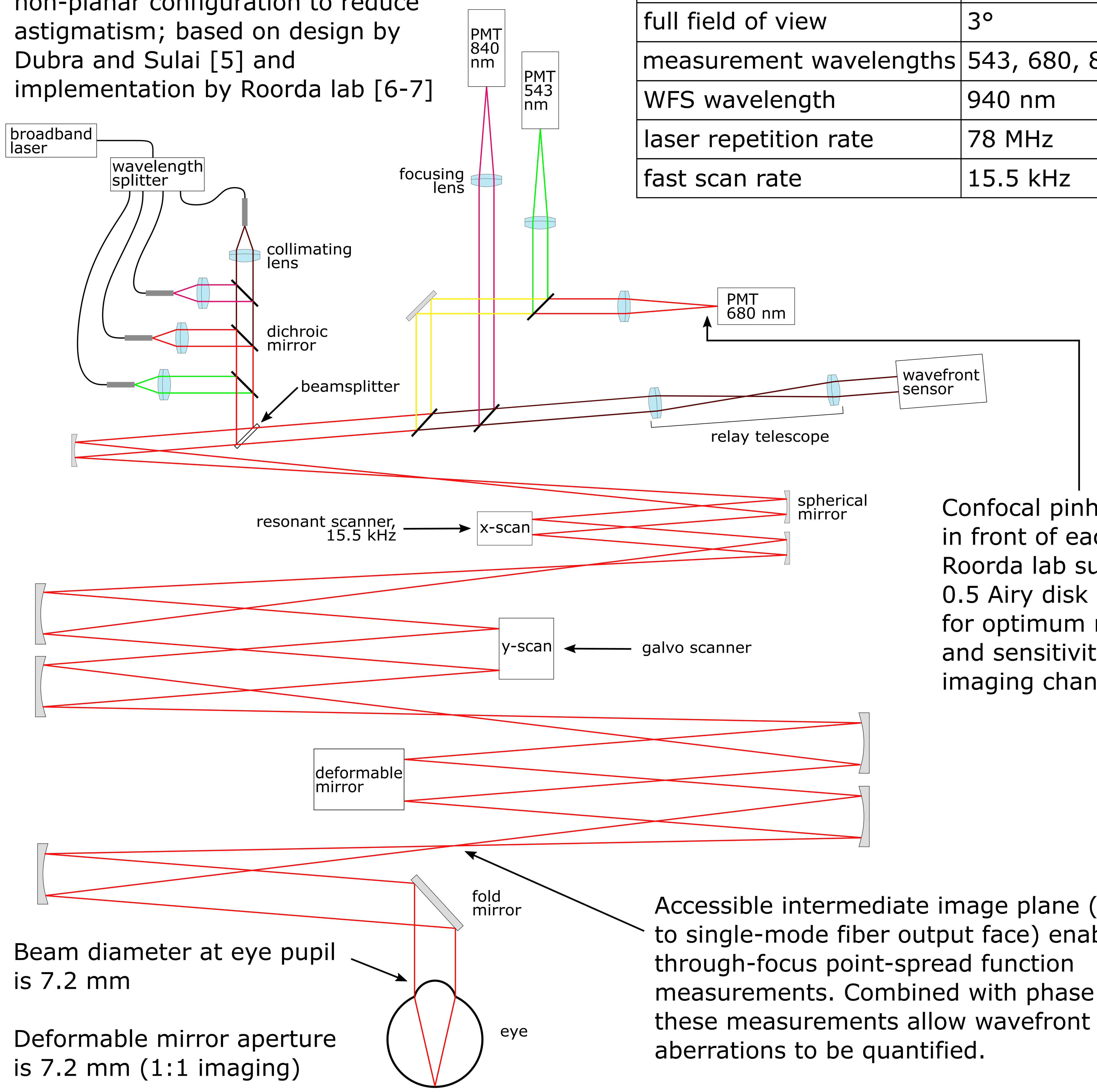
Our lab has shown that fine spatial vision is not uniform across the foveola, and that finely controlled fixational eye movements and selective attention within the foveola enhance fine spatial vision [3-4]

To what extent do anatomical characteristics of the foveola explain visual performance in high acuity tasks and the observed oculomotor behavior?

Addressing these questions requires an imaging system capable of resolving with high resolution the cone mosaic in the central fovea

Optical system design

Uses off-axis spherical mirrors in non-planar configuration to reduce astigmatism; based on design by Dubra and Sulai [5] and implementation by Roorda lab [6-7]



Confocal pinhole placed in front of each PMT. Roorda lab suggests 0.5 Airy disk diameter for optimum resolution and sensitivity for all imaging channels [7].

Accessible intermediate image plane (conjugate to single-mode fiber output face) enables through-focus point-spread function measurements. Combined with phase retrieval, these measurements allow wavefront aberrations to be quantified.

Specifications

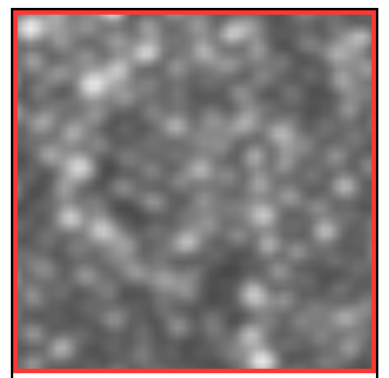
frame rate	30 Hz
full field of view	3°
measurement wavelengths	543, 680, 840 nm
WFS wavelength	940 nm
laser repetition rate	78 MHz
fast scan rate	15.5 kHz

Example of required resolution

Imaging system must resolve individual cones in the foveola, where cone density is highest

Adaptive optics enables this resolution by compensating for the aberrations of the eye [6]

Precise optical alignment is required to achieve this resolution: illumination and collection systems must be diffraction-limited [7]



Inset from (A) showing individual cones at peak density location. This view is 0.1° x 0.1° (27.9 μm x 27.9 μm).

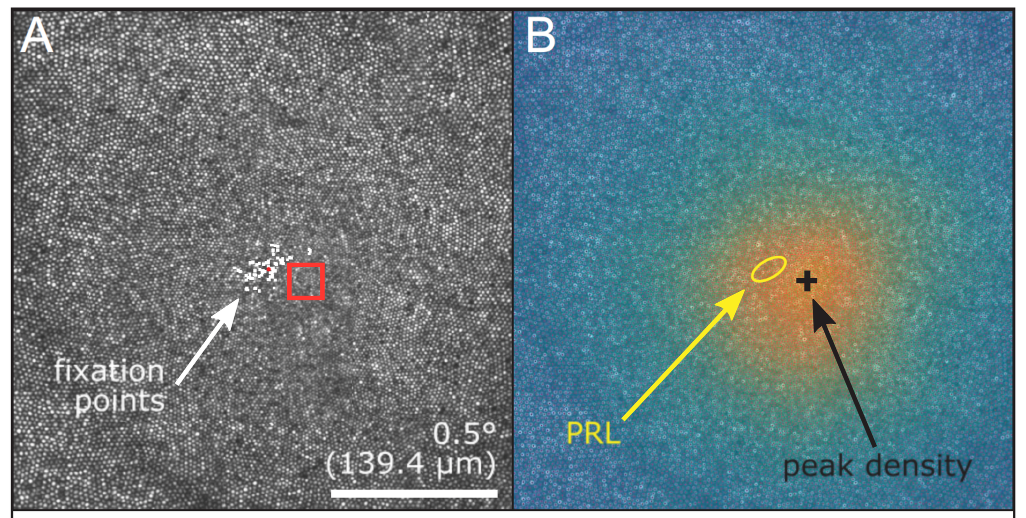
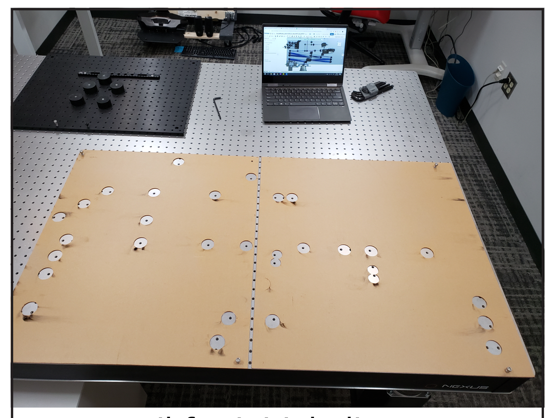


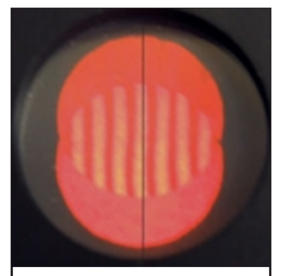
Figure adapted from Wang et al. [8] showing (A) ability to resolve individual cones in the foveola and (B) overlay of cone density map. PRL is preferred retinal locus, which is the best-fit ellipse for the measured fixation points.

Optical alignment and testing procedures

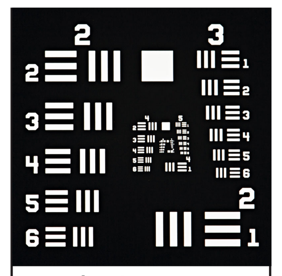
1. Carefully position all optomechanics on table using laser-cut stencil based on CAD model
2. Verify collimation of input beams using shear plate
3. Use irises and alignment guides to ensure centration on mirrors
4. Measure through-focus point-spread function at intermediate image planes and use phase retrieval to measure wavefront error
5. Use Shack-Hartmann wavefront sensor to measure aberrations in pupil planes
6. Place eye phantom in system with camera located at the retinal plane to assess resolution of illumination system
7. Use image resolution target to assess full system performance



stencil for initial alignment



shear plate

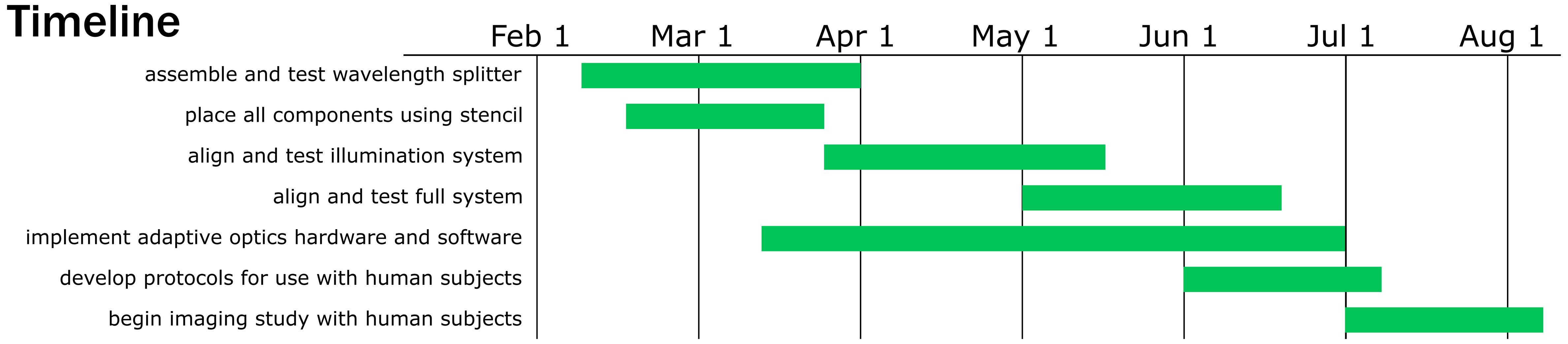


resolution target

Future system developments

Add ability to dynamically adjust the stimulus in visible channels (stimulate individual cones); incorporate eye-tracking methods based on retinal movement; make the system binocular

Timeline



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Acknowledgments

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