

Optomechanics with Adaptive Optics

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Optomechanics

Integrated design, optimization, and control of automation systems involving active optical, mechanical and electronic components.

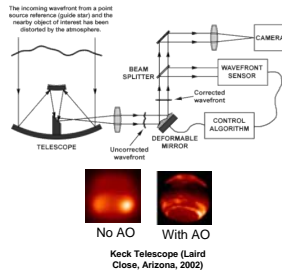
Adaptive Optics (AO): Devices that can change wavefront in real-time, in response to environmental or operating conditions.

Examples:

- Deformable mirror (DM)
 - Liquid crystal spatial light modulator (SLM)
 - Fast steering mirror
 - Liquid lens
 - Segmented micro-mirrors
 - Digital micromirror device (DMD)
-

Existing Applications of AO

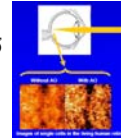
Atmospheric aberration compensation



Vision Science (Retina Imaging)



David Williams (Rochester, 1997, 2004)



Keck Telescope (Laird Close, Arizona, 2002)

New Emerging Opportunities for AO

- Microscopy: Correct for intrinsic optical aberrations to enhance resolution.
- Telescope: Correct for atmospheric disturbance as well as astigmatism from off-axis imaging
- Laser beam shaping: Modify Gaussian irradiance profile to flat top hat with different shapes

Challenges:

- Small stroke for MEMS deformable mirrors (few μm)
- One way actuation of electrostatic MEMS mirrors

Optomechanics required for integrated design!

Fundamental Limitation of Microscopes

Inherent tradeoff between **field-of-view** and **resolution** in optical microscopy:

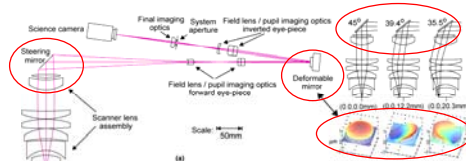


| | | |
|------------------------------|---|-----------------------|
| $f = \frac{0.61\lambda}{NA}$ | $f = \frac{0.61\lambda}{NA \sin\theta}$ | |
| 0.075 NA 2.5X | 0.13 NA 5X | 0.30 NA 10X |
| 4.5 micron resolution | 2.6 micron resolution | 1.1 micron resolution |
| 4.8 mm field diameter | 2.4 mm field diameter | 1.2 mm field diameter |

Common Solution: Moving stage, multiple parfocal objectives, multiple microscopes, zoom lens

➔ **Slow – unsuitable for dynamic events, disturbance of specimen, difficult to add additional instruments**

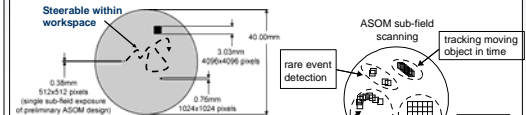
Adaptive Scanning Optical Microscope



- Post-objective image field scanning (not a point)
 - Faster than a moving stage
 - No agitation to the specimen
- Deformable mirror aberration correction
 - Two order of magnitude larger field area
 - Simplified scan lens design

Potsaid, Bellouard, Wen, Optics Express, 2005

ASOM Field of View and Scan Time

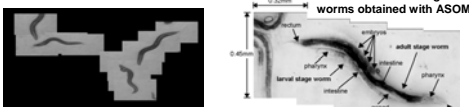


NA=2, $\lambda=510\text{nm}$, depth of field = 12.5 μm , chromatic performance: [490,530]nm

| ASOM Camera | Scan Movements for full coverage | Estimated time to scan (100 moves/sec) | |
|-------------|----------------------------------|--|-----------|
| | | 40mm DIA | 10mm DIA |
| 512x512 | 8737 | 87.4 sec. | 5.5 sec. |
| 1024x1024 | 2184 | 21.8 sec. | 1.4 sec. |
| 2048x2048 | 546 | 5.5 sec. | 0.3 sec. |
| 4096x4096 | 136 | 1.4 sec. | 0.09 sec. |

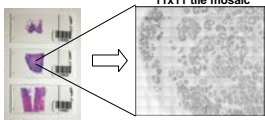
Bio-imaging Applications

- Multiscale and Longitudinal biological imaging of live organisms
 - Simultaneous observation of single cells, organisms, animals and populations with limited phototoxicity
 - Individual organisms tracked throughout their lives with behavior correlated to genetic makeup



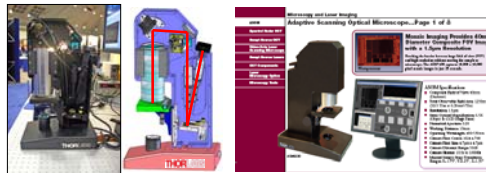
High throughput Screening

- Scanning performed only at areas of interest
- Typical biopsy has low fill ratio

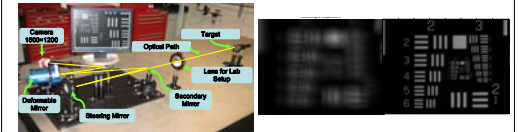
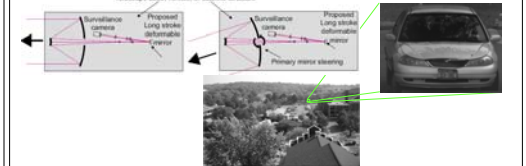


Licensing and Commercialization

- First ASOM prototype built at RPI CATS based on NSF and CATS funding. RPI licensed to Thorlabs in 2006.
- Close collaboration for Photonics West 1/07 live demo
- Thorlabs ASOM won Laser Focus World Product of the Year Award in CLEO 2007
- ASOM sold through Thorlabs catalog (8-page spread) July 2007

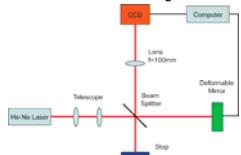
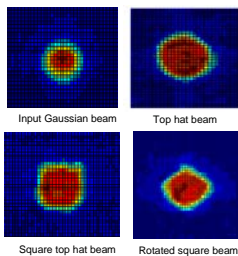


Extension: Scanning Telescope



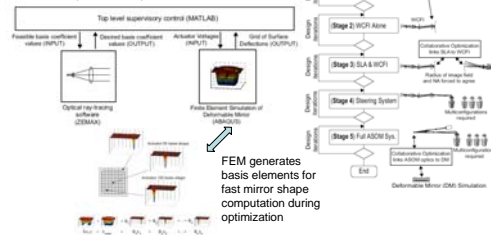
Extension: Laser Beam Shaping

- Uniform energy distribution important for laser processing (cutting, drilling, marking) and communication
- Deformable mirror based beam shaping allows flexible energy distribution specification and shaping over wide field through



Design Tool

Integrated design optimization environment coordinating optical simulation software (ZEMAX), finite element simulation (ABAQUS), mathematical computation software (MATLAB)



Summary

- **Opto-Mechatronic System design** considers interactions between optical, mechanical, electrical, and computer components at the earliest stages of device conception
- ➔ Result: **Considerable performance gains**
 - ASOM: particularly suitable for challenging biotech, MEMS, and microbotic applications:
 - Dynamic observations
 - Low fill factor
 - Low Lighting
 - High Throughput
 - ASOM extension: subsurface imaging, LED illumination
 - New AO devices (ready for commercialization in a few years):
 - Scanning telescope
 - Wide field laser beam shaping

Acknowledgements:

