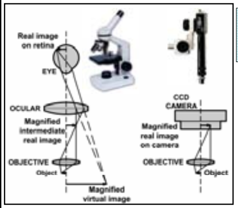
Adaptive Scanning Optical Microscope (ASOM)

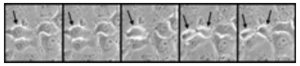
Benjamin Potsaid and John T. Wen
Center for Automation Technologies and Systems

The Optical Microscope



Resurgence of interest in the optical microscope:

- Biological Research
- MEMS and Microdevices
- Medical Diagnostics
- Industrial Manufacturing



Observation of mitosis in living cells for cancer research (NYS Wadsworth Center DOH)

Mirror assembly for interferometer (RPI-CATS 2004)

1

Problem: Field of View and Resolution Tradeoff

There is an inherent tradeoff between the field-of-view and resolution in the optical microscope:

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

This tradeoff is a significant hindrance when using the optical microscope in practice, reducing throughput and preventing challenging spatial-temporal observations.

2

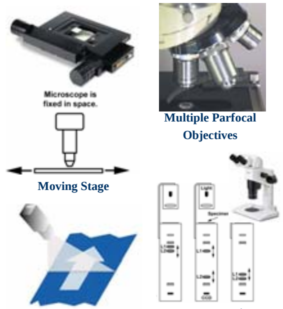
Existing Solutions Are Not Adequate

Existing Solutions:

- Moving Stage
  - Dynamically slow
  - Agitates Specimen
- Line Scan
  - Requires Bright Illumination
- Multiple Parfocal Lenses
- Zoom Lens Design
  - Tradeoff resolution

We Need:

- Fast Dynamic Scanning
- Low Light Imaging
  - Live cell imaging
  - Fluorescent imaging
- No Agitation to Specimen



Moving Stage

Multiple Parfocal Objectives

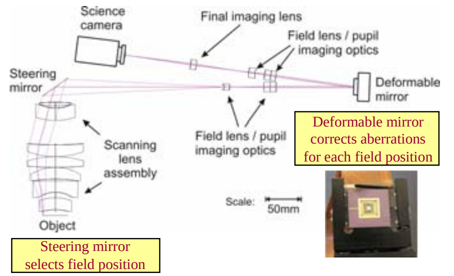
Line Scan

Zoom Lens Design

3

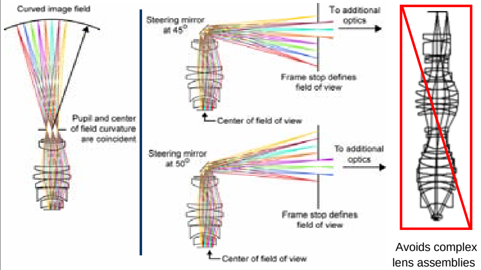
RPI-CATS Novel Scanning Optical Microscope

Novel Optical Microscope: Fast Dynamic Scanning, High Throughput, Low Light Imaging, No Agitation to Specimen



4

Curved Intermediate Image Field Scanning



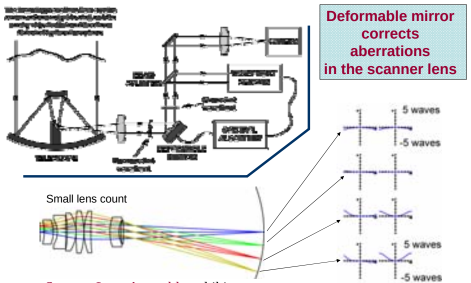
- Low mass steering mirror for rapid 2D scanning
- Steering mirror angle selects field of view
- Curved image field reduces lens complexity

Avoids complex lens assemblies such as this lithography lens

5

Deformable Mirror Technology

Deformable mirror corrects aberrations in the scanner lens

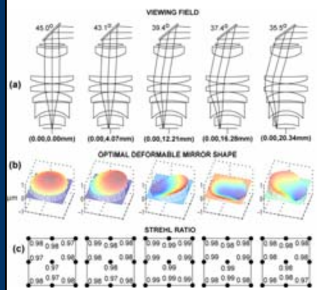


Scanner Lens Assembly exhibits significant wavefront aberration.

Diffraction limit = ¼ wave

6

Diffraction Limited Imaging Over All Field Positions



2D steering mirror angle defines observable field location

Deformable mirror stays within 2 µm stroke

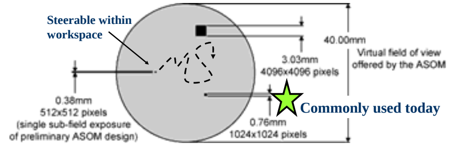
Image quality is diffraction limited over all field positions

Perfect Strehl = 1.0
Diffraction limited > 0.8

7

ASOM Field of View Advantage

2 orders of magnitude larger field area than traditional microscope:



Rapid scan times:

ASOM Camera	Scan Movements for full coverage	Estimated time to scan (100 moves per second)
512x512	8737 **Current design**	87.4 sec.
1024x1024	2184	21.8 sec.
4096x4096	136	1.4 sec.

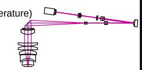
← Faster than standard camera technology

8

Systematic Design Methodology

Design Challenges:

- Size of design problem is intractable (All-at-once does not work!)
  - Requires optimization over different field positions
  - Mixed continuous (dimensions) and discrete (glass type) variables
  - Global search required (no initial starting design for scan lens in literature)
  - Large number of design constraints
  - Simulation and optimization of deformable mirror surface
- ASOM Design Methodology
  - Break the design problem up into manageable sub-problems
  - Use tools from the field of Multidisciplinary Design Optimization (MDO)



Multidisciplinary Design Optimization:

Methods and frameworks to coordinate design optimization process
"Collaborative Optimization" introduces relaxation and coordination.

"Collaborative Optimization"

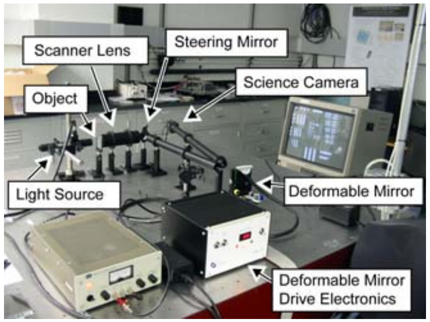
ASOM System — Coordinates system wide design optimization

Optics Simulation (ray tracing)

Deformable Mirror Simulation (Finite Element Analysis)

9

ASOM Experimental Prototype



10

ASOM Demonstrations

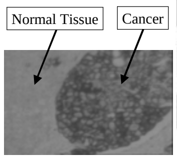
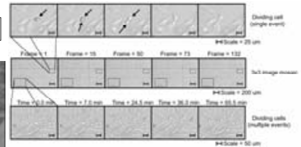
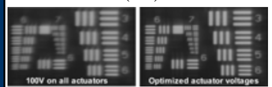


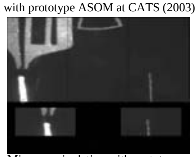
Image taken with prototype ASOM at CATS (2005)



Live cell imaging with prototype ASOM at CATS (2003)



Deformable mirror improves image quality in ASOM at CATS (2005)



Micro-manipulation with prototype ASOM at CATS (2002)

11

Summary and Conclusions

- **Opto-Mechatronic System design** considers interactions between optical, mechanical, electrical, and computer components at the earliest stages of device conception
  - Result: **Considerable performance gains in optical microscopy.**
  - ASOM occupies a unique space in the performance domain and is particularly suitable for challenging biotech, MEMS, and microrobotic applications:
    - Dynamic observations
    - Low fill factor
    - Low Lighting
    - High Throughput
  - ASOM collaborations
    - Biologists (RPI, Wadsworth, Forsyth Inst.)
    - Robotics researchers (Eindhoven, Karlsruhe)
    - Medical and manufacturing companies
  - First prototype completed and IP filed
  - A primarly program of the Smart Optics Lab

Acknowledgements: CATS

12