NSF Engineering Research Center
for Computer Integrated Surgical
Systems and Technology

LABORATORY FOR
Computational
Sensing + Robotics
THE JOHNS HOPKINS UNIVERSITY

Single Fiber Optical Coherence Tomography Microsurgical Instruments for Computer and Robot-Assisted Retinal Surgery

Marcin A Balicki
PhD Student in Computer Science, The Johns Hopkins University
marcin@jhu.edu

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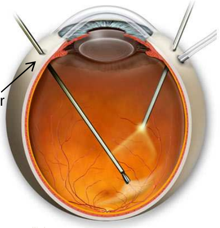
microSurgical BRP workstation

Vitreoretinal Microsurgery

British Journal of Ophthalmology 2004 - Akifumi Ueno et al



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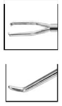
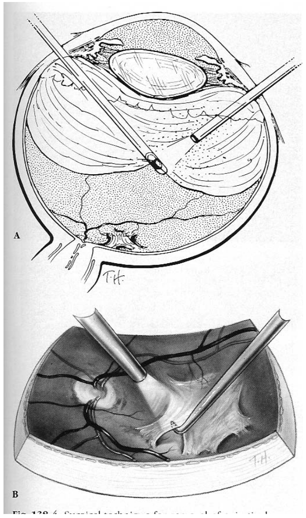


Alcon Vitreosurgery Instrument

Vitreoretinal Microsurgery Challenges

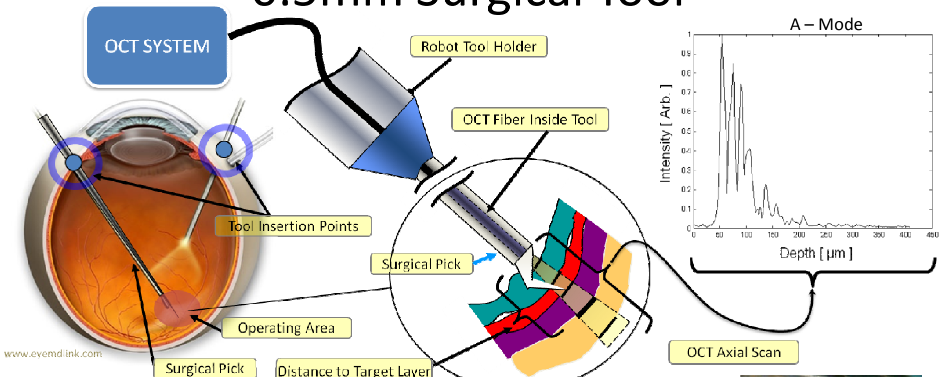
- Manipulating delicate **1-100µm structures** is inherently difficult
- *Gupta et al.* shows that majority of retinal surgical manipulation is below force perception threshold of the surgeon
- High risk of retinal damage due physiological tremor and lack of force feedback, and **accidental collisions**
- **Inadequate visual spatial resolution and tissue depth perception thru operating microscopes**
- Force attenuation from tool – trocar interaction
- **Voluntary/Involuntary patient motion**
- Poor Ergonomics (#1 cause of Vitreoretinal surgeon disability*)



Membrane peeling

*American College of Retinal Surgeon Survey

Concept: Imaging (OCT) Built Into 0.5mm Surgical Tool



OCT SYSTEM

Robot Tool Holder

OCT Fiber Inside Tool

Tool Insertion Points

Surgical Pick

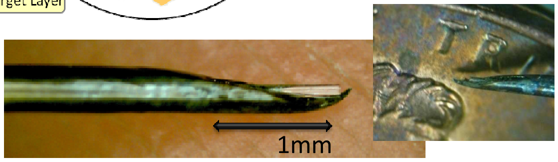
Operating Area

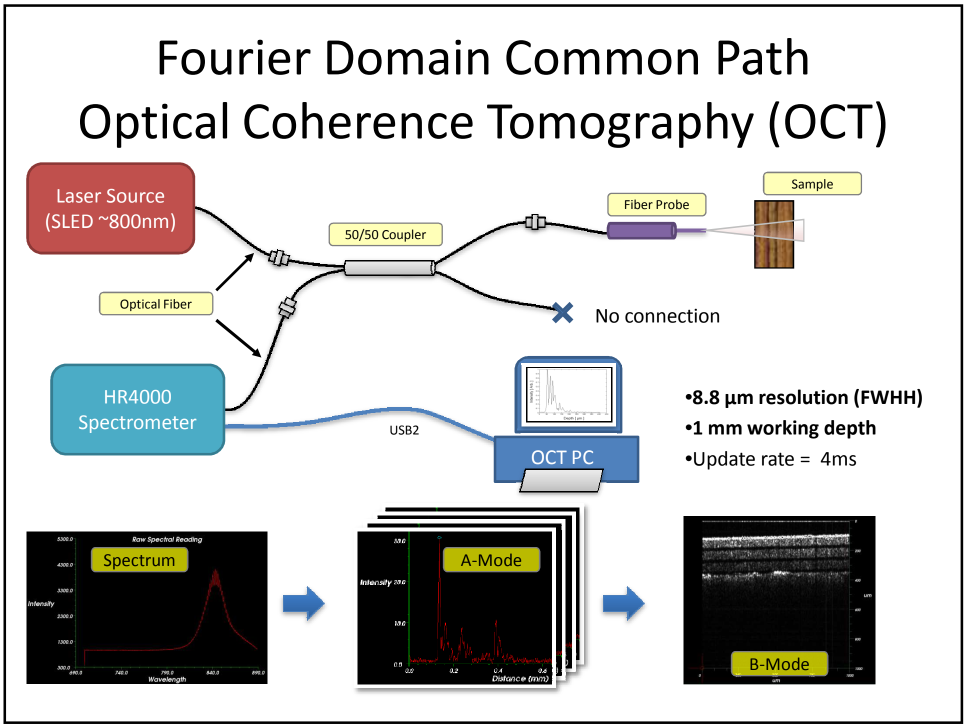
Surgical Pick

Distance to Target Layer

OCT Axial Scan

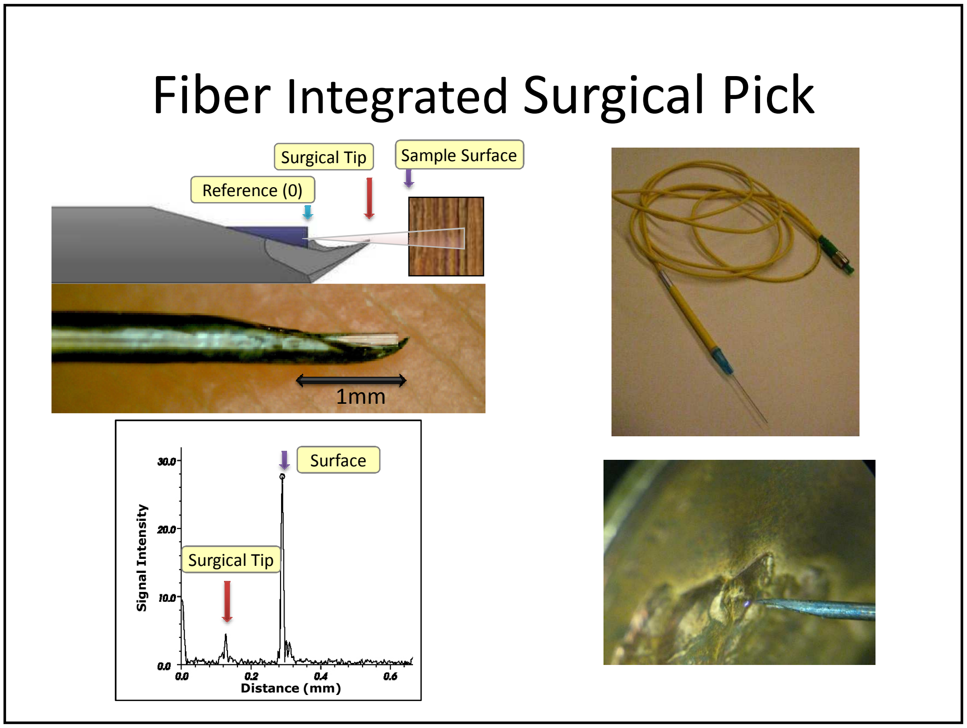
M. Balicki, I. Iordachita, …,
J. Handa, P. Gehlbach, J. Kang, R. Taylor





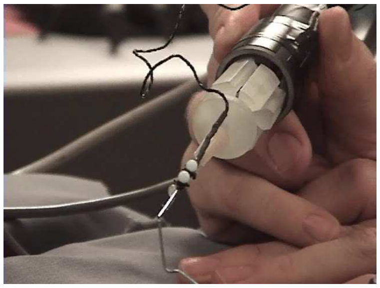
Fourier Domain Common Path Optical Coherence Tomography (OCT)

- **8.8 µm resolution (FWHH)**
- **1 mm working depth**
- Update rate = 4ms



Fiber Integrated Surgical Pick

Integration with Assistive Robots



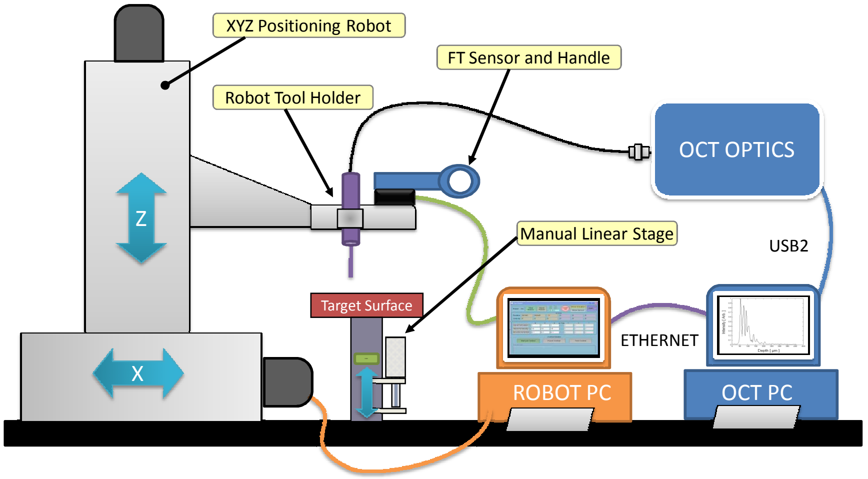
Micron - Carnegie Mellon University (Riviere et al)

Steady Hand Eye Robot – Johns Hopkins University (Taylor et al)

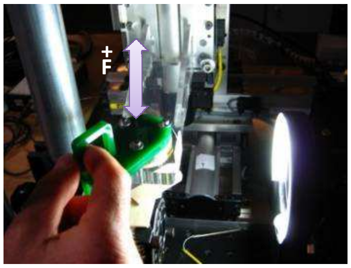
Demonstration Goals

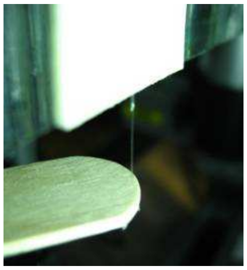
1) enforcement of safety constraints preventing unintentional collisions of the instrument with the retinal surface. (**Safety Barrier**)
2) the ability to scan the probe across a surface while maintaining a constant distance offset (**Surface Tracking**)
3) the ability to place the pick over a subsurface target identified in a scan and then penetrate the surface to hit the target (**Targeting**)

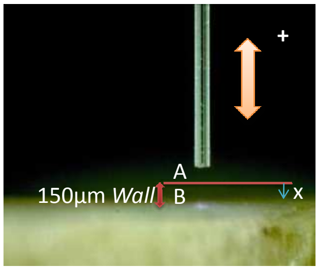
Experimental System



Cooperative Control with Safety Barrier (1D motion)







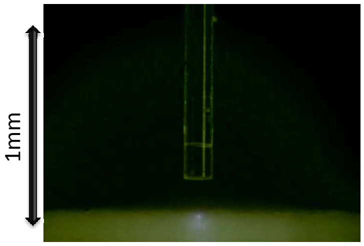
Safety Barrier Control Law:

$$Velocity_{A,B\ F>=0} = k_f F$$

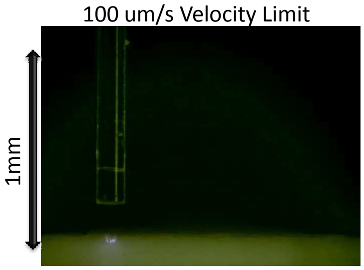
$$Velocity_{A,\ F<0} = \min\{\, k_A x\, ,\ k_f F \,\}$$

$$Velocity_{B,\ F<0} = k_B x$$

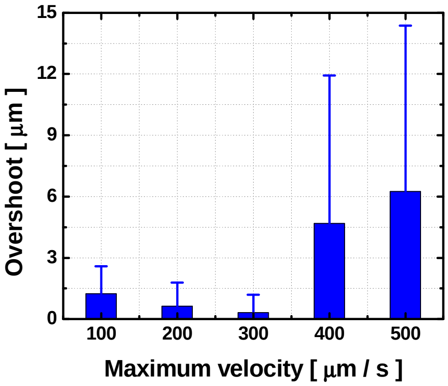
Safety Barrier – 150µm



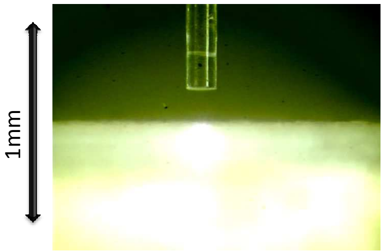
100 um/s Velocity Limit



500 um/s Velocity Limit

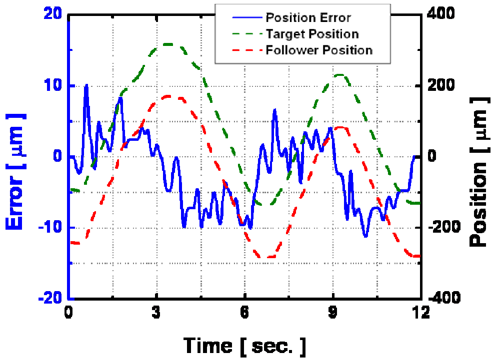


Autonomous Surface Following – 150µm



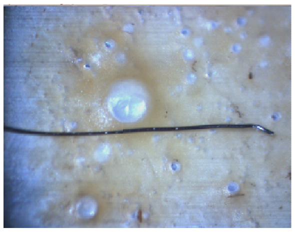
500 um/s Velocity Limit

Noise Rem. /Thresholded/Canny

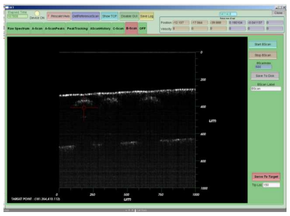


2.5µm/pixel

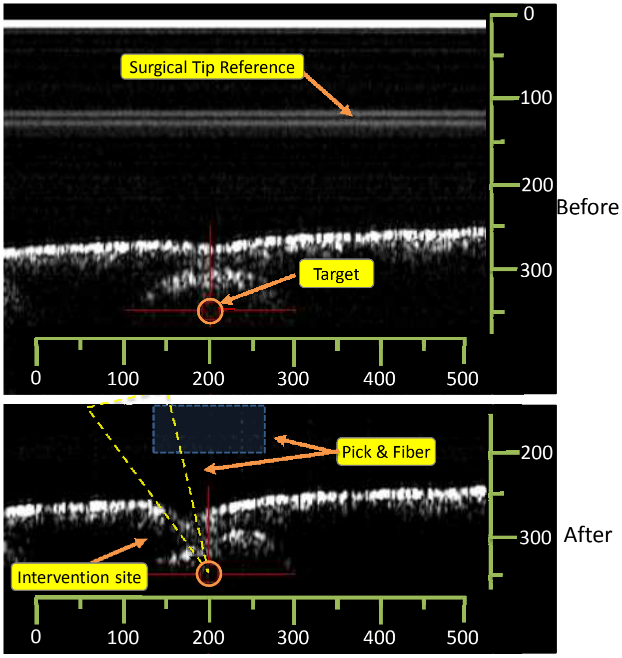
Servo to Target



Wax phantom with bubbles. (100µm wire for reference)



Sample scan (50 µm thick membranes)

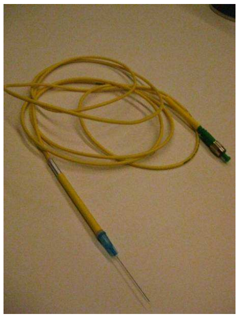


Conclusions

- Great potential for OCT-based “smart instruments” in robotic assisted microsurgical interventions and training
- Current performance is limited by OCT spectrometer and robot dynamics
- Instrument fabrication and handling is challenging
- Existing metrology methods for experiments need improvement

Future

- New OCT
  - 28Khz A Scan Rate
  - 2µm resolution
- Integrate with Micron
- Refine Instrument Calibration
- Use in aqueous environment
- Sensory substitution
  - Auditory
  - Visual overlays



Thank You

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