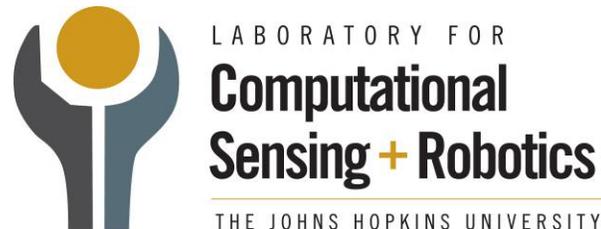
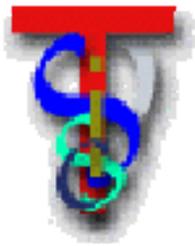


Robots in Image-Guided Interventions

Peter Kazanzides

Associate Research Professor
Dept. of Computer Science
The Johns Hopkins University



My Background

- 1983-1988 Ph.D. EE (Robotics), Brown University
- 1989-1990 Postdoctoral research at IBM on ROBODOC
- 1990-2002 Co-Founder of Integrated Surgical Systems
 - Director of Robotics and Software
 - Commercial development of ROBODOC® System
 - Sales in Europe (CE Mark) and Asia
 - Clinical trials in U.S. and Japan
- 2002-present Research faculty at JHU
 - Leader of CISST ERC engineering infrastructure
 - Research in use of robotics for neurosurgery, cancer research and therapy, telesurgery, microsurgery, ...



Disclaimer

- Dr. Kazanzides currently receives research support from Curexo Technology, manufacturer of the Robodoc® System, and has served as a consultant to the company.



Laboratory for Computational Sensing and Robotics (LCSR)



Hackerman Hall



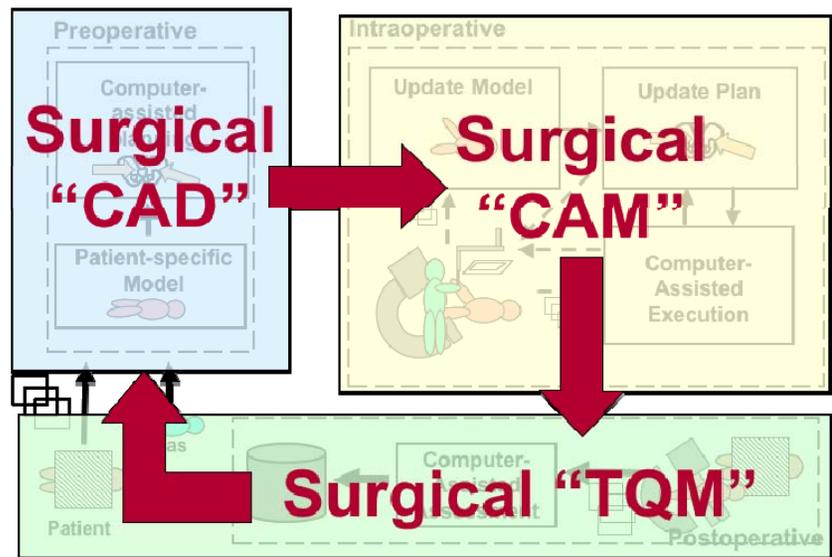
Swirnow Mock Operating Room



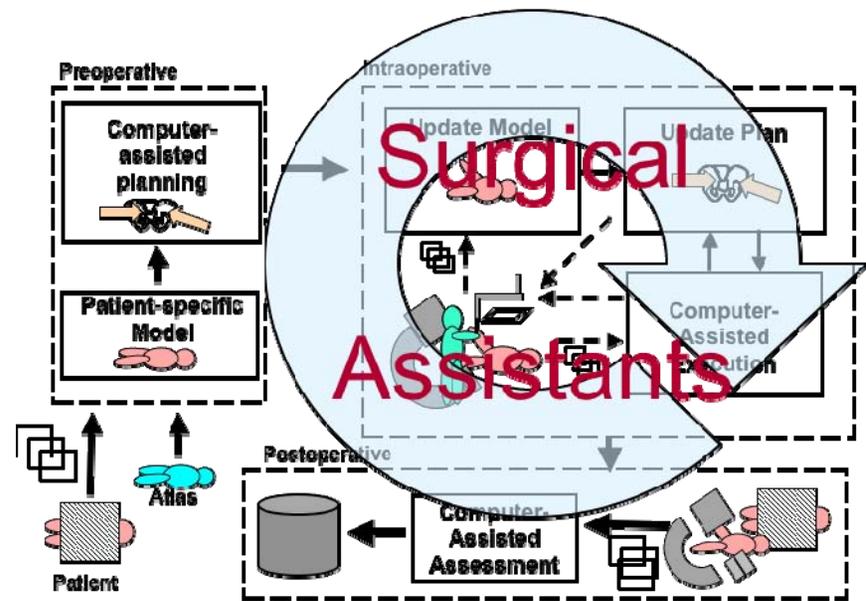
Rotorium (shared lab)

What is Robotic Surgery?

The integration of information processing with sensing and robotics to produce a “super-human” man-machine team



Surgical CAD-CAM
(image-guided robots)



Surgical Assistance

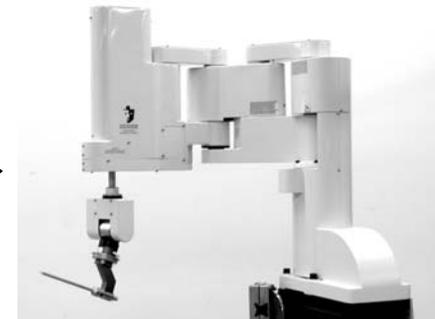
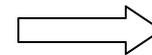
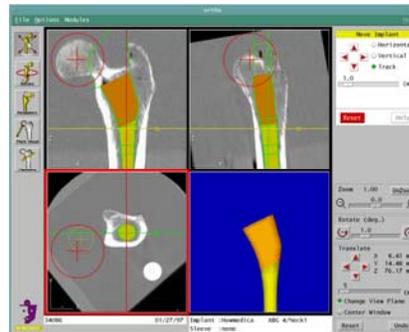
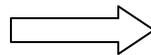
Themes of Today's Talk

- Origins of Robotic Surgery
 - Surgical CAD/CAM: Robodoc ® , Neuromate, ...
 - Surgical Assistance: da Vinci ®, Aesop, ...
- Current and Future Research
 - Merger of Surgical CAD/CAM and Surgical Assistance
 - Better situational awareness in Surgical CAD/CAM
 - Adding image guidance to Surgical Assistance



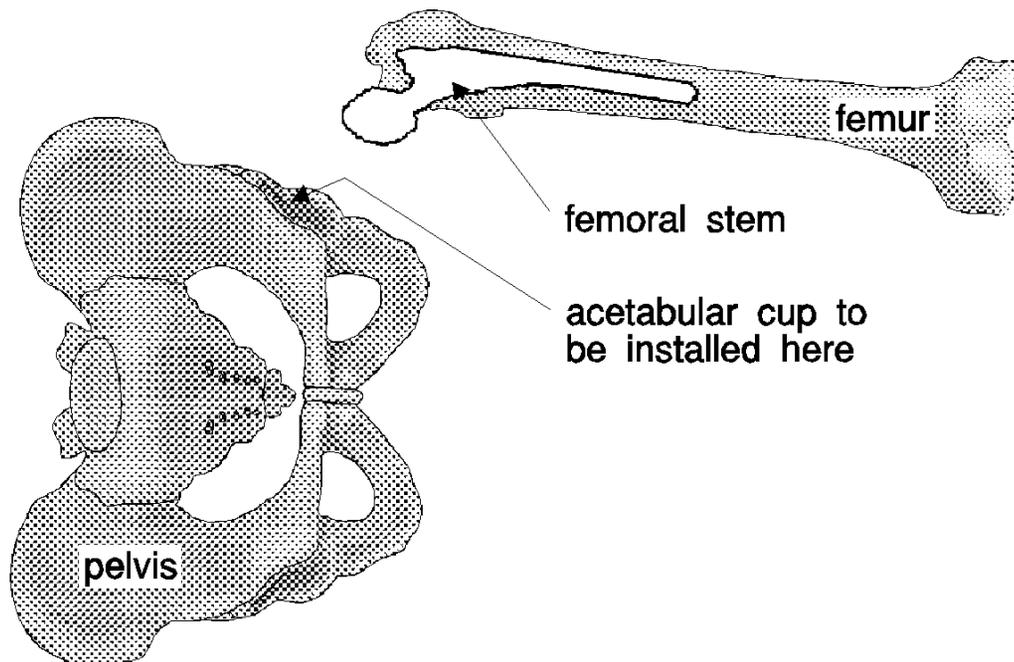
Surgical CAD/CAM: Overview

- Preoperative imaging (e.g., CT scan)
- Preoperative planning
- Intraoperative registration
- Computer assistance to execute plan
 - (e.g., autonomous or semi-autonomous robot)



Surgical CAD/CAM: ROBODOC® System

- Initially developed to assist with Total Hip Replacement (THR) surgery
 - machine femur for cementless prosthesis (femoral stem)

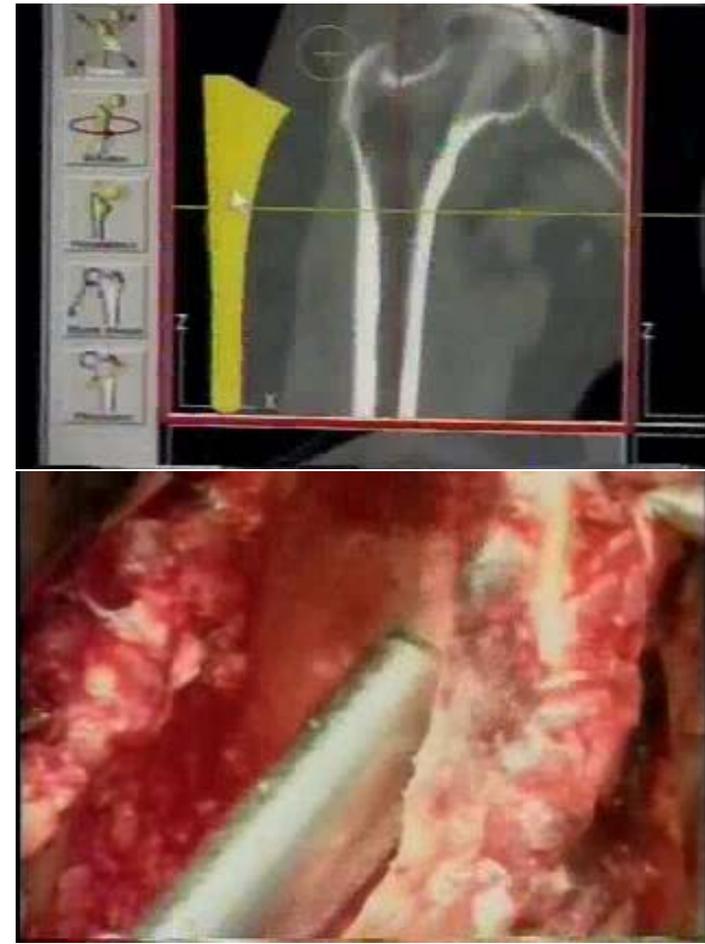


ROBODOC® System

Conventional procedure
(mallet and broach)



Computer-assisted
planning and execution



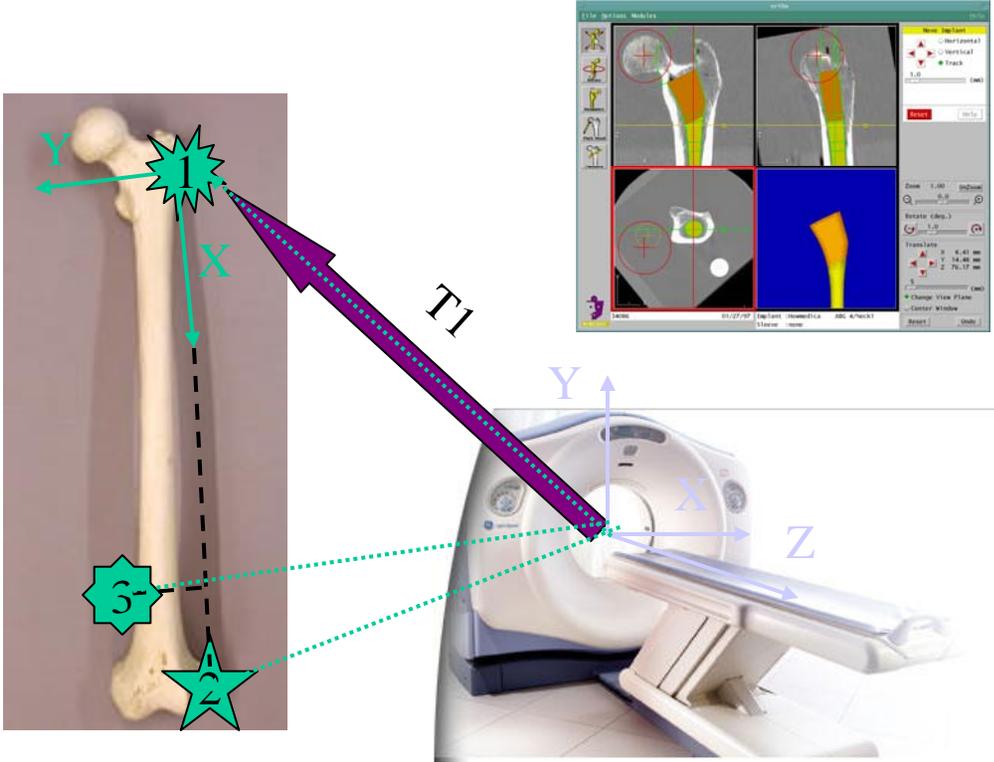
ROBODOC Pin-Based (Fiducial) Registration

Surgery to implant pins (bone screws) prior to CT



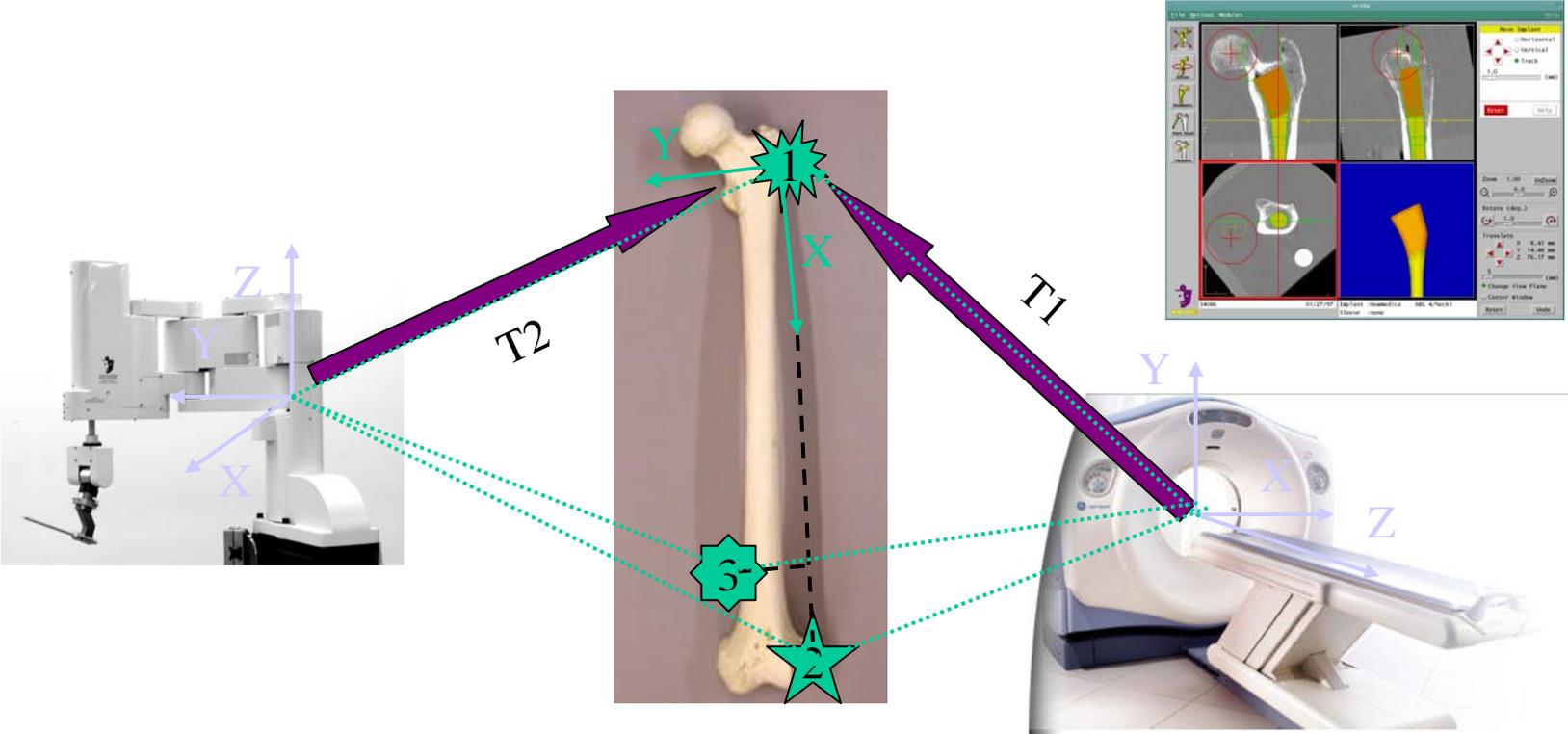
ROBODOC Pin-Based (Fiducial) Registration

Planning software detects pins in CT coordinates



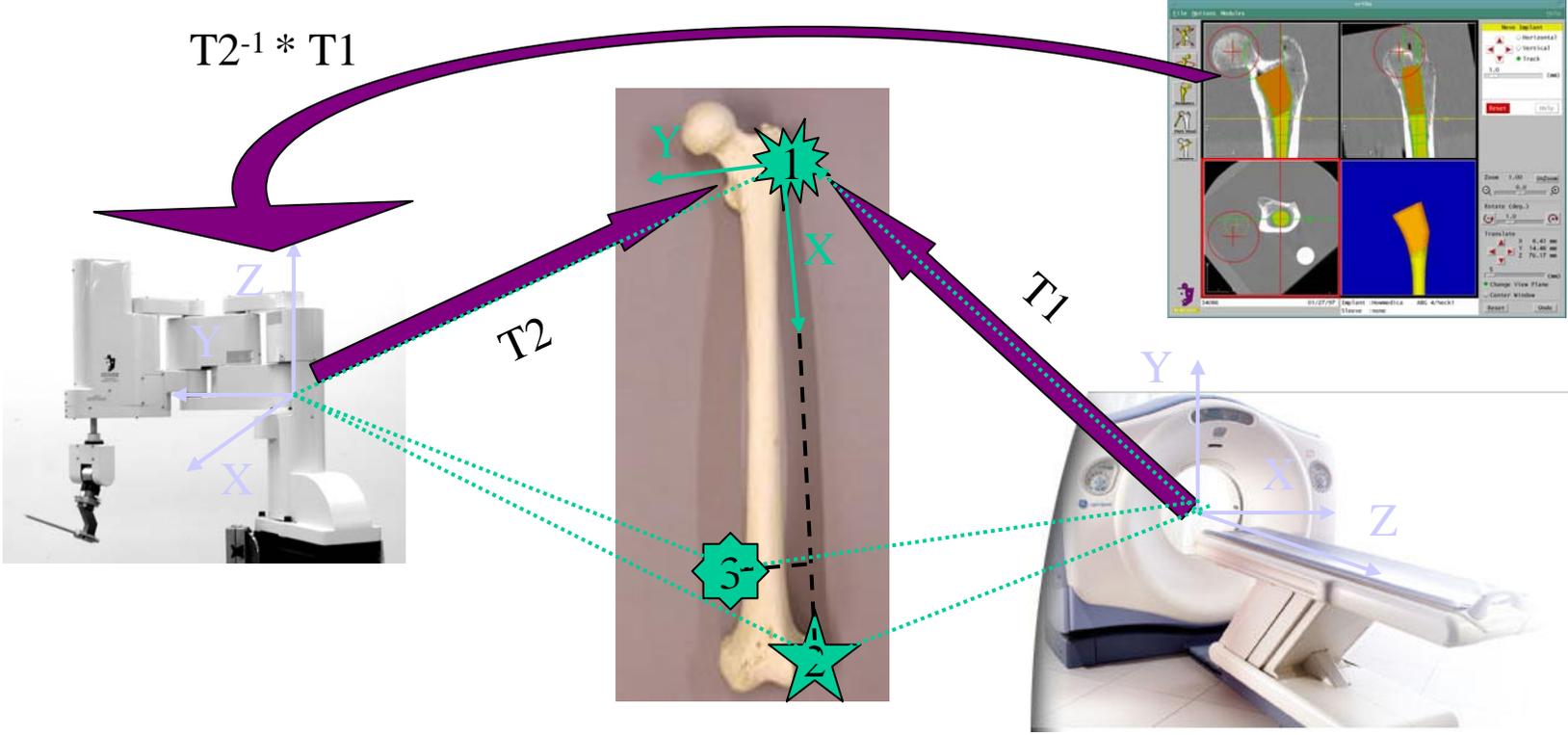
ROBODOC Pin-Based (Fiducial) Registration

Robot finds pins in Robot coordinates



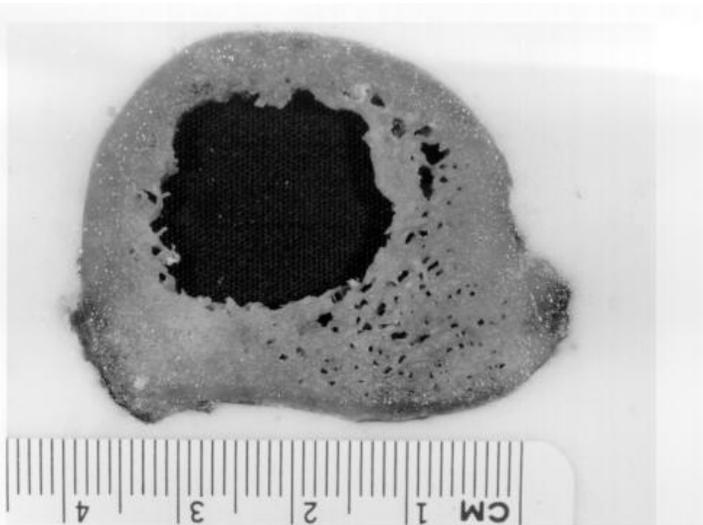
ROBODOC Pin-Based (Fiducial) Registration

Software checks pin distances (safety check) and then computes transformation between CT coordinates and robot coordinates

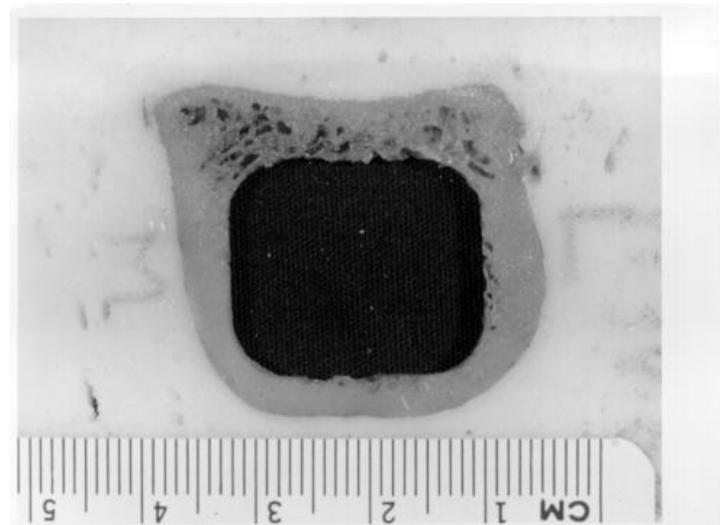


ROBODOC Benefits

- Intended benefits:
 - Increased dimensional accuracy
 - Increased placement accuracy
 - More consistent outcome



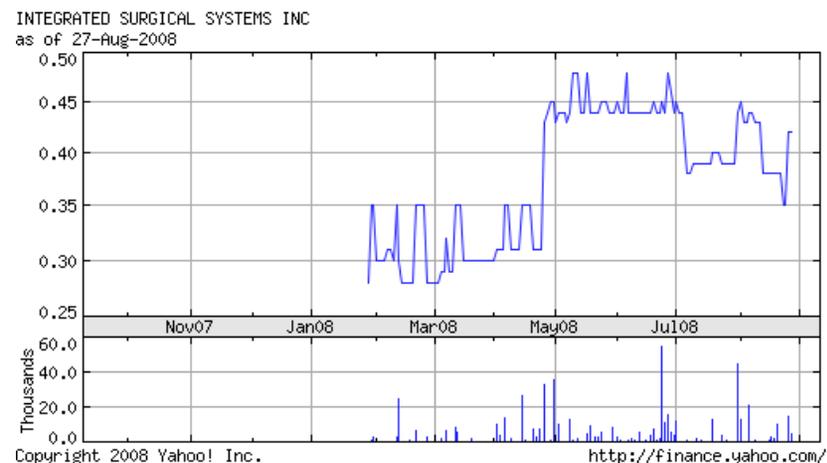
Broach



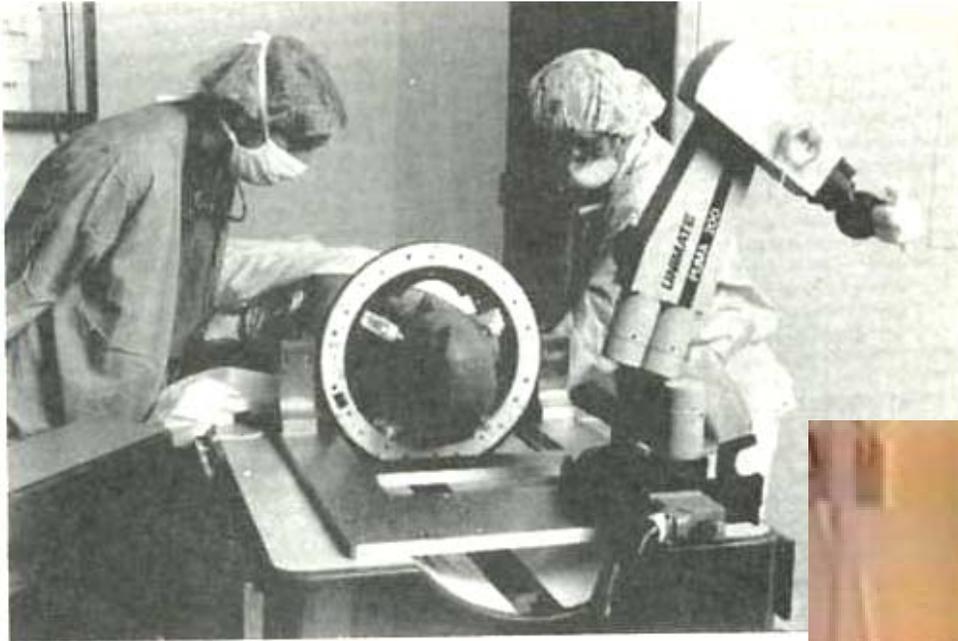
Robot

ROBODOC Status

- Approximately 50 systems were installed worldwide
 - Europe (Germany, Austria, Switz., France, Spain)
 - Asia (Japan, Korea, India)
 - U.S. (Clinical trial for FDA approval)
- Over 20,000 hip and knee replacement surgeries
- ROBODOC no longer used in Europe (lawsuits still ongoing)
- Popular in Korea – one hospital claims 2,500 surgeries/year
- Curexo Technology still attempting to grow business

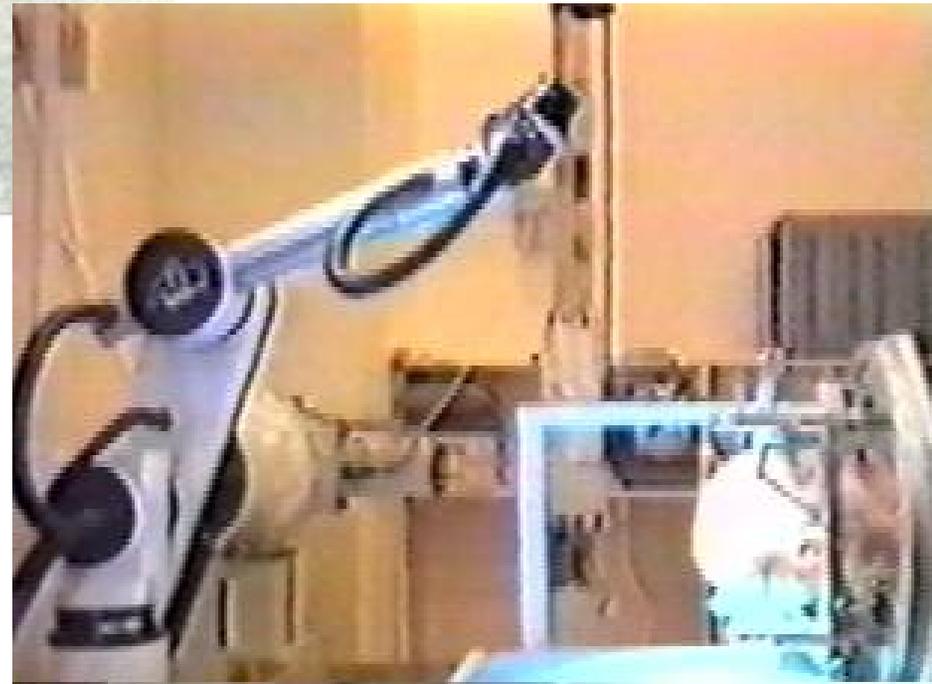


Surgical CAD/CAM: Robotic Needle Guidance for Neurosurgery

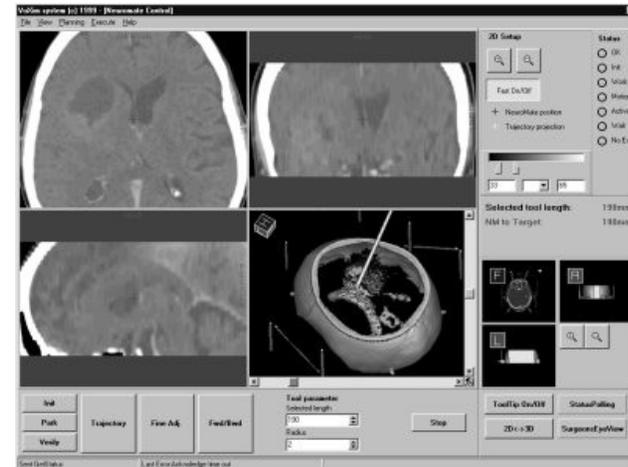


Kwoh, et al. 1988

Lavallee, Troccaz, et al. 1989

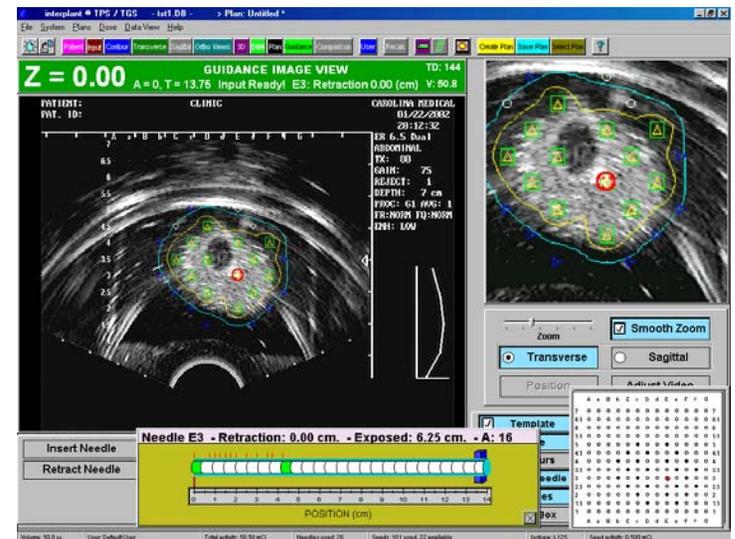
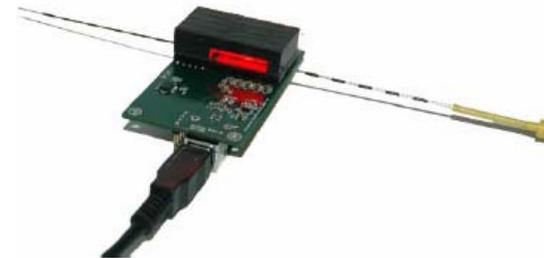
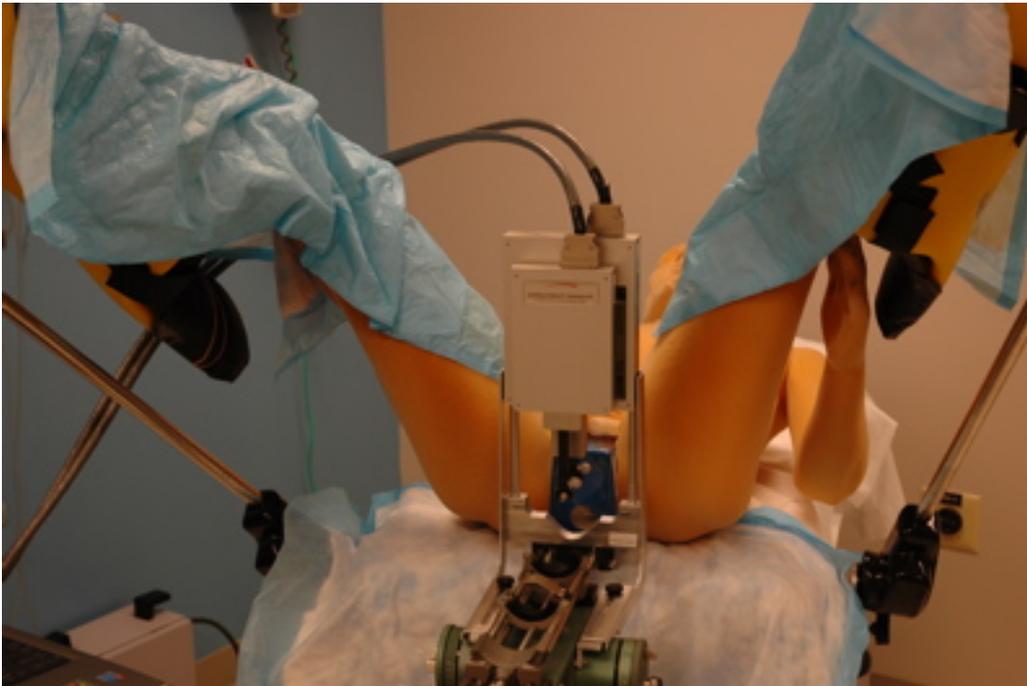


Surgical CAD/CAM: Robotic Needle Guidance for Neurosurgery



Courtesy: Integrated Surgical Systems

TRUS Guided Prostate Seed Placement (ultrasound for intraoperative planning)



JHU RadOnc: Song, DeWeese
JHU Engineering: Kazanzides
Queen's : Fichtinger
Industry: Burdette, Acoustic Medsystems
Kronreif, ProFactor



Surgical CAD/CAM: Summary

- Works well when:
 - Registration can be performed accurately
 - Anatomy does not change
 - Little or no motion, deformation
- Thus, more often used for:
 - Orthopaedics
 - Neurosurgery
 - Needle-based interventions with minimal change between imaging and insertion



Surgical Assistance: Overview

- Provide information and/or mechanical assistance during procedure
 - improve physician's existing sensing and/or manipulation
 - e.g., reduced tremor, go where physician cannot go
 - increase the number of sensors and actuators (e.g., more eyes and hands)



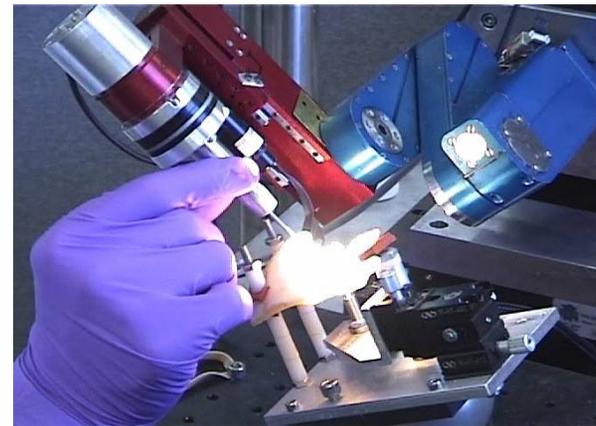
Surgical Assistance: Overview

- Control paradigms:

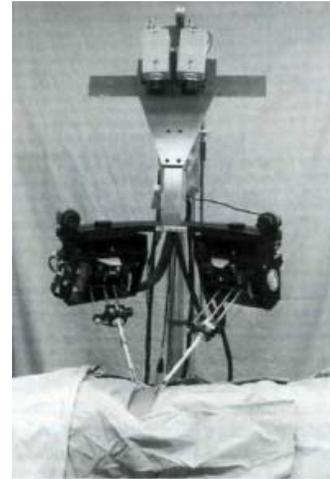
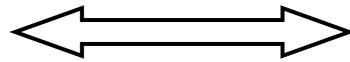
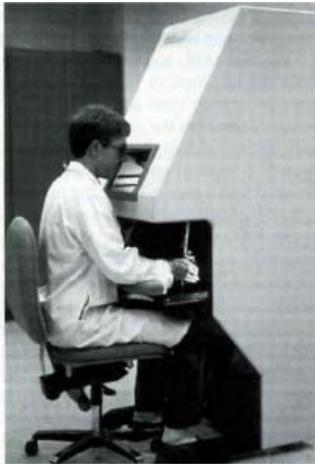
- Teleoperation



- Cooperative control



Surgical Assistance: da Vinci® System



SRI telesurgery system, *circa* 1992



da Vinci S system, *circa* 2006

da Vinci Status

- Over 1,800 systems installed worldwide
- Principle application prostatectomy
 - By 2007, over 50% of prostatectomies in US were performed by a da Vinci
- Financial success
 - 2007 revenue \$601 M
 - 2010 revenue \$1,413 M
 - Intuitive Surgical market cap. > \$15 B

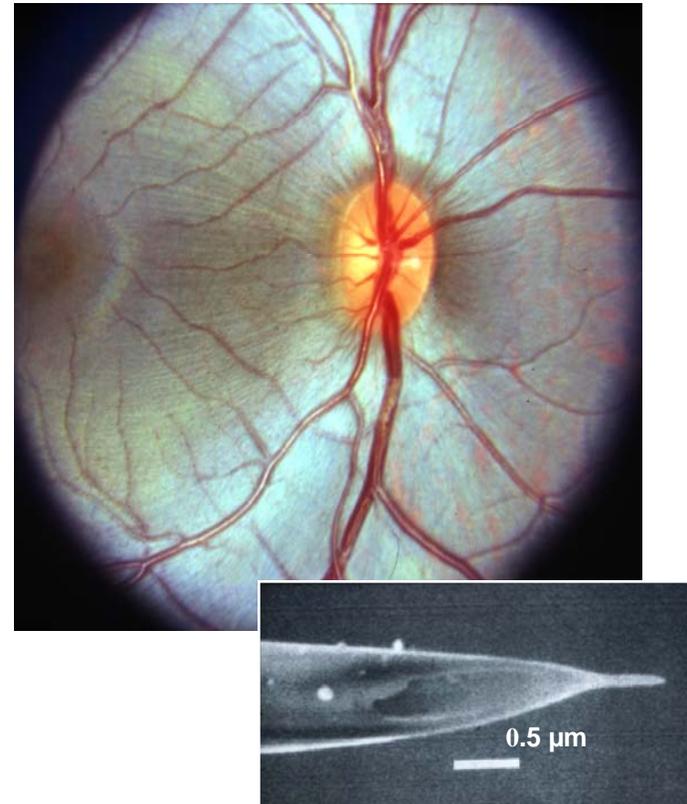


Surgical Assistance: Robotic “Third Hand” Assistants

- Limb positioners
- Retractors
- Endoscope holders
 - Aesop
 - IBM/JHU LARS
 - etc.
- Can incorporate sophisticated HMI, voice, vision, etc.

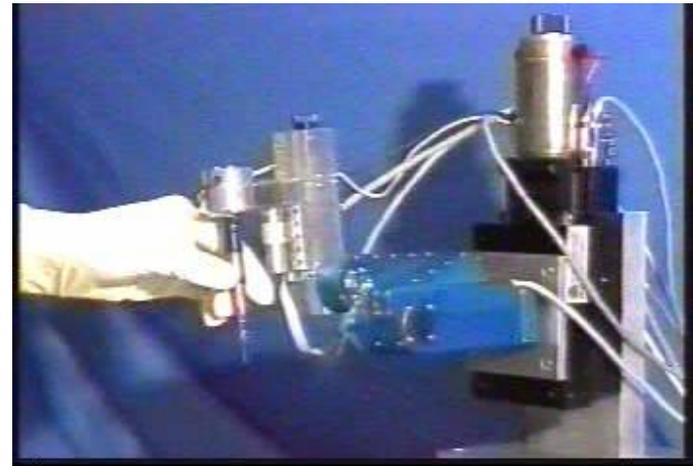
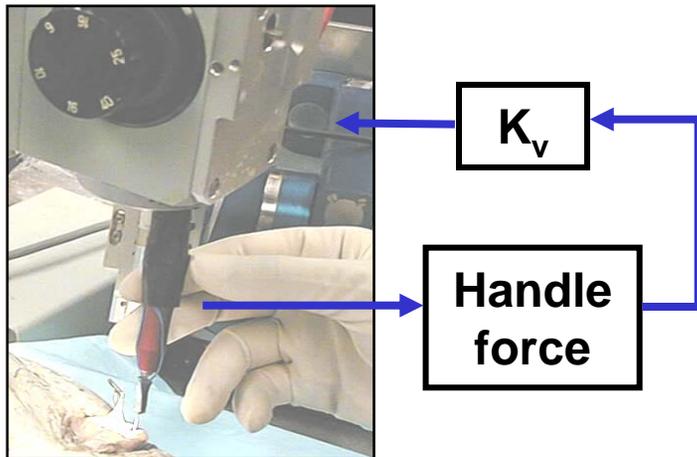


Surgical Assistance: Retinal Microsurgery



(Left) Regular setup of ophthalmic procedure and (Right) Needle used to insert into a retinal vein in vein cannulation procedure

Steady Hand Guidance for Retinal Microsurgery



Free hand motion

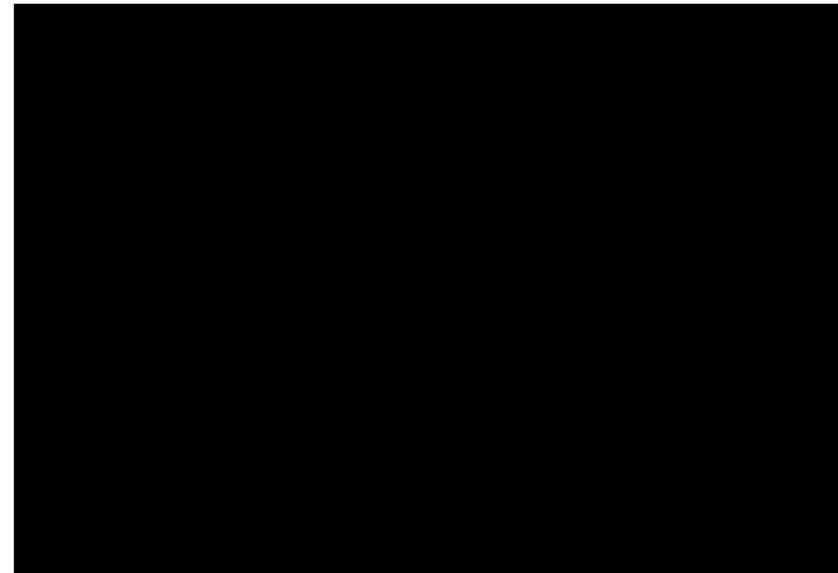


Steady hand motion

Steady Hand Guiding at the Cellular Level



Kumar, Kapoor, Taylor



The Future: Merger of Surgical CAD/CAM and Surgical Assistants

- Provides assistance to enable surgeon to execute a preoperative or intraoperative plan
 - Why should a Surgical CAD/CAM system continue to execute a preoperative plan if the situation has changed?
 - Why shouldn't a Surgical Assistance system consider preoperative information?
- Result is a human/machine collaborative system



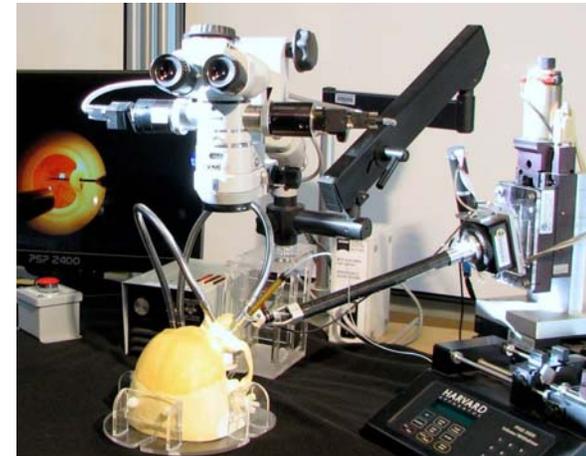
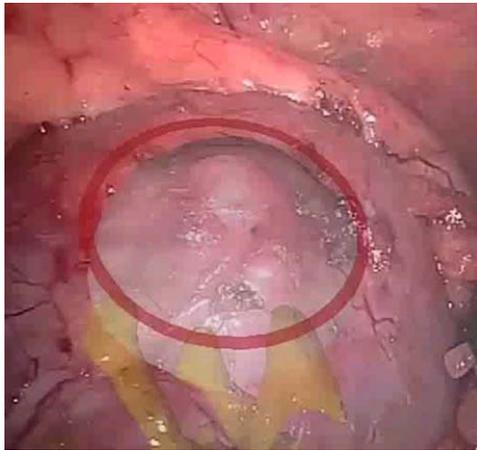
New Technical Challenges

- Provide more complete information to the surgeon
 - Pre-operative images (preferably registered to view)
 - Intra-operative images (e.g. ultrasound)
 - Local sensing: force, tissue stiffness, oxygenation
- Provide physical guidance
 - Improve safety through “no-fly” zones
 - Improve repeatability through guidance (virtual rulers)
- Improve dexterity and reduce size (mechanism design)
 - Robots for micro-surgical applications
 - Go where humans cannot go



Case Studies

- Augmented reality for (da Vinci) minimally-invasive surgery
- Retinal microsurgery system
- Cooperative control for skull base surgery



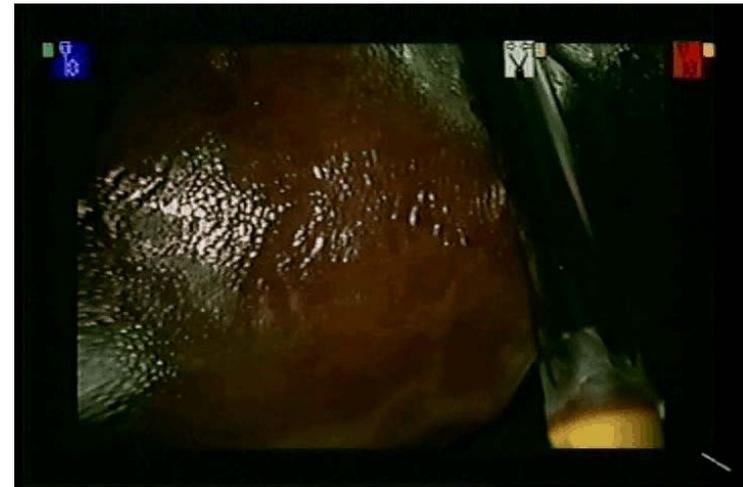
Integration of Preoperative Images



Surgical Assistant Workstation (SAW)

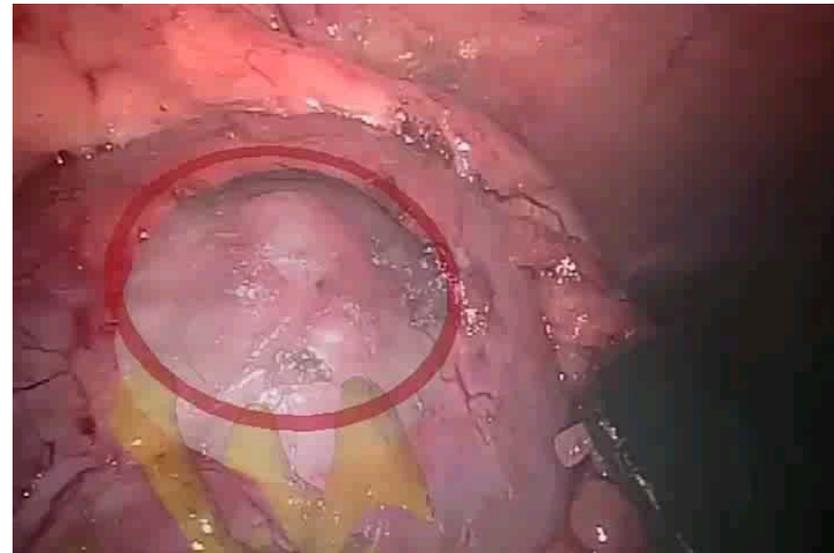
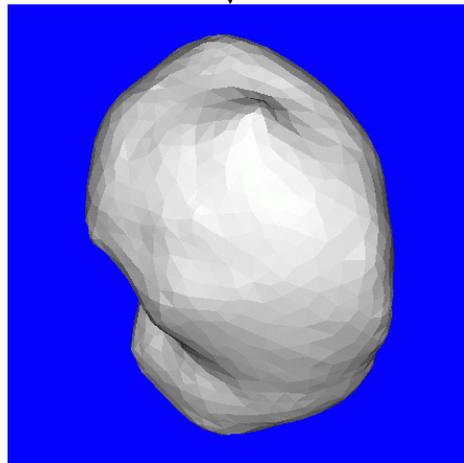
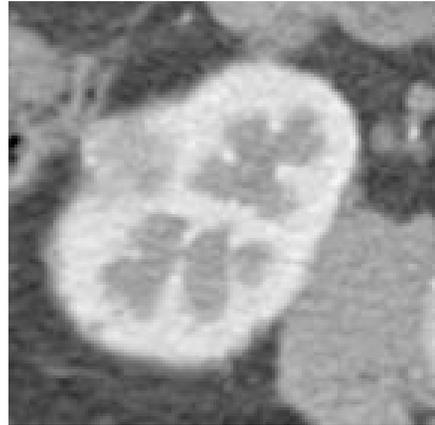
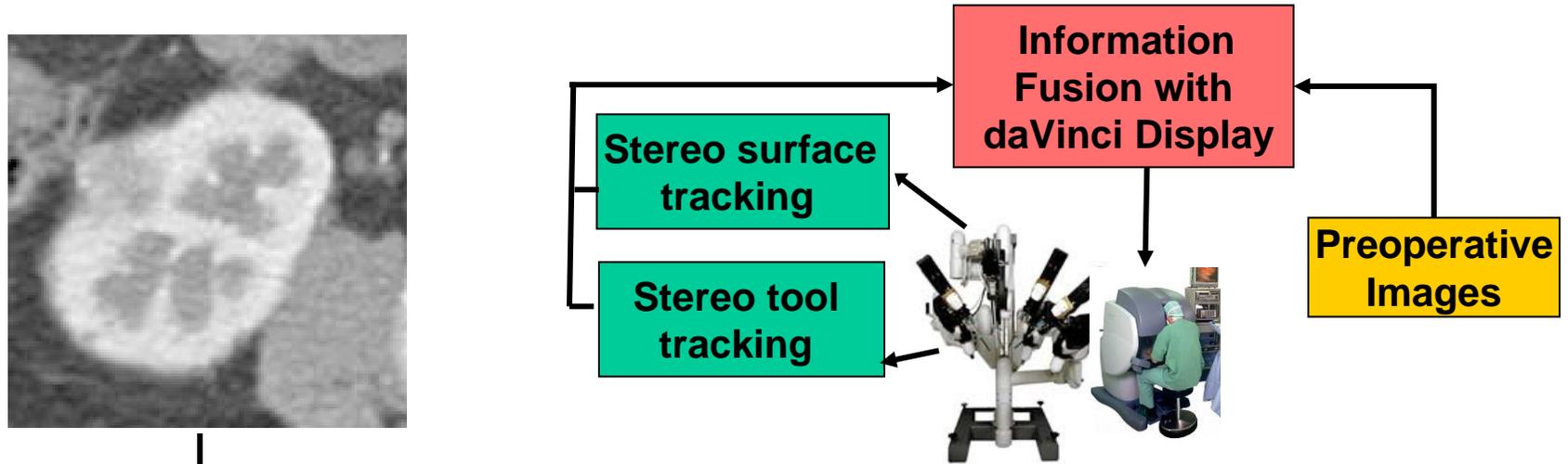
Better integration is possible!

Augmented Reality in Robot-Assisted Surgical Systems



Clockwise from upper left: daVinci surgical robot;
Information overlay of force information on daVinci
display (Okamura *et al.*); Real time overlay of
ultrasound images on daVinci display (Taylor *et al.*)

Video to CT Registration

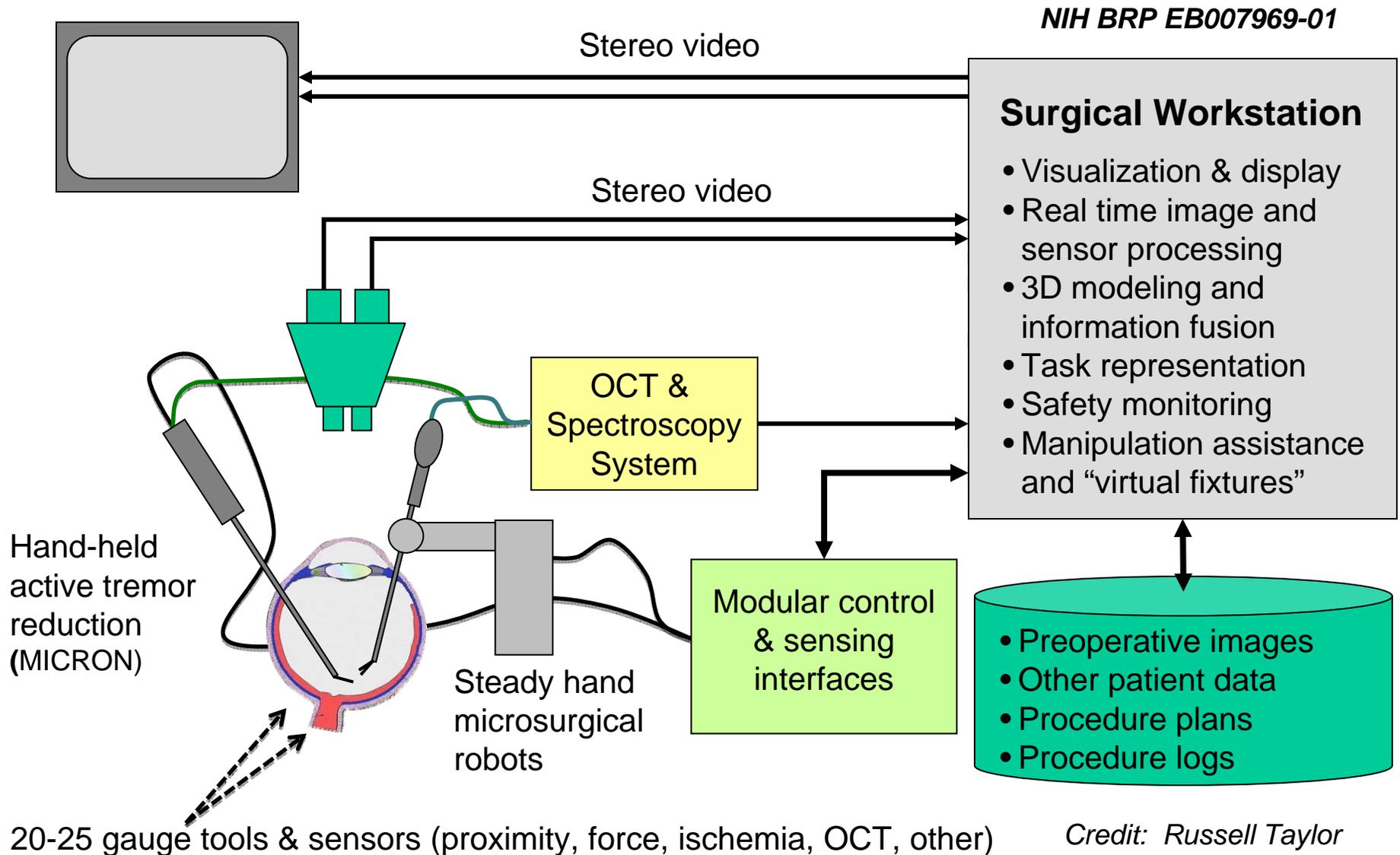


Vagvolgyi, Hager, Taylor, Su

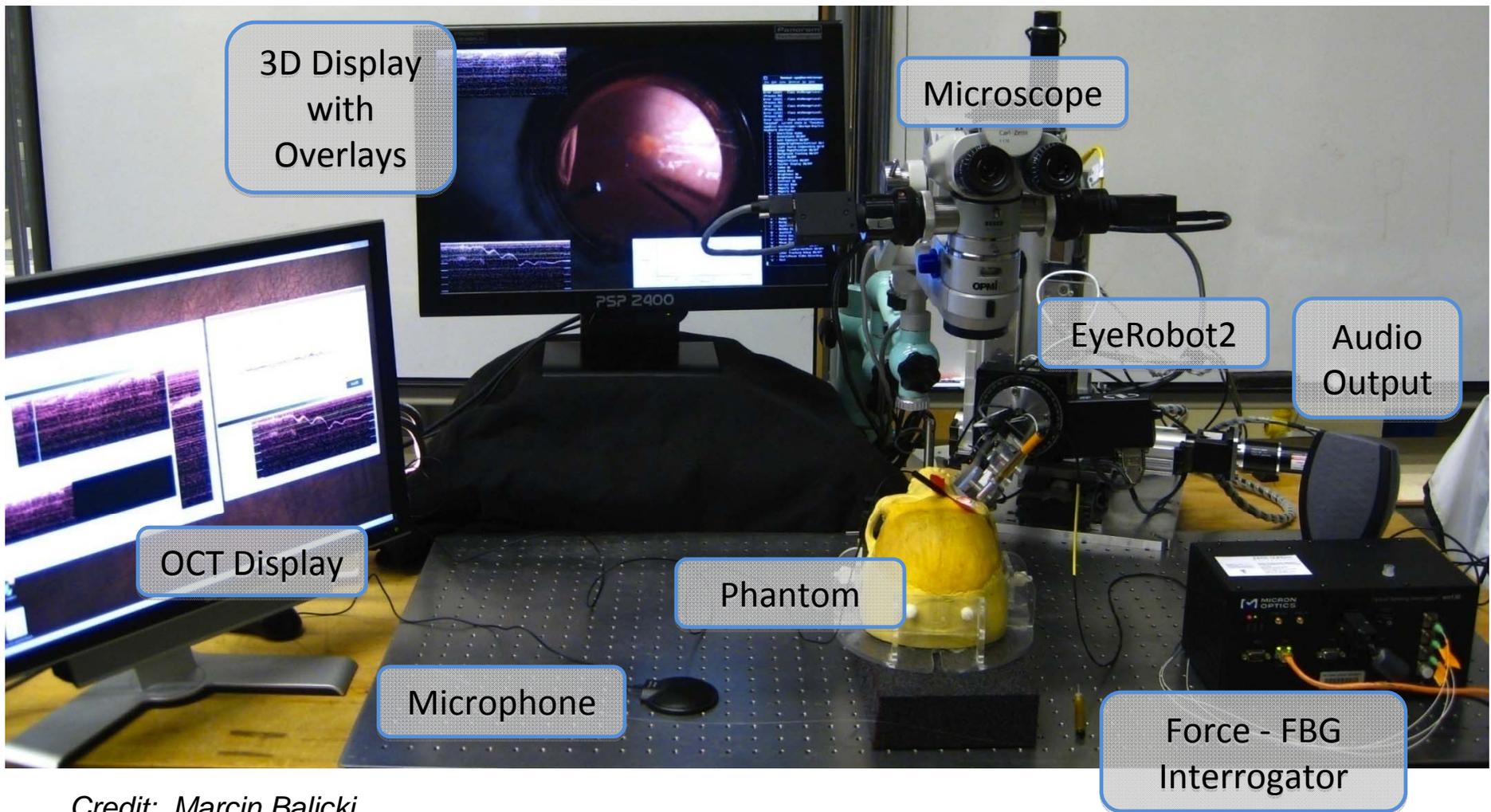




Retinal Microsurgery System

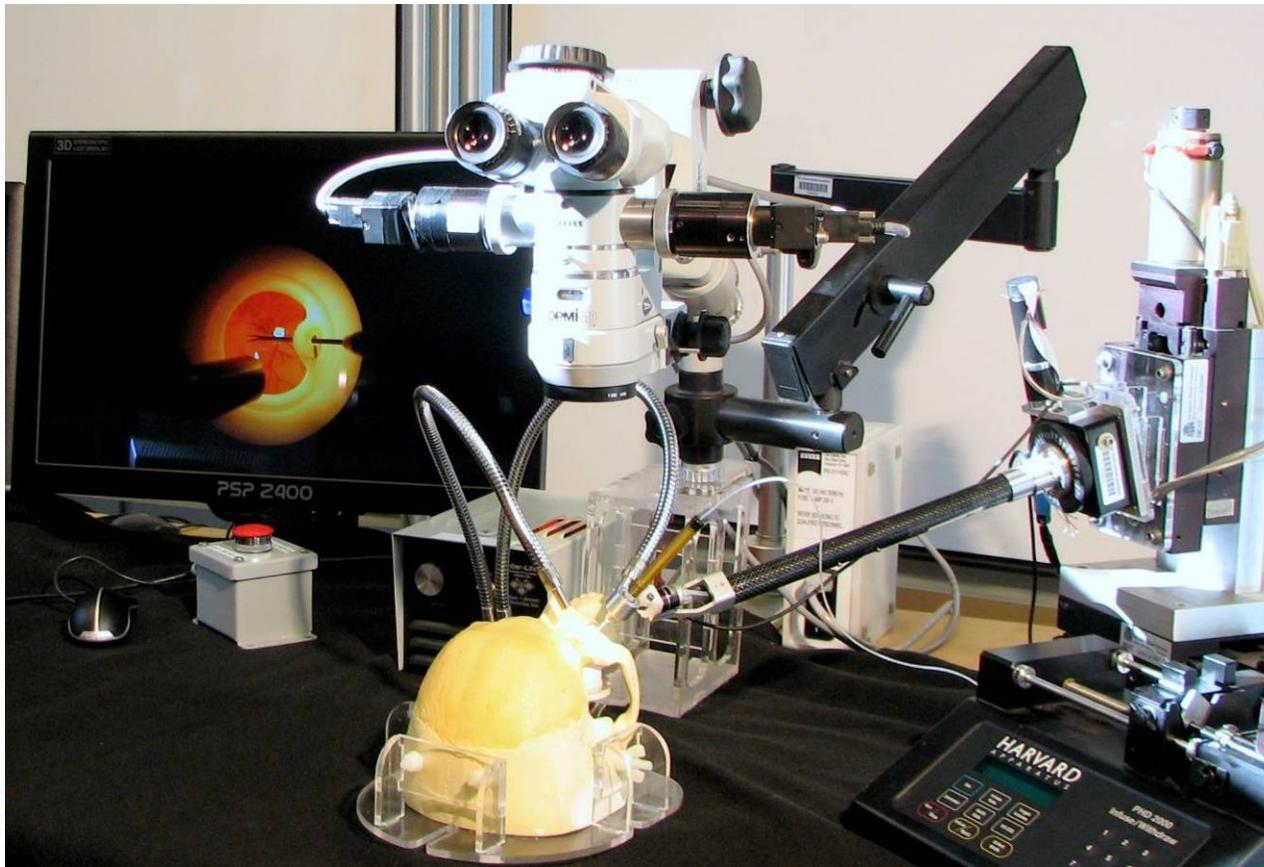


Retinal Microsurgery System



Credit: Marcin Balicki

Manipulators for Microsurgery

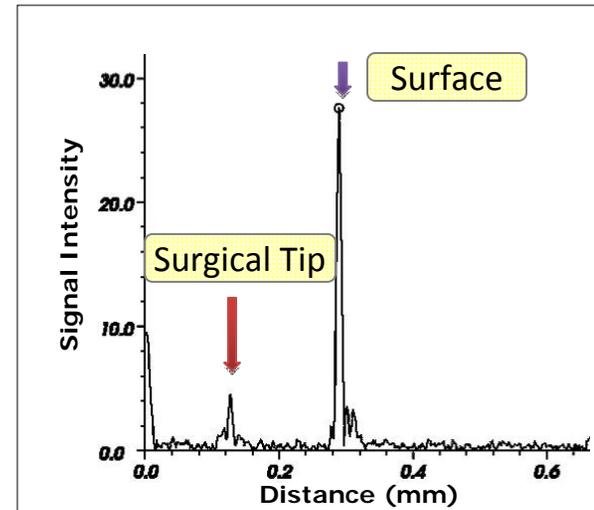
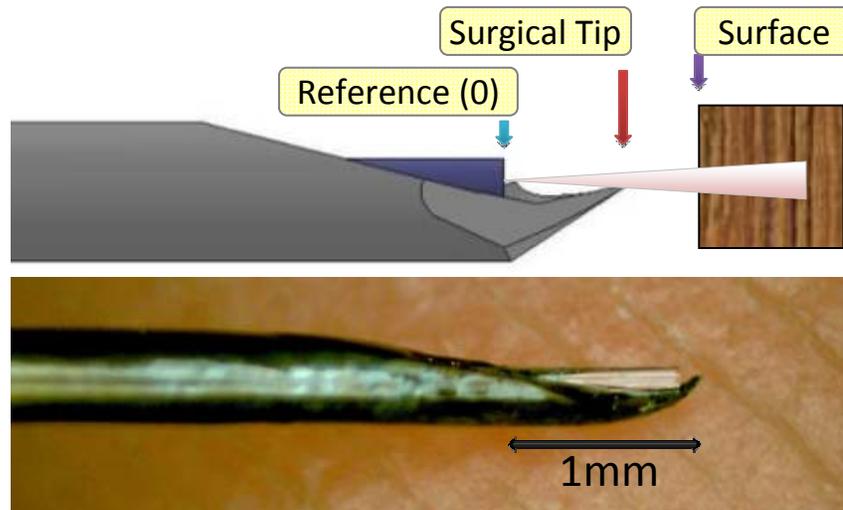


Steady Hand Robot (Rev 2)
lordachita, Balicki, Kazanzides, Taylor



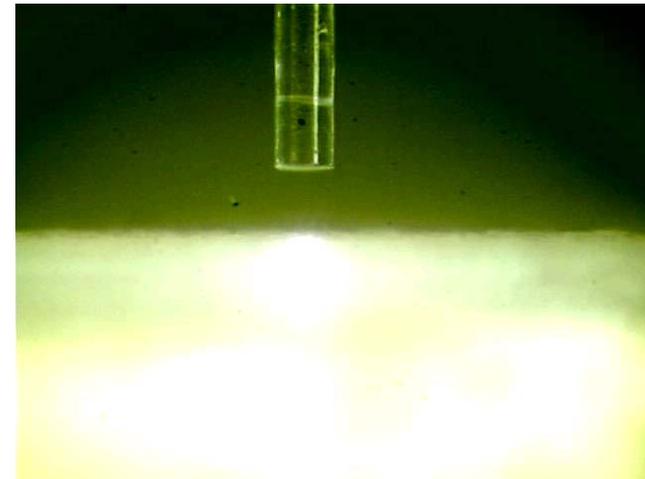
Micron
Riviere (CMU)

Sensor-Based Manipulation (OCT)

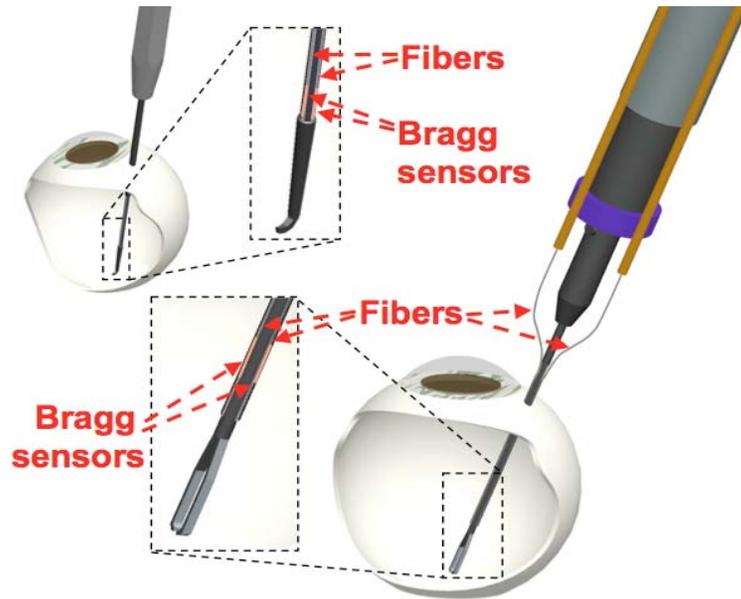


Optical Coherence Tomography (OCT)

Surface following using OCT visual servo
Balicki, Kang, Taylor

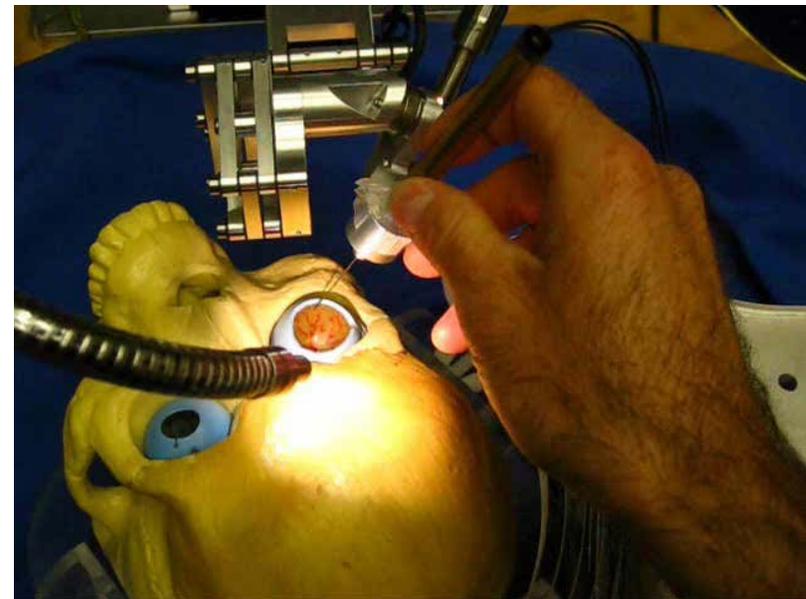


Sensor-Based Manipulation (Force)

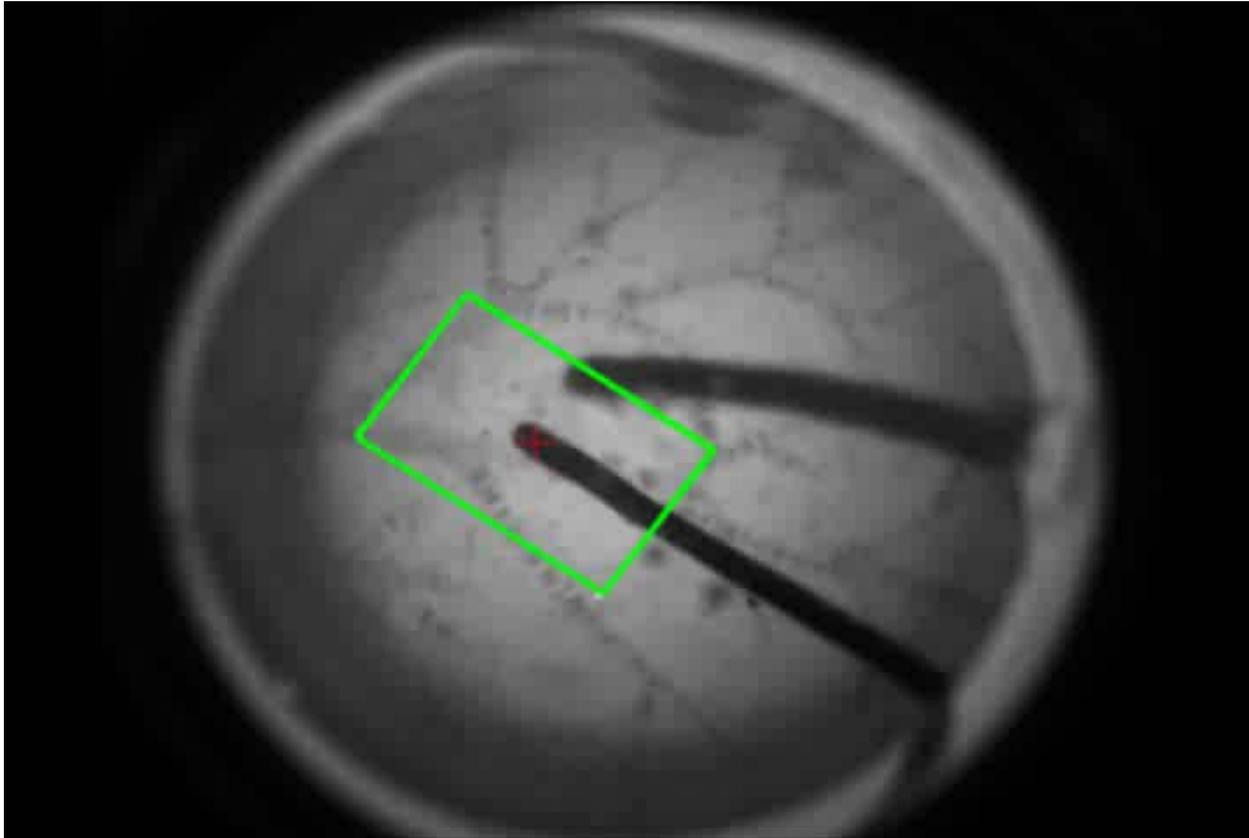


Fiber Bragg Grating (FBG) sensor and interrogator

Sensory substitution (force \rightarrow audio)
Balicki, Iordachita, Taylor



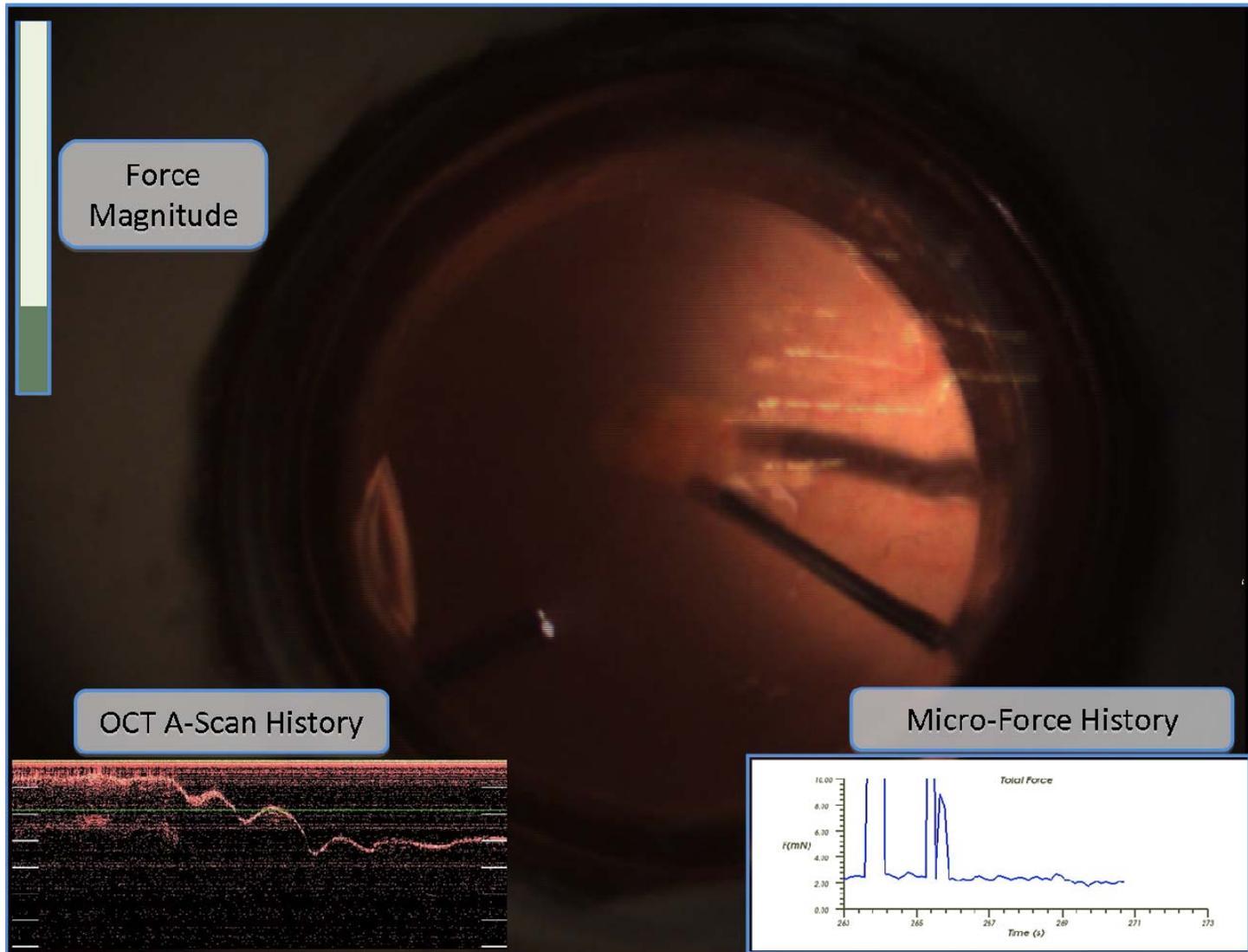
Tool Tracking



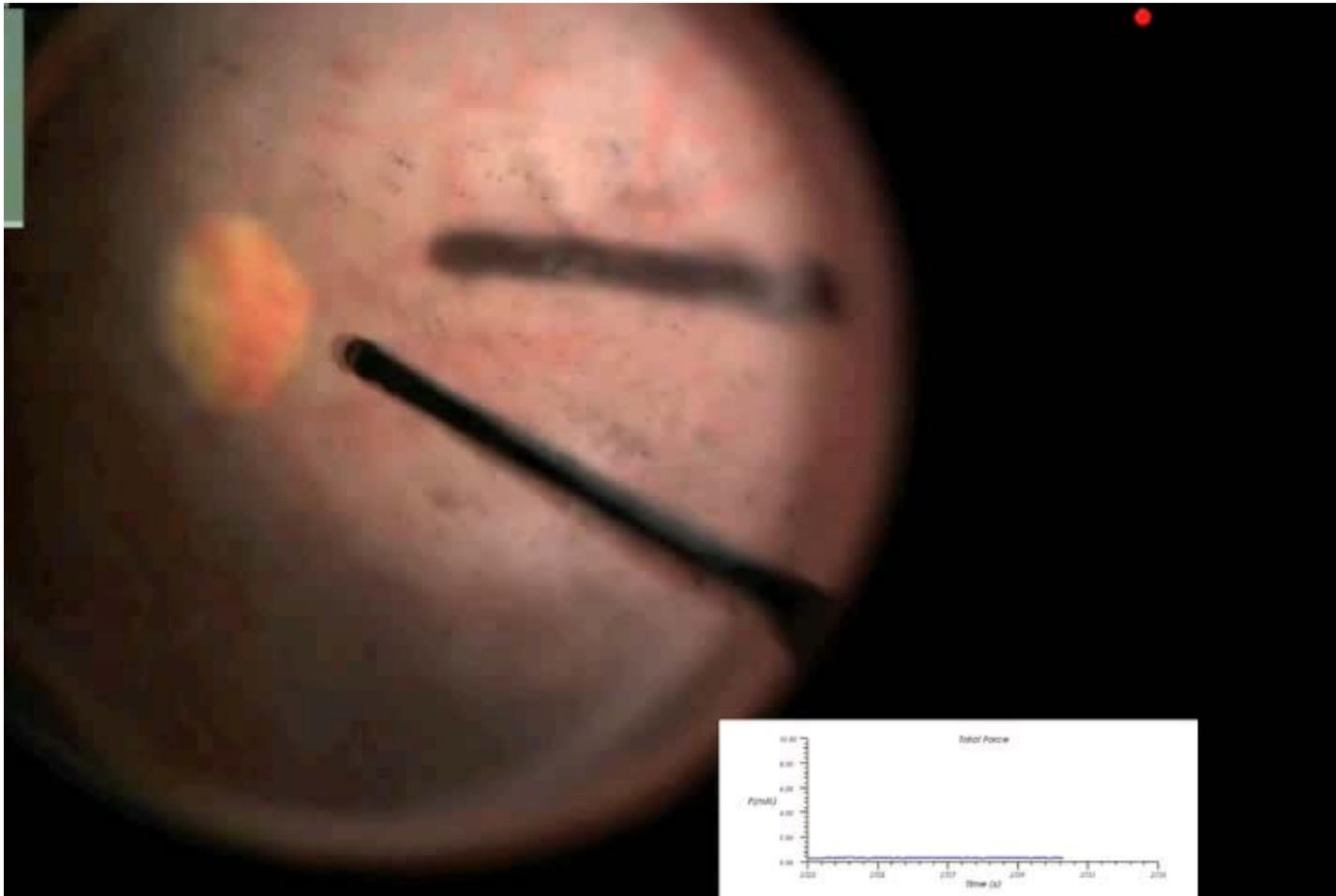
Especially useful for hand-held instruments

Credit: Rogerio Richa

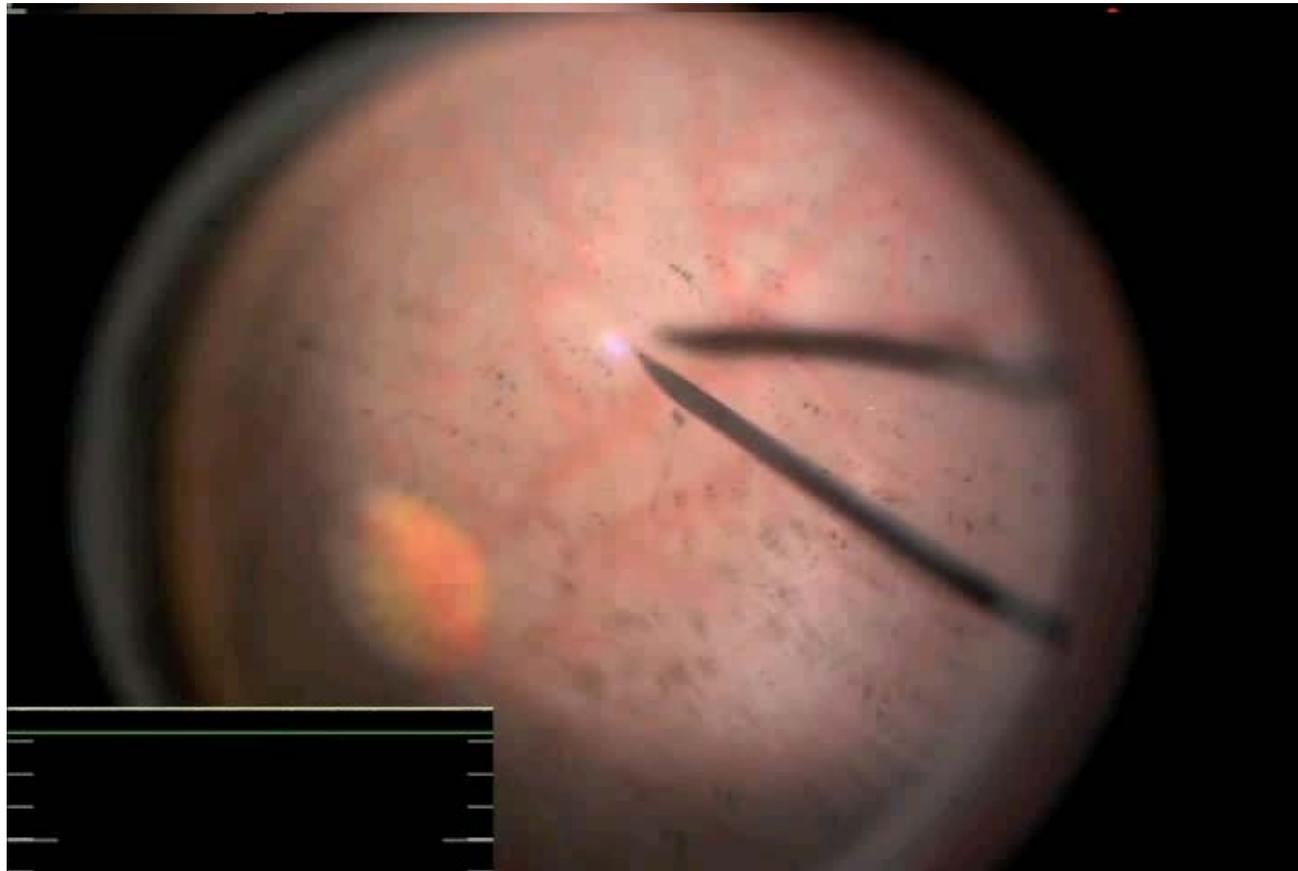
Augmented Reality Display



Micro-force overlay



Continuous OCT (MScan) scan/review



(not yet using background tracking)

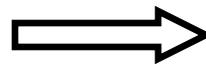
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 - Go where humans cannot go



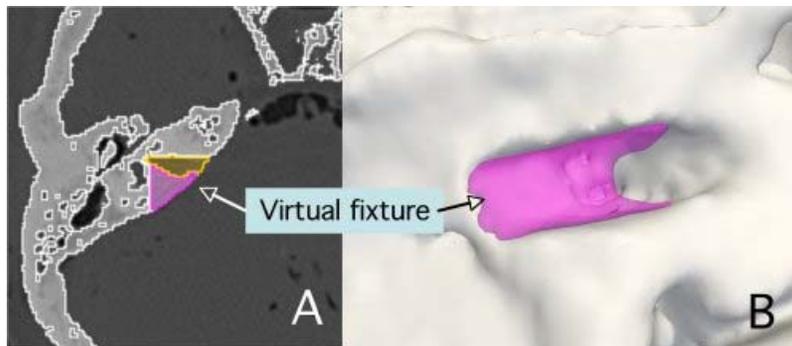
Example: Cooperatively-controlled Robot for Skull Base Surgery

- Skull base has complex 3D anatomy and traversing critical structures (nerves, vessels)
- Drilling of the skull base is often necessary to achieve access, such as for tumor removal
- Manual drilling can take hours, even when only millimeters are removed
 - Risk of damage to critical structures
 - Limits of human dexterity
 - Surgeon fatigue



Proposed Solution

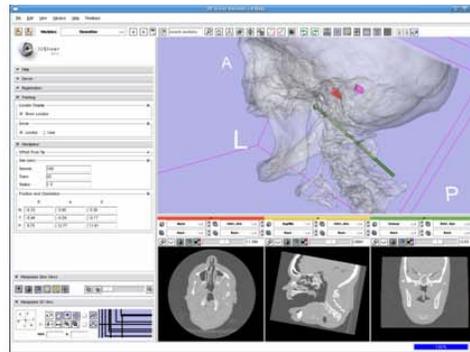
- Use robot assistance to improve safety and efficiency of skull base drilling:
 - Define “safe zone” (virtual fixture) in CT
 - Register CT, patient, and robot
 - Robot holds cutting tool
 - Cooperative control: responds to surgeon’s forces
 - Virtual fixtures: prevent excursion outside “safe zone”



System Description



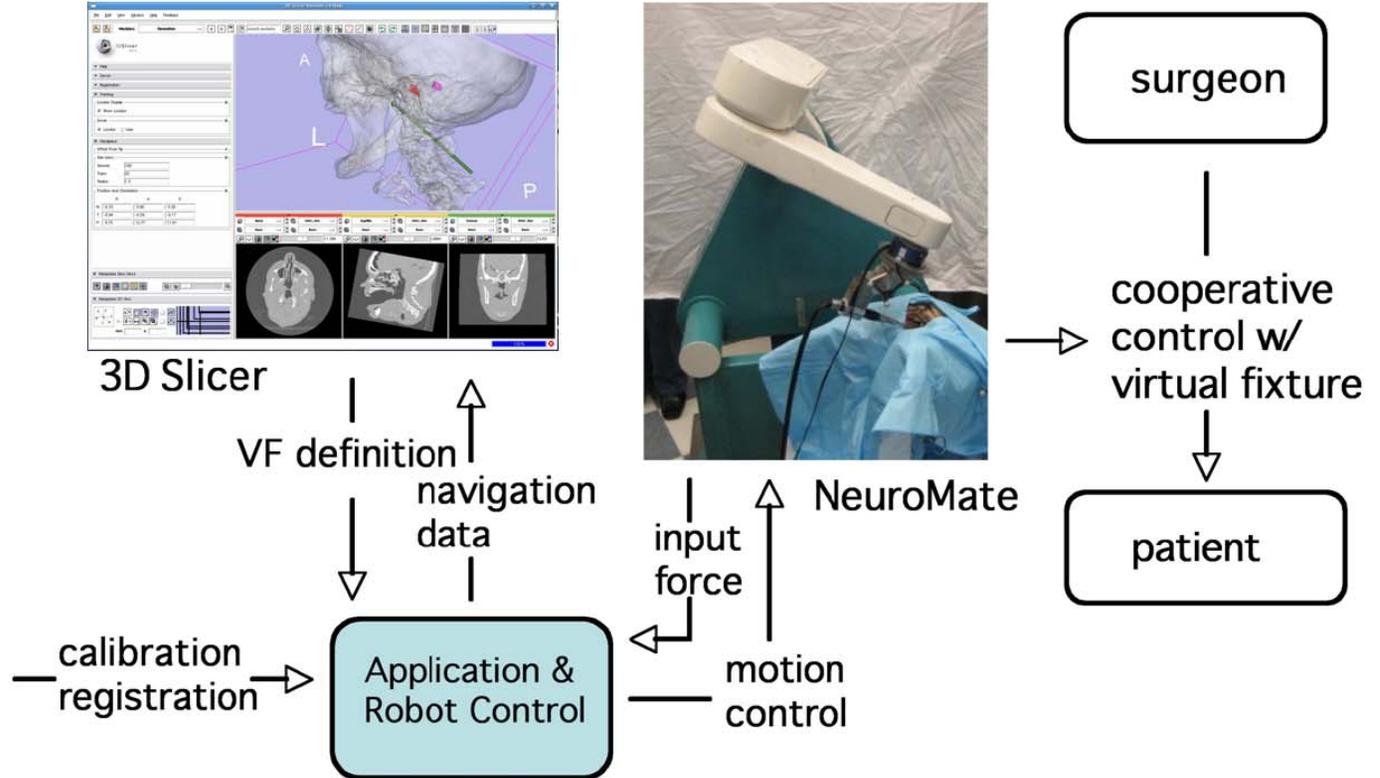
StealthStation



3D Slicer

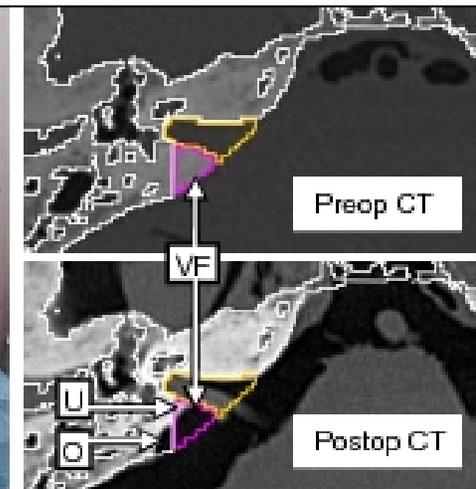
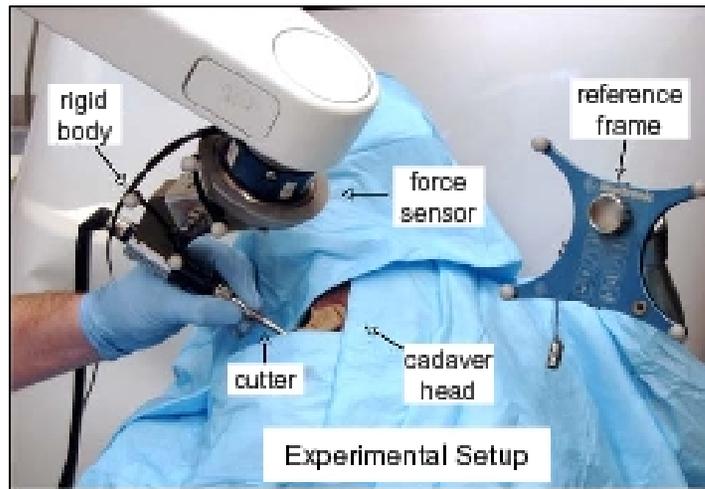


NeuroMate



Cadaver Experiments

- Drill bone around internal acoustic canal (IAC)
 - Robot provided ergonomic benefits
- Postoperative CT to assess accuracy
 - Average overcut ~1 mm
 - Maximum overcut ~3 mm



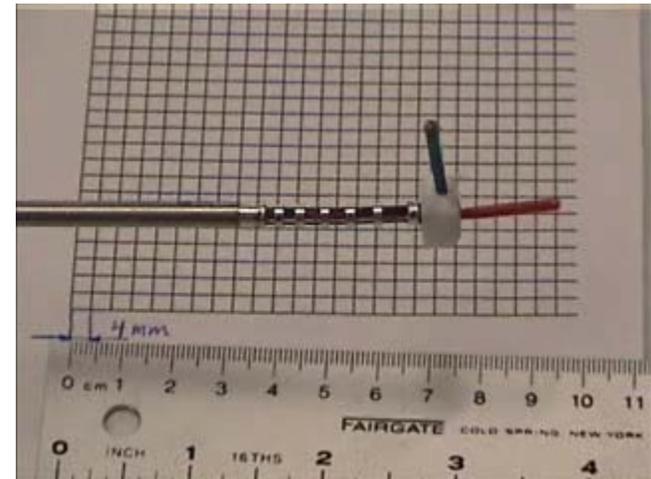
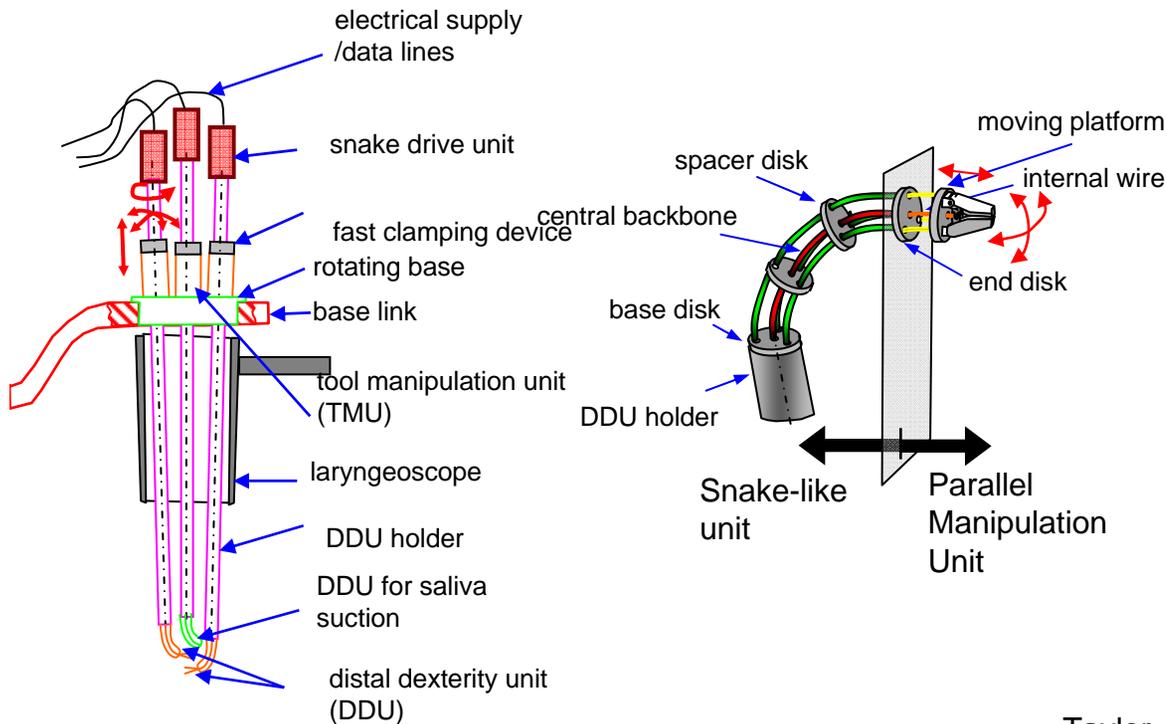
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Mechanism Design: Snake Robot for Minimally Invasive Surgery

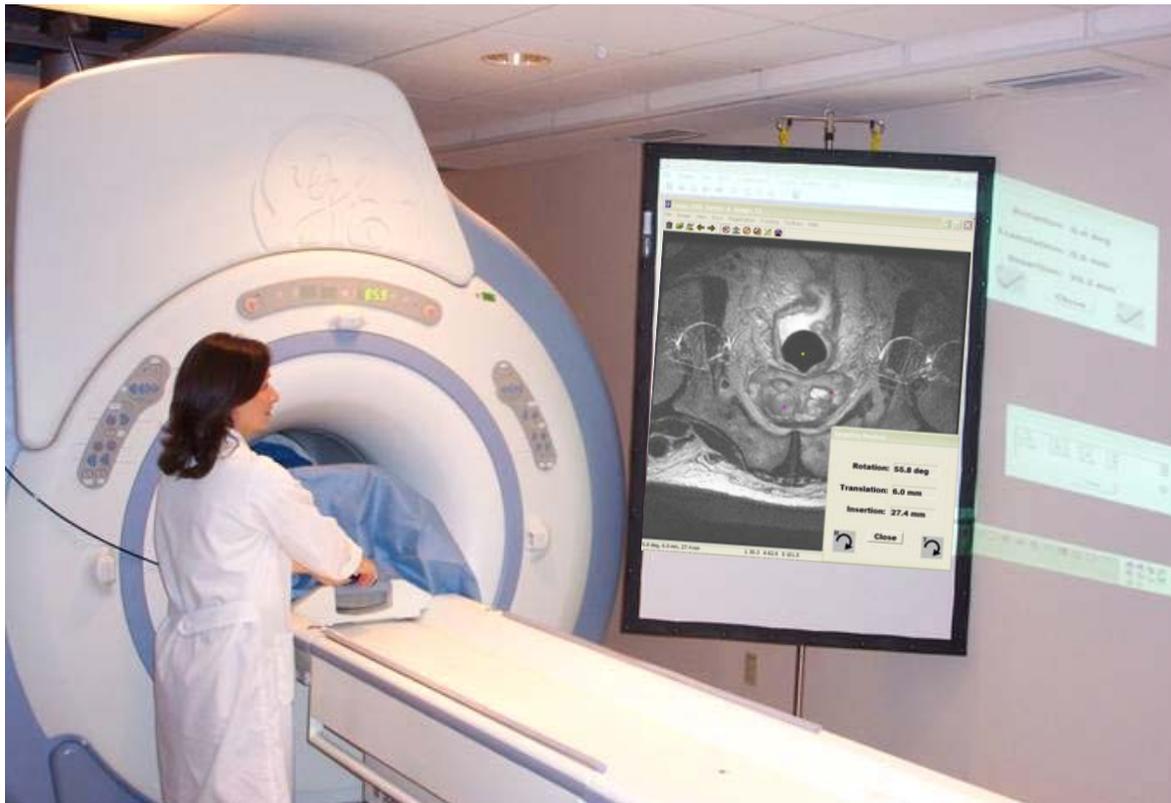
- Telerobotic system for throat MIS with high distal dexterity, force feedback and high redundancy for optimal suturing.



Taylor, Simaan, Kazanzides, Flint, Kapoor, Xu

Mechanism Design: MR-Compatible “Robot” for Prostate Biopsy

A manual “robot” with real-time MR feedback



Krieger et al, IEEE TMBE, 2005
Susil et al. J Urol., 2006
Krieger et al, MICCAI 2007

Summary

- Differing objectives means a wide variety of robot systems:
 - Surgical CAD/CAM: increase accuracy, precision, repeatability
 - Surgical Assistance: put the eyes and hands of surgeon in places they could not otherwise go
 - The Future: systems that combine both paradigms
 - Situational awareness for Surgical CAD/CAM
 - Image-guidance for Surgical Assistants



Acknowledgements

- Faculty
 - Russell Taylor
 - Greg Hager
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 - Li-Ming Su
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 - Peter Gehlbach

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