Medical Robotics and Computer-Integrated Interventional Systems:

Integrating Imaging, Intervention, and Informatics to Improve Patient Care

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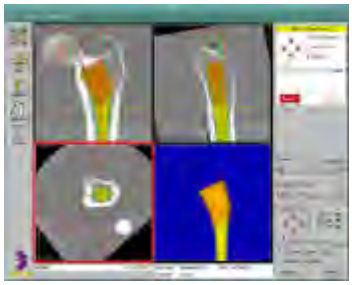
Acknowledgments

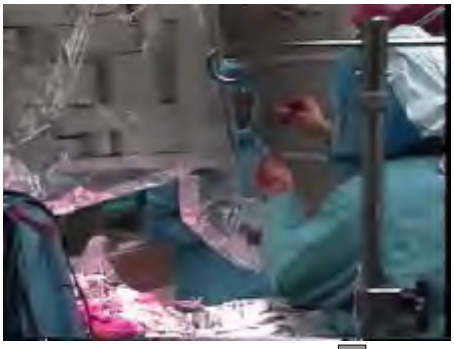
- This presentation reflects the contributions of **many** collaborators and colleagues from the CISST ERC and elsewhere. They are too many to name here, but their contributions are gratefully acknowledged.
- Partial funding or other support for the work presented likewise was provided by many sources, including
  - National Science Foundation, National Institutes of Health, Department of Defense, National Institute of Science and Technology
  - Siemens, Philips, Intuitive Surgical, General Electric, Acoustic MedSystems, Integrated Surgical Systems, Carl Zeiss Meditec, Alcon, and other Industry partners of the CISST ERC
  - Johns Hopkins University internal funds

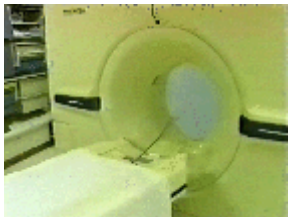
Goal: Human-machine partnership to fundamentally improve interventional medicine

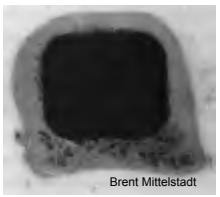
Slide credit: Marcin Balicki

20 years ago: Robotic Joint Replacement Surgery









Manual Surgery

Robotic Surgery

Taylor, Kazanzides, Paul, Mittelstadt, *et al.*

Emerging: Information-augmented robotic surgery

W. P. Liu, S. Reaugamornrat, A. Deguet, J. M. Sorger, J. H. Siewerdsen, J. Richmon, R. H. Taylor

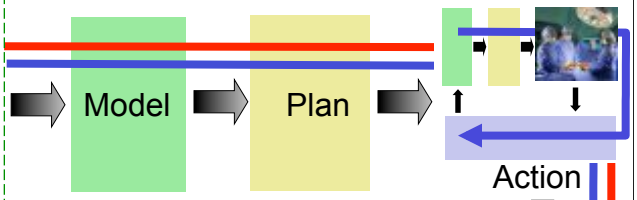
Experimental System: not for clinical use

Closed Loop Interventional Medicine

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)



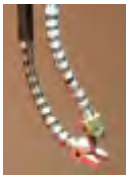
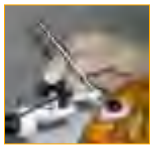
Patient-specific loop

Patient-specific Evaluation

Process Loop

Statistical Analysis

Engineering Research Center for Computer Integrated Surgical Systems and Technology (CISST ERC)


http://www.cisst.org

The CISST ERC is developing a family of surgical systems that combine innovative algorithms, robotic devices, imaging systems, sensors, and human-machine interfaces to work cooperatively with surgeons in the planning and execution of surgical procedures.

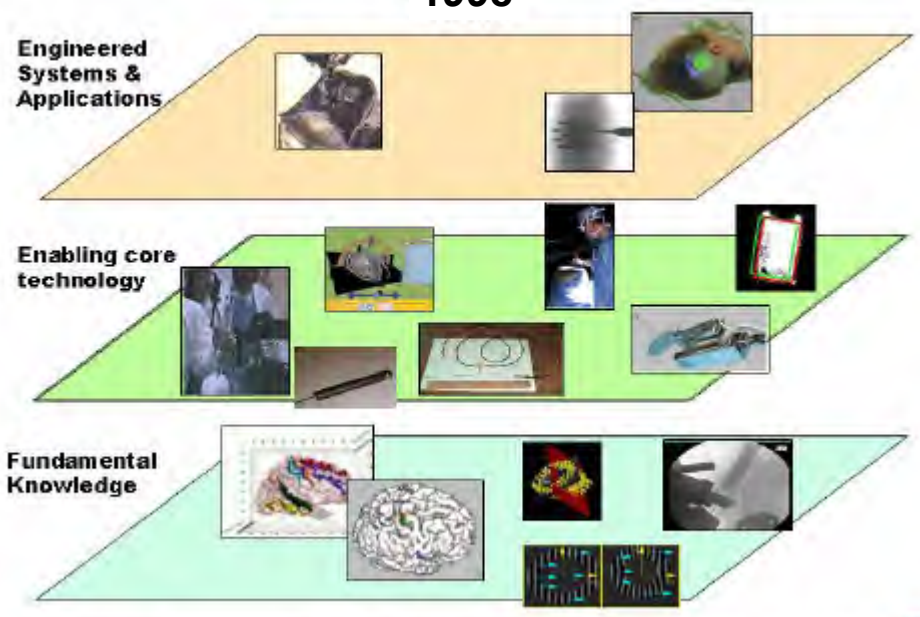
Areas of Research

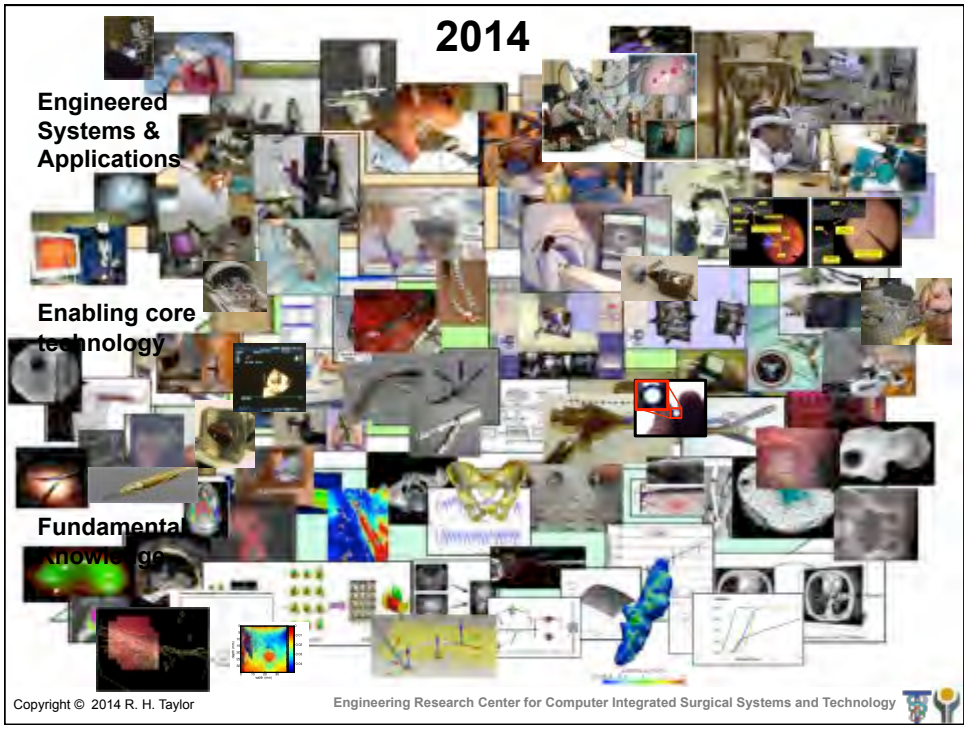
- Robotic surgical assistants
- Image-guided interventional systems
- Focused interdisciplinary research in algorithms, imaging, robotics, sensors, human-machine systems

Institutions & Funding

- Johns Hopkins, MIT, CMU, BWH, Harvard, Penn, Morgan State, Columbia
- Years 1-11: NSF = $32.7M; Total = ~$64.7M
  In-kind support = ~$13.9M
- Now mix of NSF, NIH, Industry through LCSR

1998




2014
Engineered Systems & Applications
Enabling core technology
Fundamental
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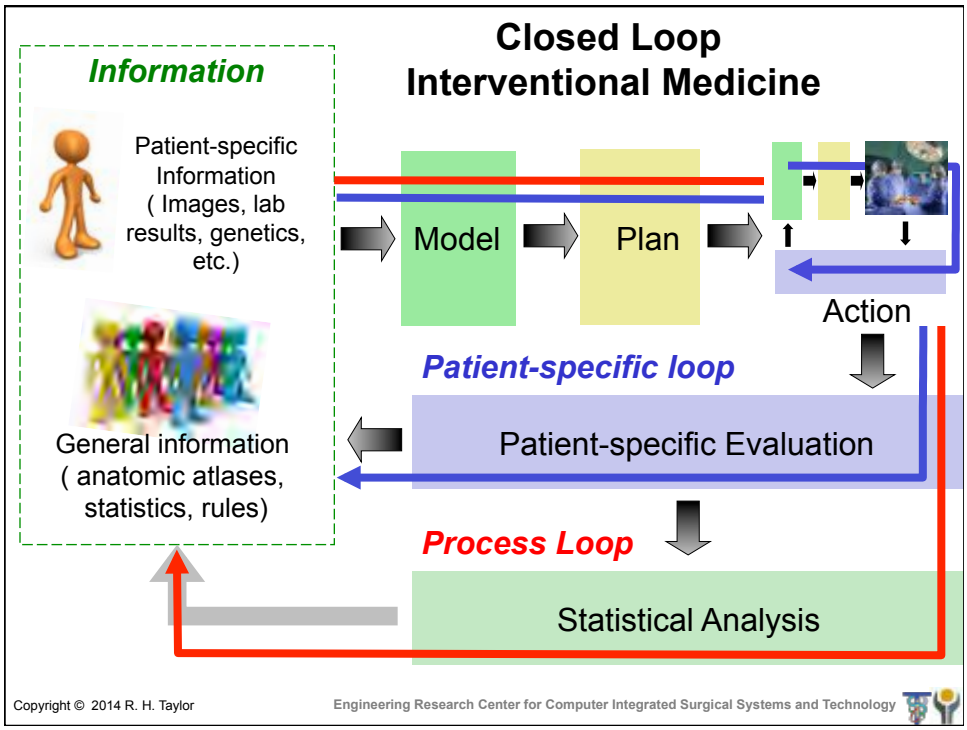
Closed Loop
Interventional Medicine
Information
Patient-specific Information (Images, lab results, genetics, etc.)
General information (anatomic atlases, statistics, rules)
Model
Plan
Action
Patient-specific loop
Patient-specific Evaluation
Process Loop
Statistical Analysis
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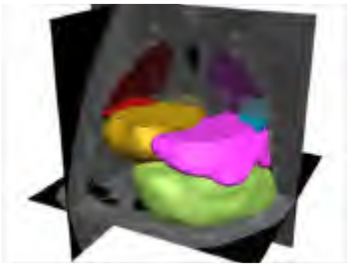
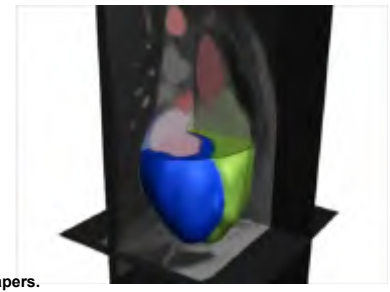
Patient-Specific Models for Interventions

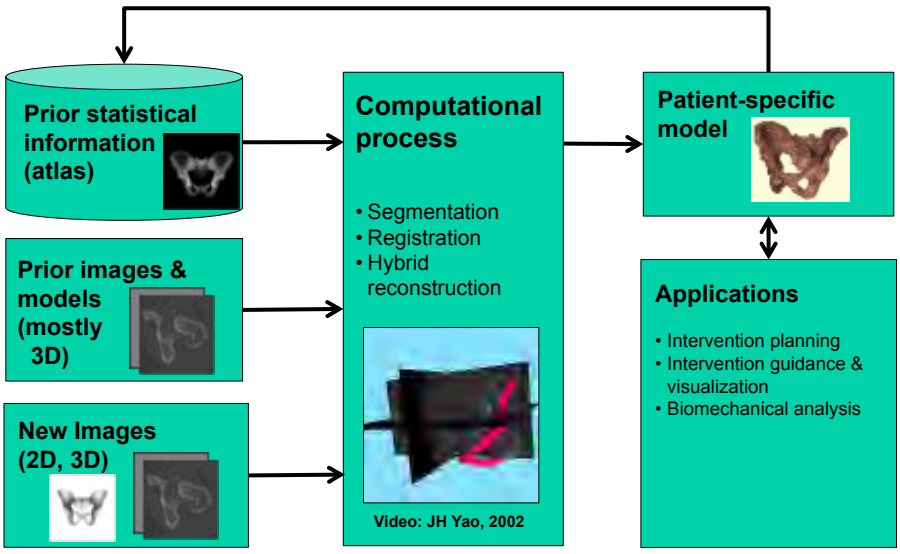
- Computationally efficient **representation of patient** enabling computer to assist in planning, guidance, control, and assessment of interventional procedures
- Generally focus on **anatomy**, but may sometimes include biology or other annotations
- Predominately derived from medical images and image analysis
- Increasingly reference statistical "**atlases**" describing patient populations



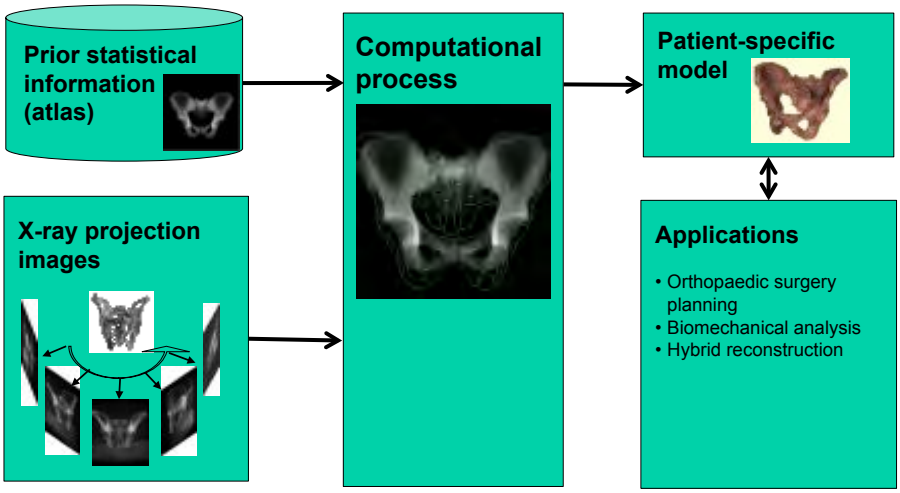


Video: Blake Lucas, "SpringLS…", *MICCAI 2011* & subsequent papers.
Data courtesy of Terry Peters and Eric Ford

Combining prior knowledge with online images



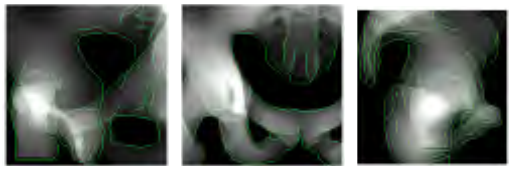
Deformable 2D/3D Registration to Statistical Atlas



Examples: R. Taylor, J. Yao, O. Sadowsky, G. Chintalapani, O. Ahmad, …

2D/3D Registration – Hip Model

- Registration with truncated images
  - FOV: 160mm
  - Three views
- Avg surface registration accuracy: 2.15 mm



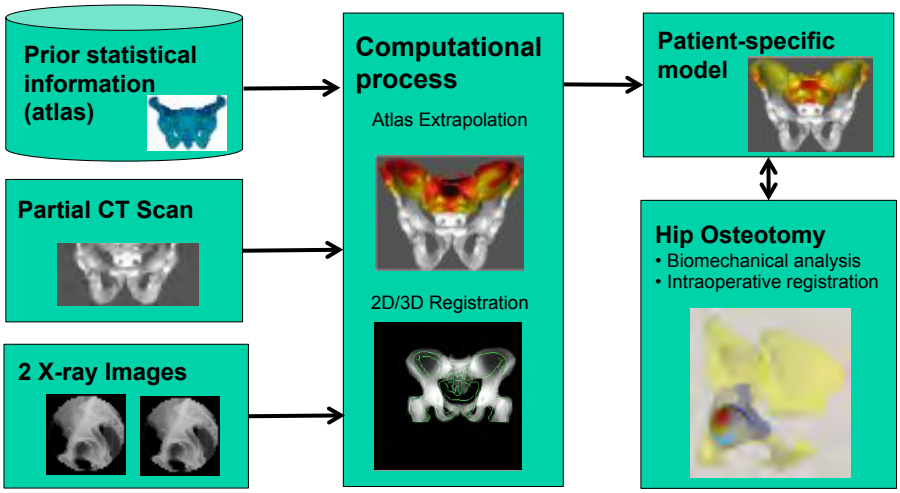
Atlas projections overlaid on DRR images after registration

2D/3D deformable registration

Chintalapani *et al.* CAOS 2009

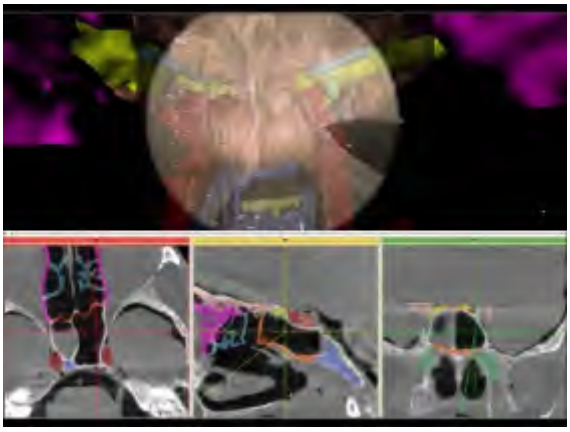
Model Completion, Given Partial CT + X-rays

G. Chintalapani, *et al.* "Statistical Atlas Based Extrapolation of CT Data for Planning Periacetabular Osteotomy", SPIE Medical Imaging 2010



Information Overlay in Endoscopic Skull Base Surgery

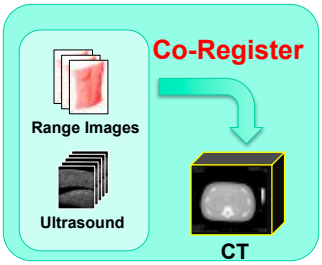
Siewerdsen, Hager, Mirota, *et. al.*

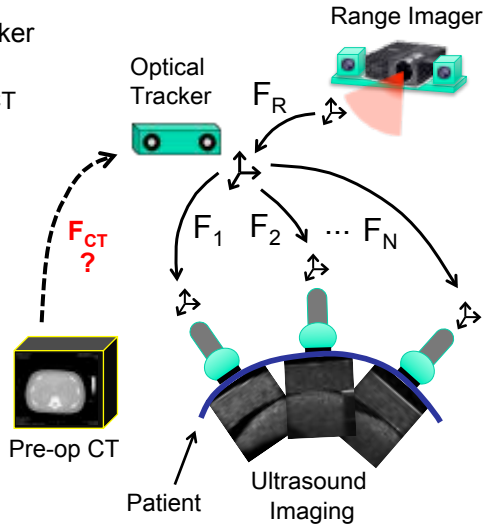


- D. Mirota and T. R. Wang H, Ishii M, Gallia G, Hager G, "A System for Video-based Navigation for Endoscopic Endonasal Skull Base Surgery.", *IEEE Trans Med Imaging*, 2011. PMID 22113772.
- D. J. Mirota, A. Uneri, S. Schafer, S. Nithiananthan, D. D. Reh, G. L. Gallia, R. H. Taylor, G. D. Hager, and J. H. Siewerdsen, "High-accuracy 3D image-based registration of endoscopic video to C-arm cone-beam CT for image-guided skull base surgery", in *Medical Imaging 2011: Visualization, Image-Guided Procedures, and Modeling*, Orlando, 79640J-1 to 79640J-10, 2011.

Registration of intraoperative data to preoperative models

- Want to know registration from tracker to CT space
  - Provides tool positions relative to CT
- Data sources for registration
  - Tracked ultrasound
  - Tracked (or calibrated) range data

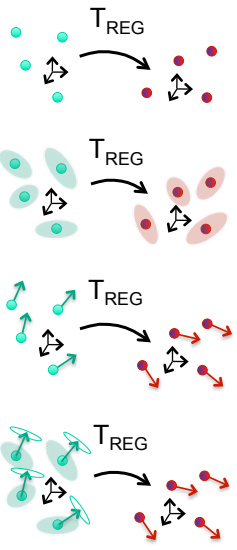




S. Billings and R. H. Taylor, "Iterative Most Likely Oriented Point Registration", *in Medical Image Computing and Computer-Assisted Interventions (MICCAI)*, Boston, October, 2014. (accepted).

Paired Point Algorithms Outline

- Iterative Closest Point (ICP)
  - the standard algorithm
  - position-only method
  - isotropic (Gaussian) noise model
- Iterative Most Likely Point (IMLP)
  - position-only method
  - generalized Gaussian noise model
- Iterative Most Likely Oriented Point (IMLOP)
  - position & orientation method
  - isotropic orientation (Fisher) and position (Gaussian) noise model
- Generalized IMLOP
  - extension of IMLOP
  - generalize orientation (Kent) and position (generalized Gaussian) noise model

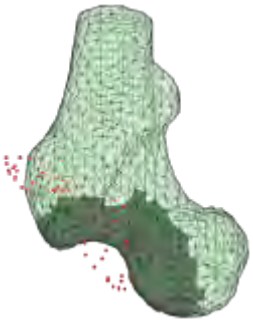


S. Billings and R. H. Taylor, "Iterative Most Likely Oriented Point Registration", *in Medical Image Computing and Computer-Assisted Interventions (MICCAI)*, Boston, October, 2014. (accepted).

Experiments

Performance comparison of IMLOP vs. ICP was made through a simulation study using a human femur surface mesh segmented from CT imaging.

- source shape created by randomly sampling points from the mesh surface (10, 20, 35, 50, 75, and 100 points tested)
- Gaussian [wrapped Gaussian] noise added to the source points (0, 0.5, 1.0, and 2.0 mm [degrees] tested)
- Applied random misalignment of [10,20] mm / degrees
- 300 trials performed for each sample size / noise level
- Registration accuracy (TRE) evaluated using 100 validation points randomly sampled from the mesh
- Registration failures automatically detected using threshold on final residual match errors



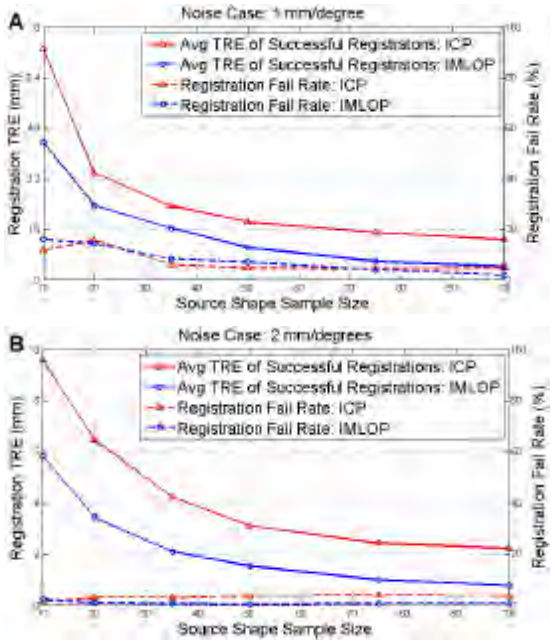
Example source point cloud sampled from dark region of target mesh.

ICP: threshold on position residuals only
IMLOP: threshold on position & orientation residuals

S. Billings and R. H. Taylor, "Iterative Most Likely Oriented Point Registration", *in Medical Image Computing and Computer-Assisted Interventions (MICCAI)*, Boston, October, 2014. (accepted).

Average TRE of successful registrations and registration failure rates across all sample sizes for noise levels of 1 (A) and 2 (B) mm [degrees].

Registration failure threshold set to twice the noise level for both position and orientation.



S. Billings and R. H. Taylor, "Iterative Most Likely Oriented Point Registration", *in Medical Image Computing and Computer-Assisted Interventions (MICCAI)*, Boston, October, 2014. (accepted).

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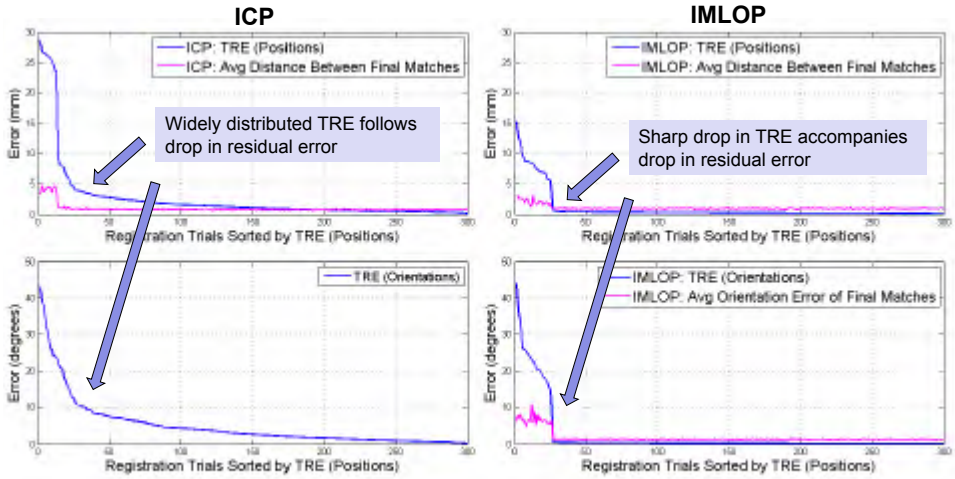
Experiments

Results from 300 trials within a single sample size (75 points) and noise level (1.0 mm [degree]). NOTE: improved accuracy and failure detection capability for IMLOP.



S. Billings and R. H. Taylor, "Iterative Most Likely Oriented Point Registration", *in Medical Image Computing and Computer-Assisted Interventions (MICCAI)*, Boston, October, 2014. (accepted).

Procedure Planning

- **Highly procedure-specific**
- **Occurs at many time scales**
  - Preoperative
  - Intraoperative
  - Preop. + intraop. update
- **Typically based on images or segmented models**
- **May involve:**
  - Optimization
  - Simulations
  - Visualization & HCI

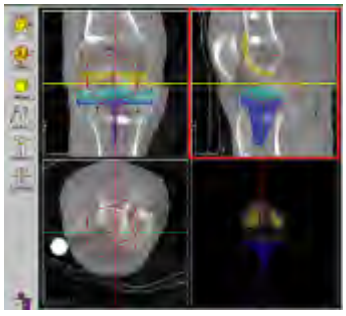
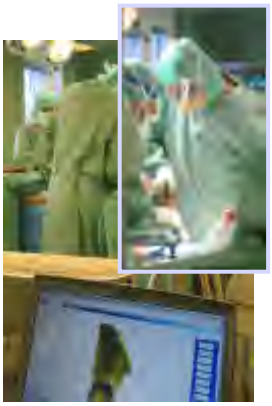
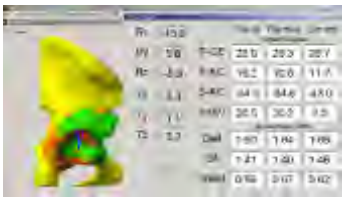


Photo: Integrated Surgical Systems

Procedure Planning

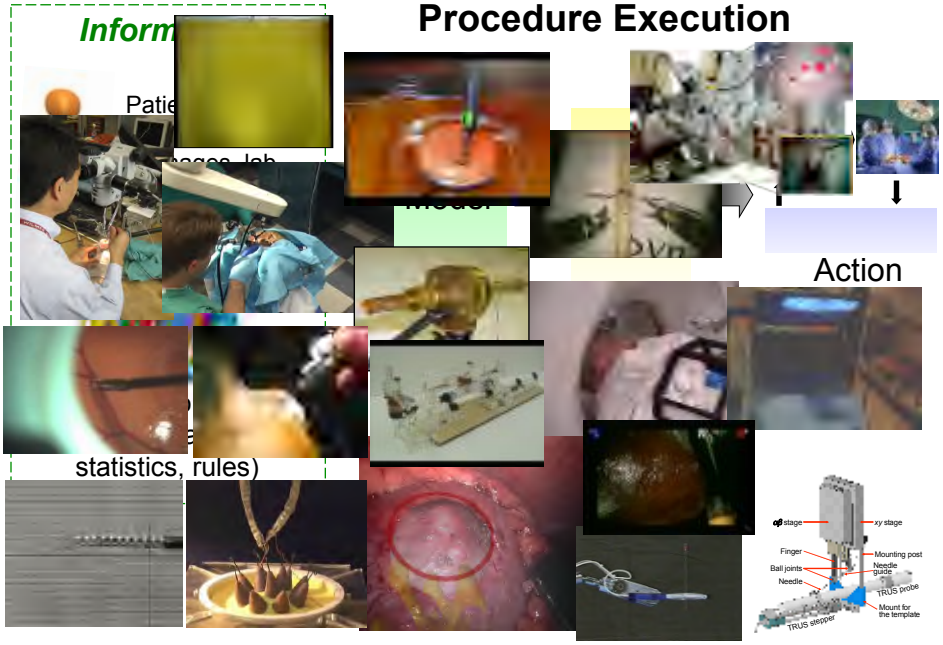
- **Typical outputs**
  - Target positions (seeds, biopsies, ablation sites, etc.)
  - Tool paths
  - Desired geometric relationships
  - Key-frame visualizations
  - Images, models & control parameters
- **Emerging themes**
  - Atlas-based planning
  - Statistical process control & integration of outcomes into plans
  - Dynamic, interactive replanning





Photos: Mehran Armand

Procedure Execution



Procedure Execution

- **Highly procedure-specific**
- **Don't always have a robot**
  - Surgical Navigation
  - Image Overlay
- But robots can transcend human limitations
  - to make procedures less invasive,
  - more precise,
  - more consistent,
  - and safer

Medtronic

Taylor

Masamune, Fischer, Deguet, Csoma, Taylor, Sauer, Iorchidata, Masamune, Zinreich, Fichtinger, ...

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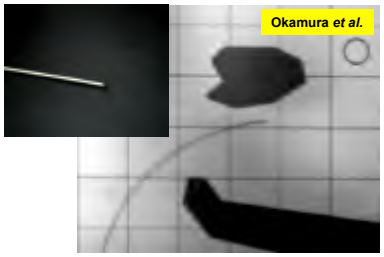

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Taylor, Hager, Handa, Kazanzides, Kang, Iordachita, Gehlbach, *et al.*

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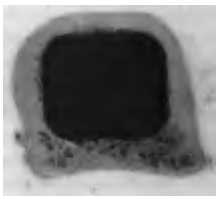

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P. Kazanzides, T. Haiddeger, T. Xia, C. Baird, G. Jallo, N. Hata, …

Procedure Execution

- **Intraoperative systems typically combine multiple elements**
  - Imaging
  - Information fusion
  - Robotics
  - Visualization and HMI
- **Issues**
  - Design
  - Imaging compatibility
  - OR compatibility
  - Safety & sterility
  - Intelligent control
  - Human-machine cooperation

G. Hager, B. Vagvolgyi , L-M. Su, *et al.*

Stoianovici, Taylor, Whictomb, *et al.*

To be continued …

Medical Robotics and Computer-Integrated Interventional Systems:

Integrating Imaging, Intervention, and Informatics to Improve Patient Care

PART B

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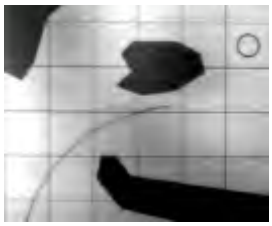
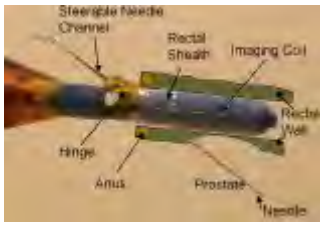
The Johns Hopkins University
rht@jhu.edu

Image-guided needle placement

Masamune, Fichtinger, Iordachita, …



Okamura, Webster, …



Krieger, Fichtinger, Whitcomb, …

Fichtinger, Kazanzides,Burdette, Song …

Iordachita, Fischer, Hata…

Taylor, Masamune, Susil, Patriciu, Stoianovici,…

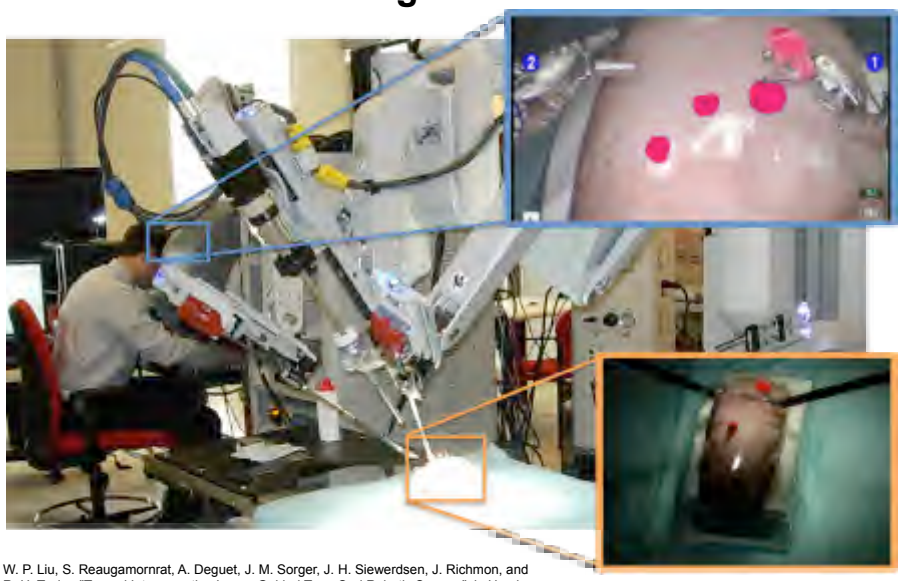
Information-enhanced robotic surgery

augmented reality displays imaging

safety barriers shared control "virtual fixtures"

SAW

Video-CBCT guidance for TORS



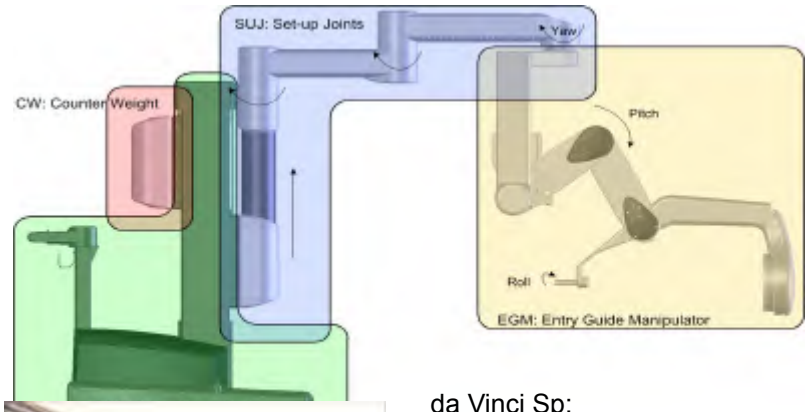
W. P. Liu, S. Reaugamornrat, A. Deguet, J. M. Sorger, J. H. Siewerdsen, J. Richmon, and R. H. Taylor, "Toward Intraoperative Image-Guided TransOral Robotic Surgery", in Hamlyn Symposium on Medical Robotics, London, July 1-2, 2012

Video-CBCT guidance for TORS

W. P. Liu, S. Reaugamornrat, A. Deguet, J. M. Sorger, J. H. Siewerdsen, J. Richmon, R. H. Taylor

Experimental System: not for clinical use

da Vinci Sp



da Vinci Sp:

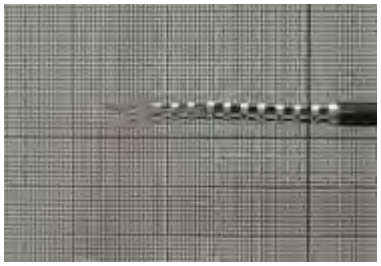
- Research daVinci model, approved by FDA, April 2014
- Single-incision, 25 mm trocar
- Articulated camera
- 3 articulated endo-wrist instruments
- Entry Guide Manipulator (EGM)

da Vinci Sp: Video Augmentation

Experimental System: not for clinical use

Snake-like robot for minimally invasive surgery

- **Goals**
  - Develop scalable robotic devices for high dexterity manipulation in confined spaces
  - Demonstrate in system for surgery in throat and upper airway
- **Approach**
  - "Snake-like" end effectors with flexible backbones and parallel actuation
  - Integrate into 2-handed teleoperator system with optimization controller
- **Status**
  - Evaluation of prototype ongoing
  - Licensed to industry partner
- **Funding**
  - NIH R21, CISST ERC, JHU, Columbia
  - NIH proposals pending



R. Taylor, N. Simaan, *et al.*

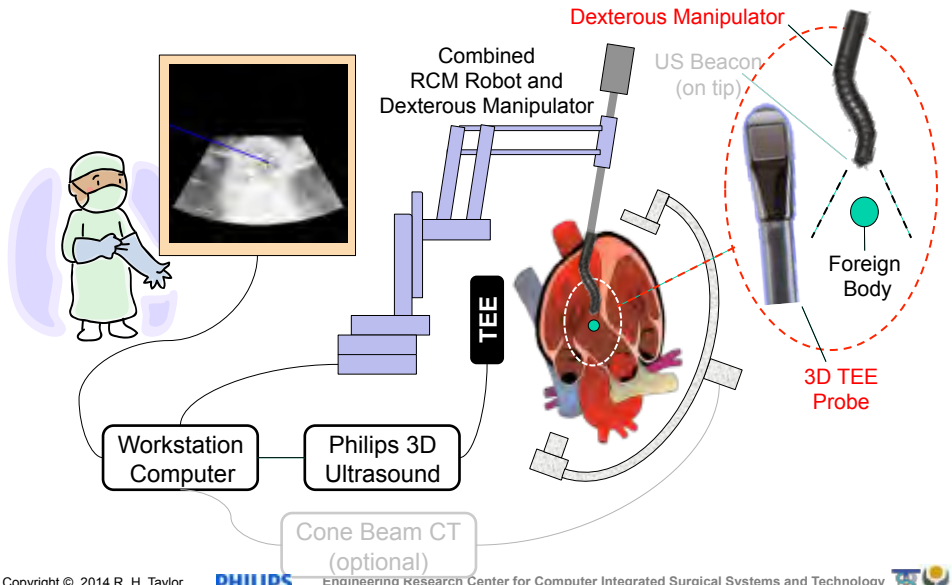
Single Port Access Surgery

Nabil Simaan (Vanderbilt, Columbia), with
P. Allen (Columbia), D. Fowler (Columbia)

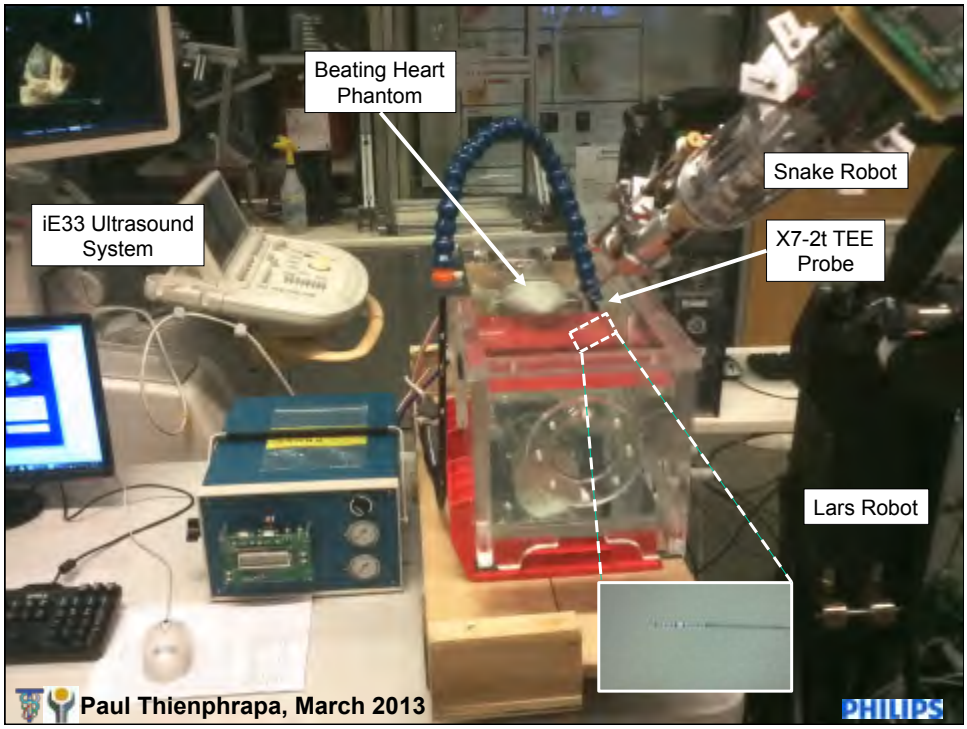
New technology finally allows true evaluation of the potential of single port access surgery. Systems raise new questions about control and telemanipulation infrastructure/cooperative control.

Beating Heart MIS with 3D US Guidance

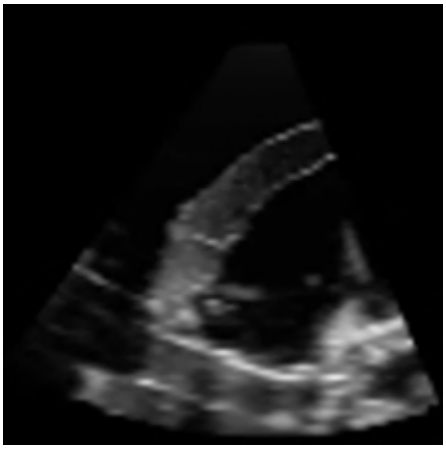
Paul Thienphrapa, Aleksandra Popovic, Russell Taylor

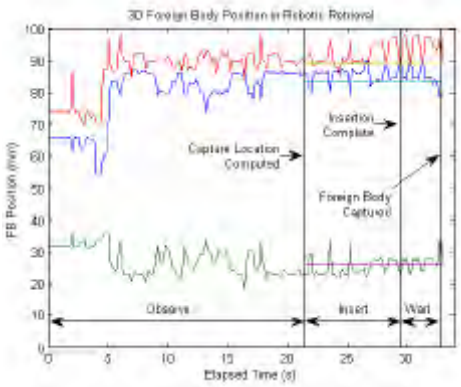


PHILIPS



Retrieval Experiment Results



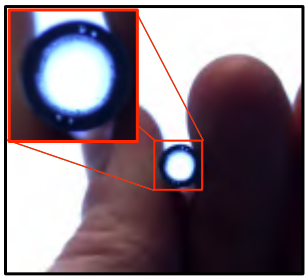


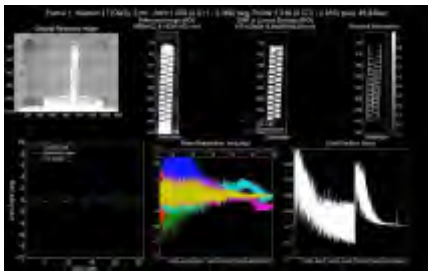
PHILIPS

Thienphrapa *et al. 2013*

Large Lumen, Dexterous Snake for MIS

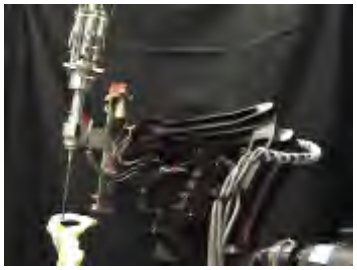
- Joint project with JHU APL
- Innovative fabrication process completely isolates drive cables
- Current prototypes
  - 2 DoF (C-bend) and 4DoF (S-bend)
  - Nitinol structure with high stiffness
  - 6 mm OD; Large 4 mm lumen allows insertion of surgical instruments
- Initial application: minimally-invasive curettage of osteolytic lesions

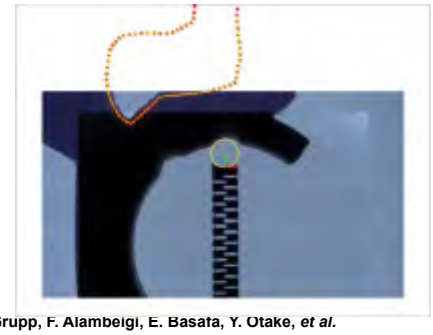




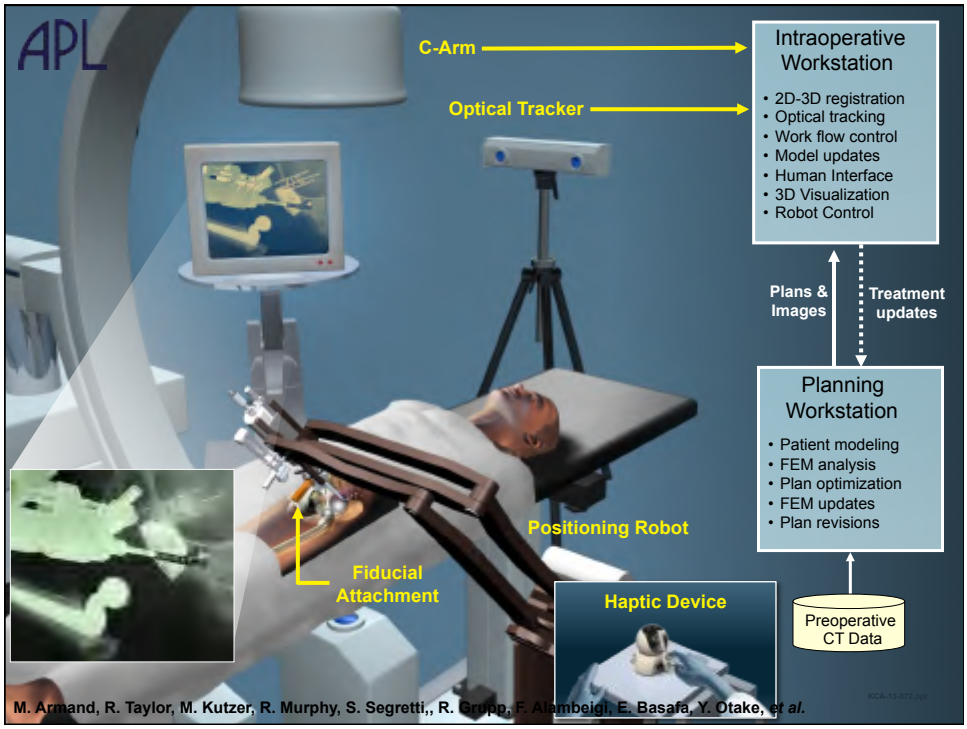
M. Armand, R. Taylor, M. Kutzer, R. Murphy, S. Segretti,, R. Grupp, F. Alambeigi, E. Basafa, Y. Otake, *et al.*

Minimally-Invasive Osteolysis Curettage





M. Armand, R. Taylor, M. Kutzer, R. Murphy, S. Segretti,, R. Grupp, F. Alambeigi, E. Basafa, Y. Otake, *et al.*



Large Lumen, Dexterous Snake for MIS

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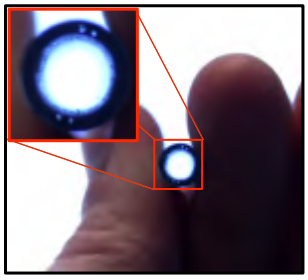

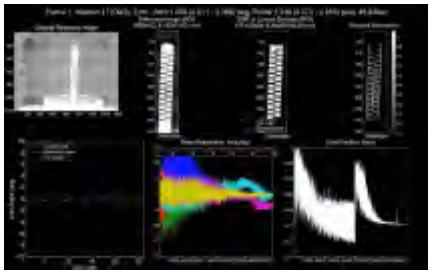

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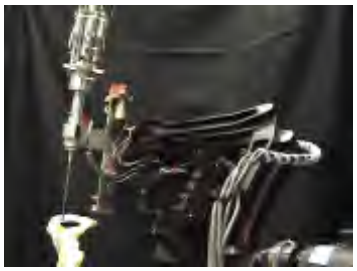
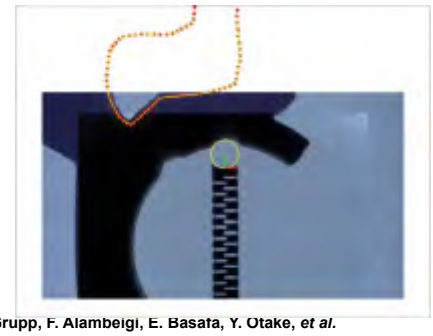
Minimally-Invasive Osteolysis Curettage



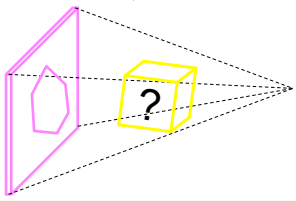


M. Armand, R. Taylor, M. Kutzer, R. Murphy, S. Segretti,, R. Grupp, F. Alambeigi, E. Basata, Y. Otake, *et al.*

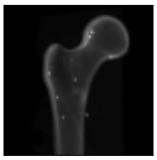
Image-based 2D-3D Registration

Interpret 3D objects from 2D image via simulation of projection

Input 2D ⇨ Estimate 3D



Rigid ⟺ Piecewise-Rigid ⟺ Deformable

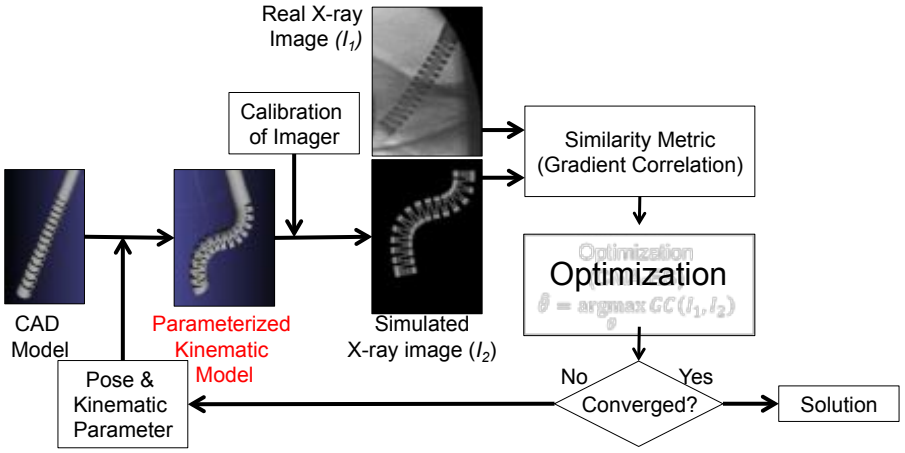


	Target object	Prior information	Parameters to estimate
Rigid	Bone	3D shape (CT, MRI)	6 DoF
Piecewise-Rigid	Manipulators	3D Shape + kinematics	6 DoF + Joint angles
Deformable	Soft tissue	Mode of deformation, Physical constraint	6 DoF + Deformation field (control points or mode weights)

Yoshito Otake *et al.*, SPIE 2014

Proposed Solution: Piecewise Rigid 2D-3D Registration

Maximize similarity between simulated and real image

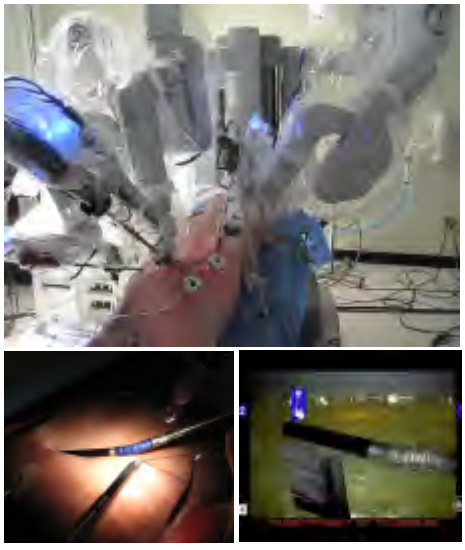


Yoshito Otake *et al.*, SPIE 2014

Robotically Assisted Laparoscopic Ultrasound

C. Schneider, P. Peng, R. Taylor, G. Dachs, C. Hasser, S. Dimaio, and M. Choti, "Robot-assisted laparoscopic ultrasonography for hepatic surgery", *Surgery*, Oct 5. (Epub), 2011.

- NIH STTR between CISST ERC and Intuitive Surgical
- Goals
  - Develop dexterous laparoscopic ultrasound instrumentation and software interfaces for DaVinci surgical robot
  - Produce integrated system for LUS-enhanced robotic surgery
  - Evaluate effectiveness of prototype system for liver surgery
- Approach
  - Custom DaVinci-S LUS tool
  - Software built on JHU/ISI "SAW" interface
- Status
  - Evaluation of prototype by surgeons



Research DaVinci Application – Not for Human Use

Ultrasound Elastography with DaVinci

(Boctor, Billings, Taylor)

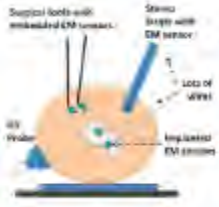
Human-robotic collaboration for in-vivo detection of tumors and monitoring of therapy

(Research DaVinci Application – Not for Human Use)

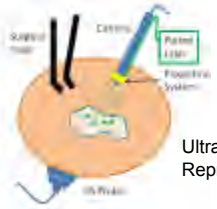
Direct 3D Ultrasound to Video Registration Using Photoacoustic Effect

A. Cheng, J. U. Kang, R. H. Taylor, E. M. Boctor
The Johns Hopkins University

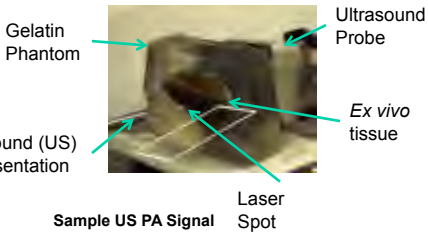
Standard Electromagnetic Surgical Navigation System



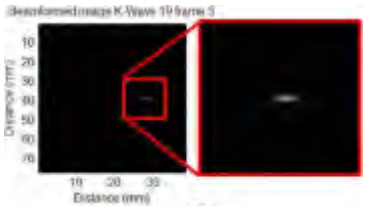
Proposed Photoacoustic (PA) Surgical Navigation System



Experimental Setup



Sample US PA Signal



Advantages of PA system

- No wires
- No markers or sensors
- No Calibration Process
- Directly register video and 3D Ultrasound

Literature shows registration errors of approximately 3mm
Our synthetic and *ex vivo* tissue phantom experiments show **submillimeter** errors!

ERC | CISST

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Computational Sensing + Robotics

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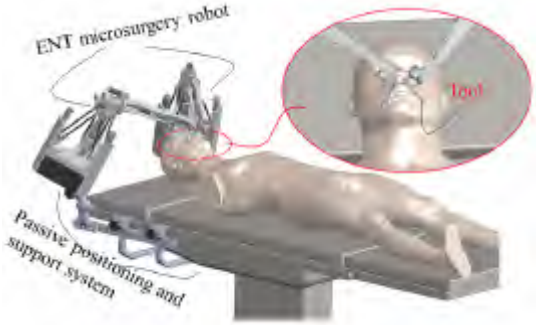
MUSiiC Medical UltraSound Imaging and Intervention Collaboration

Robots for Head and Neck Surgery

- **Collaboration with JHU Department of Otolaryngology**
- **Robot to manipulate flexible endoscopes (RoboELF)**
  - Prototype for flexible laryngoscope
  - "No significant risk" from FDA; IRB pending at JHU
- **Steady-hand robot for head and neck surgery (REMS)**
  - Initial targets: laryngeal, sinus, ear, open microsurgery
  - Readily adapted for spine, brain, other microsurgery
  - First prototype constructed

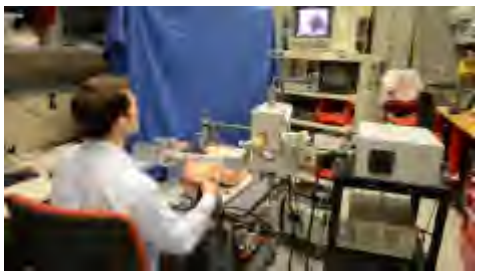


Kevin Olds

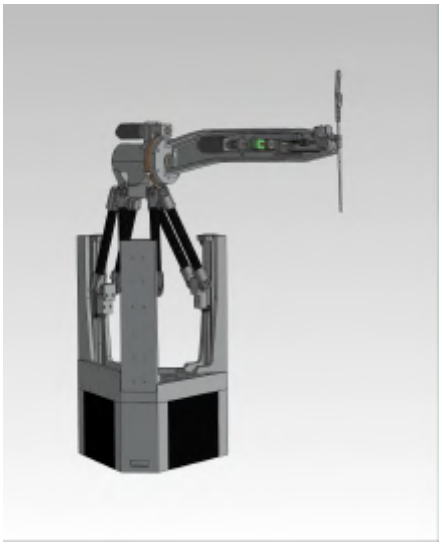
A Robotic Assistant for Trans-Oral Surgery: The Robotic Endo-Laryngeal Flexible (Robo-ELF) Scope

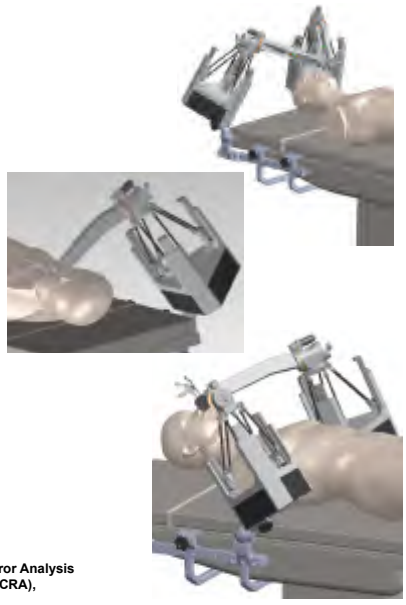
K. Olds, A. Hillel, E. Cha, J. Kriss, A. Nair, L. Akst, J. Richmon, R. Taylor

- **Goals**
  - Develop clinically usable robot for manipulating flexible endoscope in throat and airways
  - Permit bimanual surgery
  - Manipulation of ablation catheter
- **Approach**
  - Simple hardware for manipulating unmodified flexible scope
  - Simple joystick control
  - Platform for image guidance
- **Status**
  - In process of obtaining IRB approval for clinical use



Steady Hand Robot for Head and Neck Microsurgery





C. He, K. Olds, I. Iordachita, and R. Taylor, "A New ENT Microsurgery Robot: Error Analysis and Implementation", in International Conference on Robots and Automation (ICRA), Karlsruhe, May 6-10, 2013. pp. 1221-1227.

Steady Hand Robot for Head and Neck Microsurgery

C. He, K. Olds, I. Iordachita, and R. Taylor, "A New ENT Microsurgery Robot: Error Analysis and Implementation", in International Conference on Robots and Automation (ICRA), Karlsruhe, May 6-10, 2013. pp. 1221-1227.

Human-Machine Collaborative Surgery

Nicholas Padoy, Greg Hager (IROS 2011)

Research DaVinci Application – Not for Human Use

To be continued …

100 YEARS
JOHNS HOPKINS ENGINEERING

Computational Sensing + Robotics

Medical Robotics and Computer-Integrated Interventional Systems:

Integrating Imaging, Intervention, and Informatics to Improve Patient Care

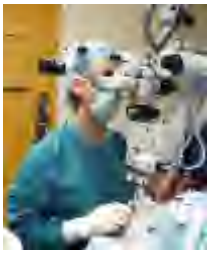
PART C

Russell Taylor
John C. Malone Professor of Computer Science
Director, Laboratory for Computational Sensing and Robotics
Director, CISST ERC
The Johns Hopkins University
rht@jhu.edu

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

Vitreoretinal Microsurgery

British Journal of Ophthalmology 2004 - Akifumi Ueno et al



www.eyemdlink.com

Alcon Vitreosurgery Instrument

Microsurgical Assistant for Retinal Surgery

Goals

- Develop technology addressing fundamental limitations in retinal microsurgery
- Integrate into comprehensive system
- Validate performance
- Transfer to clinical use

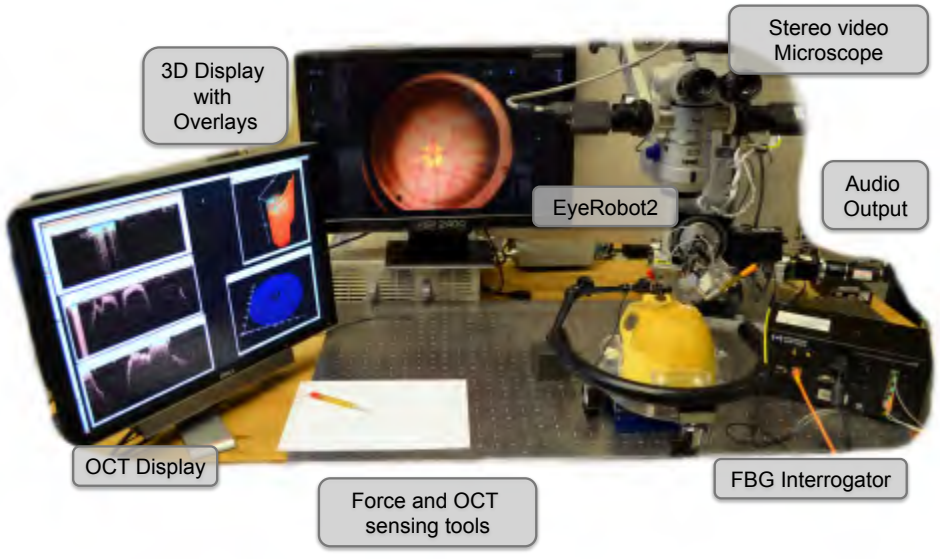
Team

- **WSE:** R. Taylor, G. Hager, J. Kang, P. Kazanzides, A. Deguet, B. Vagvolgyi, I. Iordachita, R. Richa, X. Liu, M. Balicki, X. He, B. Hu, B. Gonec, K. Olds
- **SoM:** J. Handa, P. Gehlbach, S. Sunshine, N. Cutler
- **CMU:** C. Riviere, B. Becker, R. MacLachlan

Current Funding

- NIH BRP5 R01 EB007969 (Taylor)
- NIH R01 EB000526 (Riviere)
- NIH R01 EY021540 (Kang)

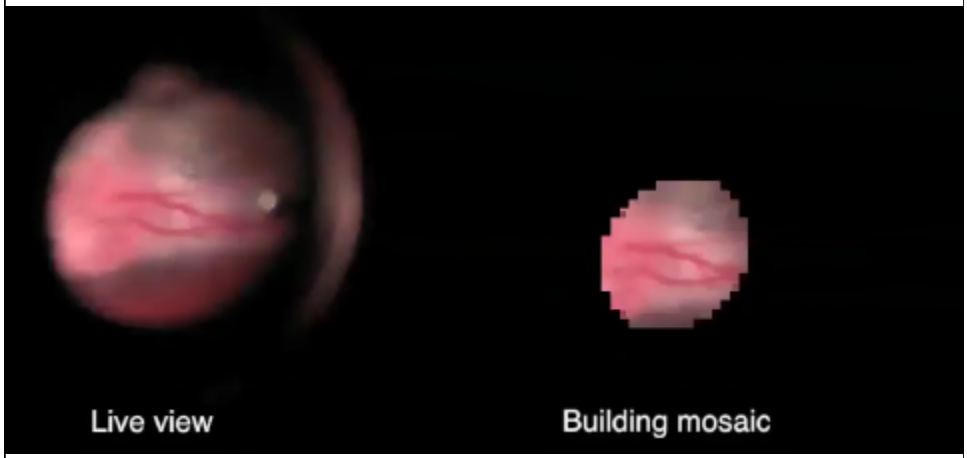
Microsurgery Assistant Workstation



In-Vivo Experiments

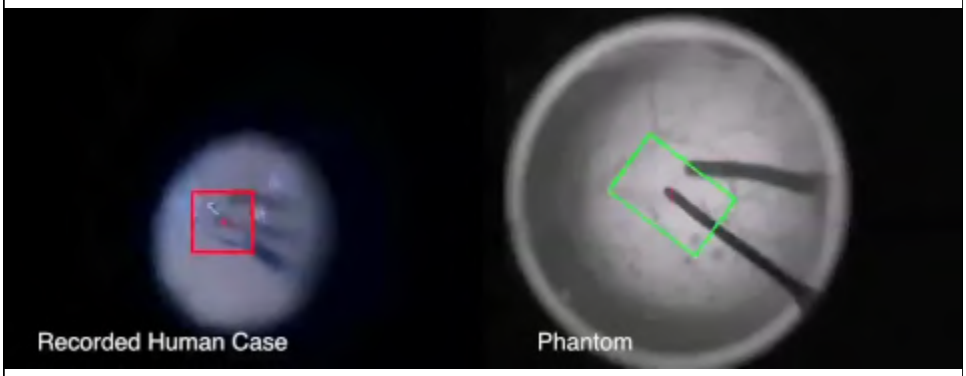
- Overall System Performance
- System Ergonomics
- Collect Data
  - Robot / Force / OCT
  - Video / Audio

Retina Mosaicking, Annotation, and Registration



R. Richa, B. Vagvolgyi, R. Taylor, G. Hager, *MICCAI 2012*,

Tool and Retina Tracking

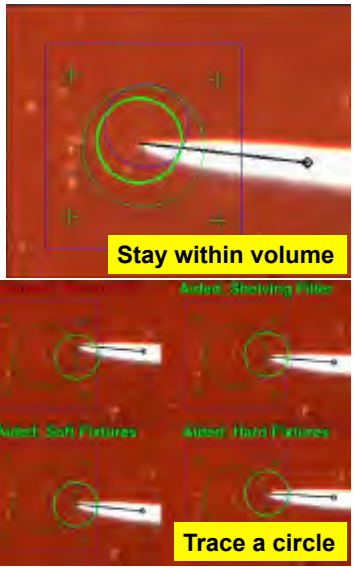


Balazs Vagvolgyi, Raphael Sznitman, Greg Hager, Rogerio Richa, Russ Taylor, *et al.*

MICRON active tremor cancellation device

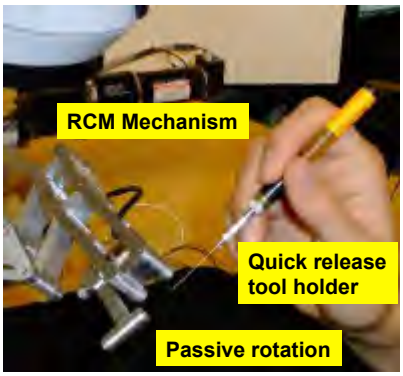
Cameron Riviere, Robert McLaughlin, B. Becker *et al.* (CMU)

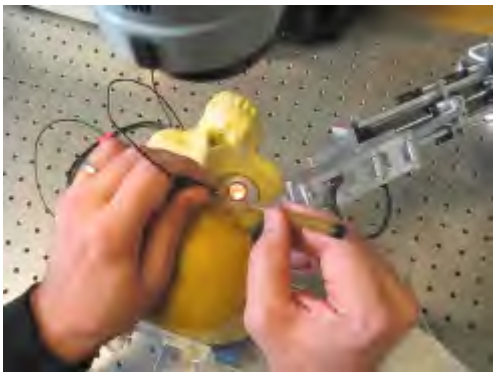
- Handheld device
- Sense tremulous motion
- Actively move to compensate
- BRP Research goals:
  - Incorporate "endpoint sensing" from vision & other sensors
  - Virtual fixtures
  - Improved device for eventual clinical use



JHU Steady Hand "Eye Robot"

Russell Taylor, Iulian Iordachita, D. Gierlach, D. Roppenocker, *et al.*

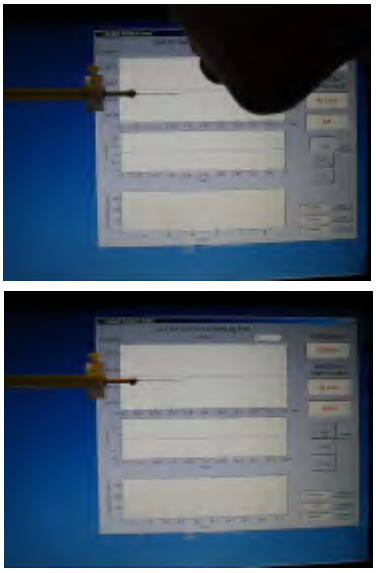




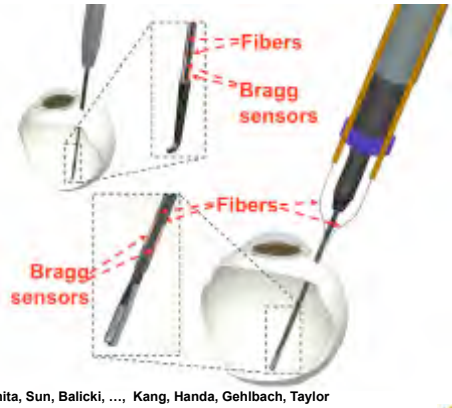
- Highly precise robot
- Hands-on cooperative control or teleoperation
- Several generations in lab

- Precise, stable platform for developing "smart" surgical instruments and sensors
- Virtual fixtures and advanced control

Force Sensing Surgical Instruments

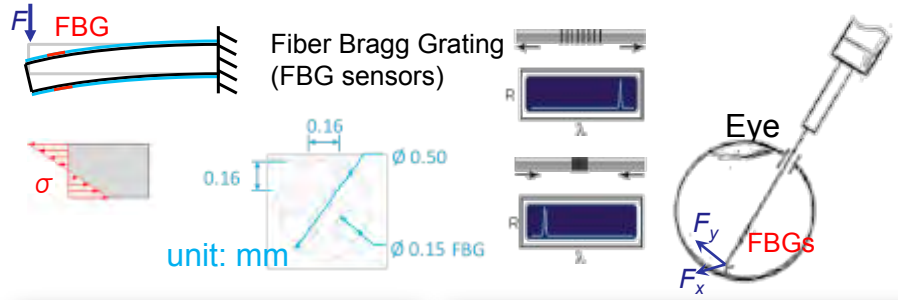


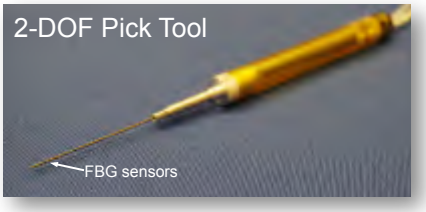
- Incorporate fiber optic force sensors into 0.5 mm diameter surgical tools
- 0.25 mN force sensitivity

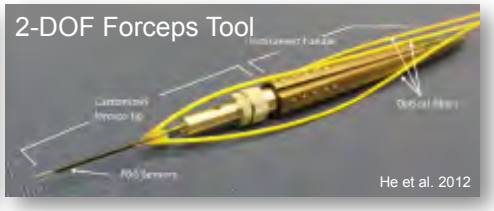


Iordachita, Sun, Balicki, …, Kang, Handa, Gehlbach, Taylor

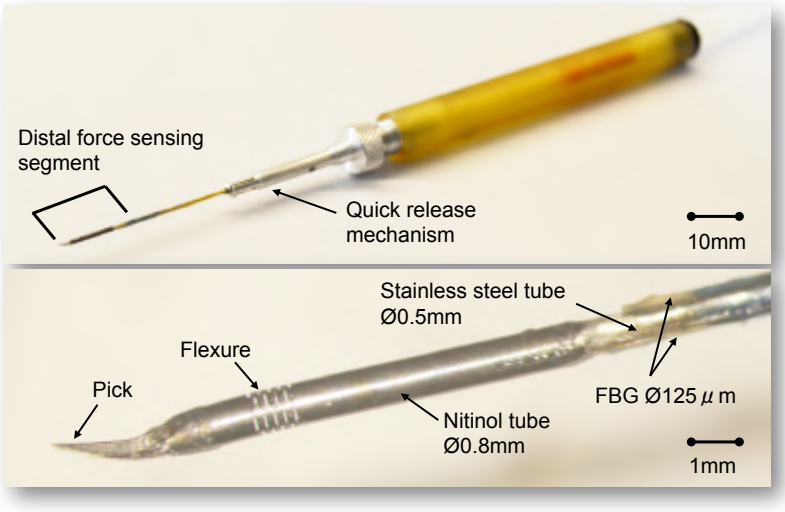
2-DOF Force Sensing Tools



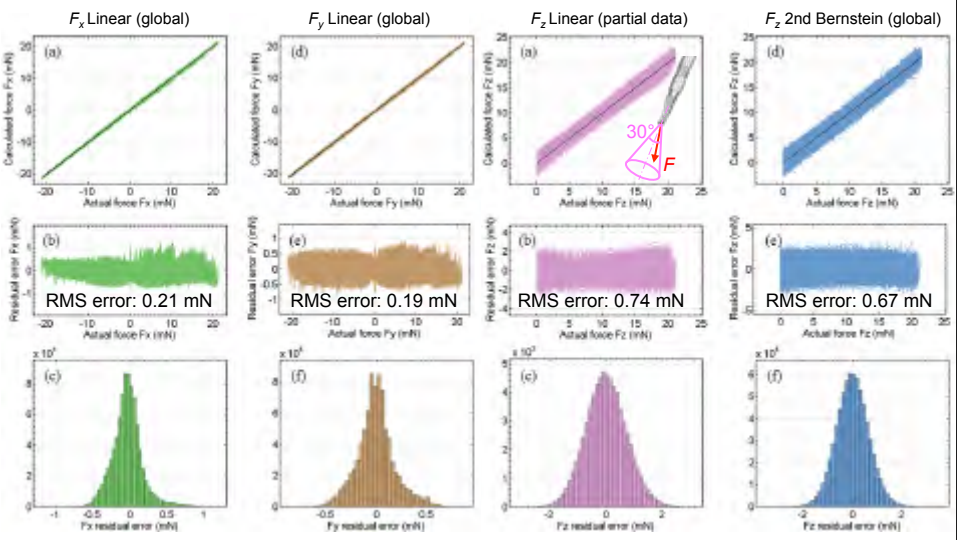




3-DOF Force Sensing Pick Tool

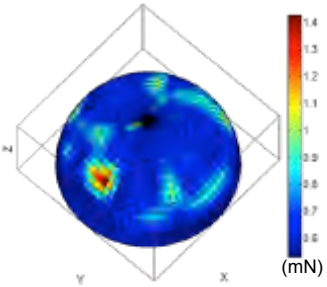


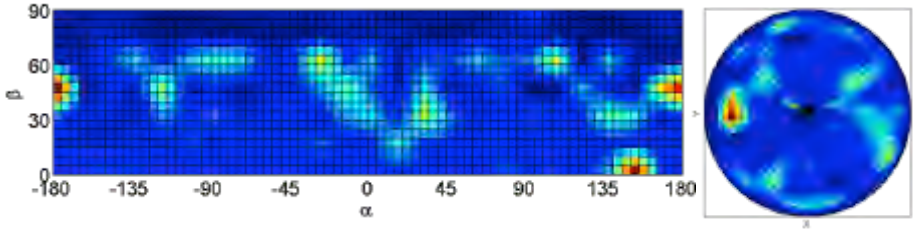
Calibration: Results



Calibration: F_z RMS Error

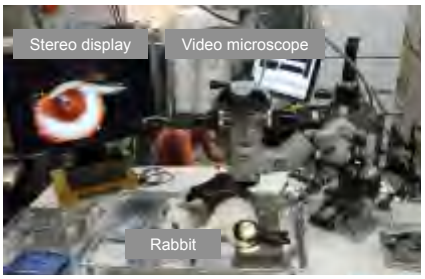
- Overall RMS error with 2nd order Bernstein polynomial: 0.67 mN
- Estimation performance in each force direction (total 168 poses)
  - 84.5% (142 poses) < 0.75 mN
  - 96.4% (162 poses) < 1 mN

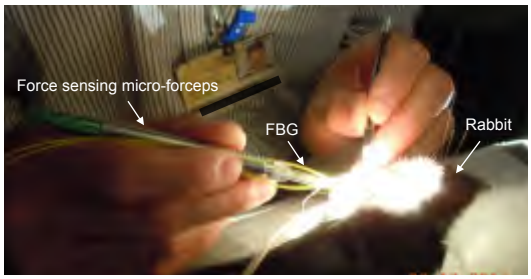




In-vivo experiments

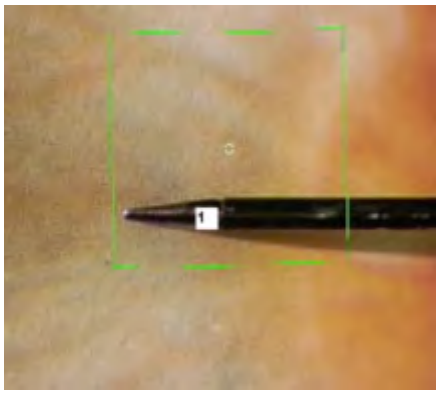
- Test the force sensing micro-forceps in-vivo using rabbit in the operating room
- Force measurements, stereo microscopic video, and surgeon's voice annotation were recorded with timestamps for synchronization and analysis

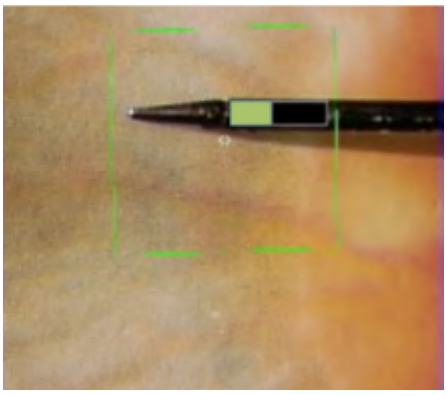




Xingchi He, Marcin Balicki, Jin U. Kang, Peter Gehlbach, James Handa, Russell Taylor, Iulian Iordachita
"Force sensing micro-forceps with integrated fiber Bragg grating for vitreoretinal surgery", SPIE 202

Video overlay of tool tip forces

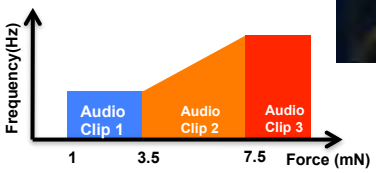




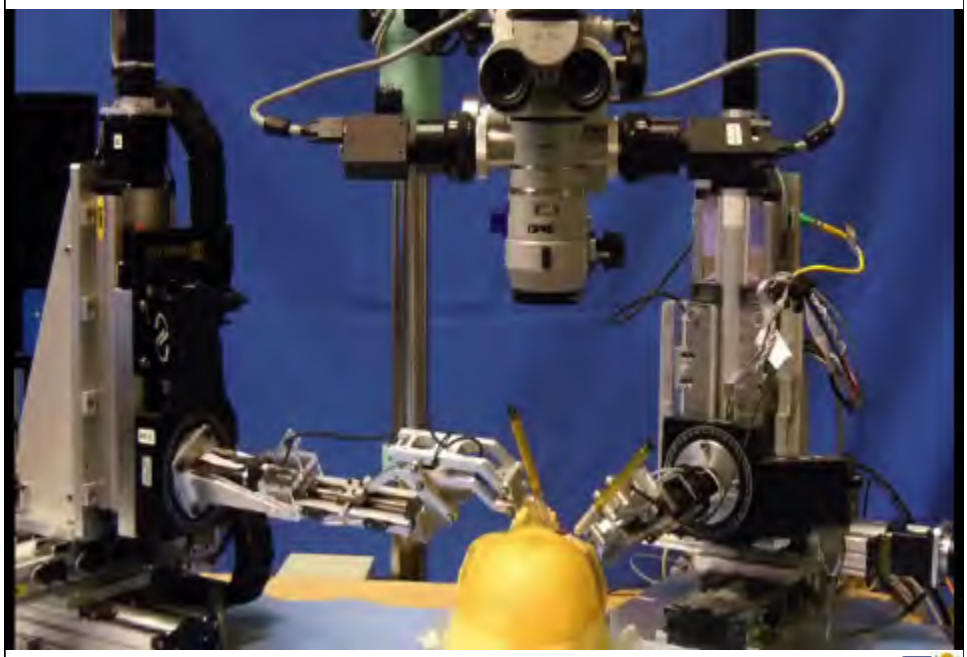
Use of Audio and Voice

- Voice commands and annotation
- Auditory sensory substitution

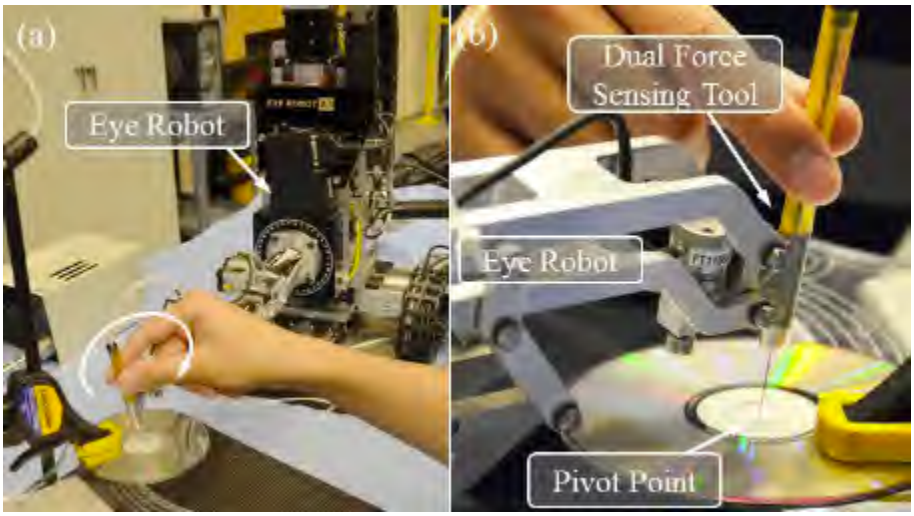
Example Audio Response to Force Input



M. Balicki, *et al.*

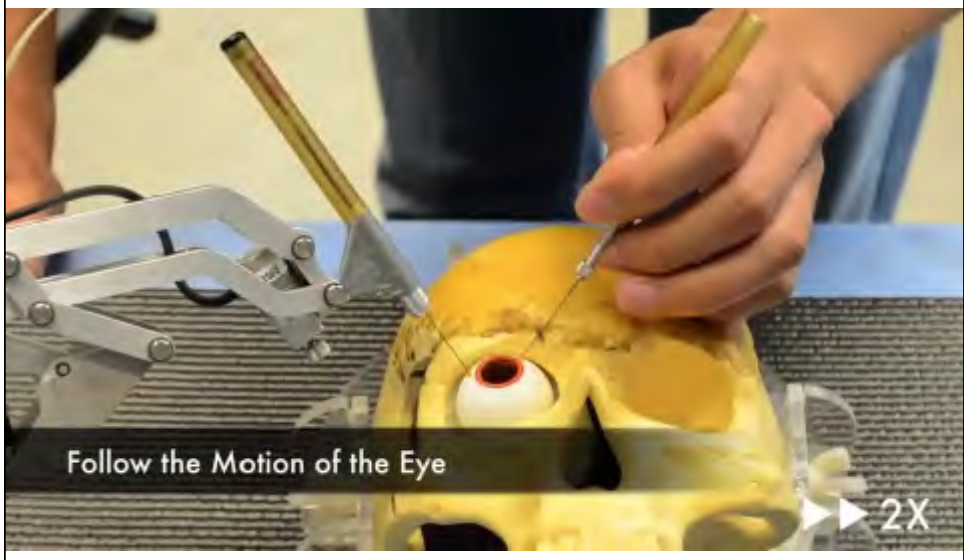


Dual Force Sensor



X. He, Marcin Balicki, P. Gehlbach, J. Handa, R. Taylo, and I. Iordachita, "Variable Admittance Robot Control with A New Dual Force Sensing Instrument for Retinal Microsurgery", *in IEEE Int. Conf. Rob. Automat*, Hong Kong, May 31-June 5, 2014..

Dual Force Sensor

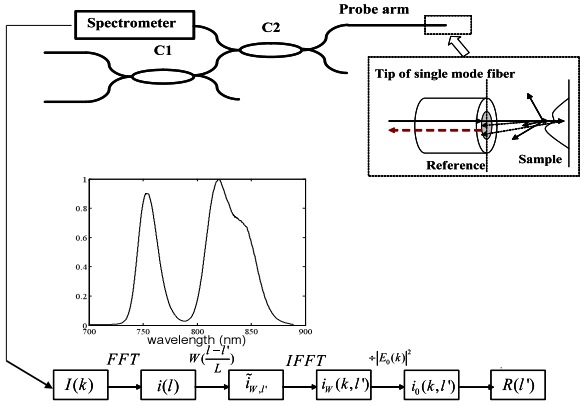


X. He, Marcin Balicki, P. Gehlbach, J. Handa, R. Taylo, and I. Iordachita, "Variable Admittance Robot Control with A New Dual Force Sensing Instrument for Retinal Microsurgery", *in IEEE Int. Conf. Rob. Automat*, Hong Kong, May 31-June 5, 2014..

Imaging (OCT) Built Into 0.5mm Surgical Tool

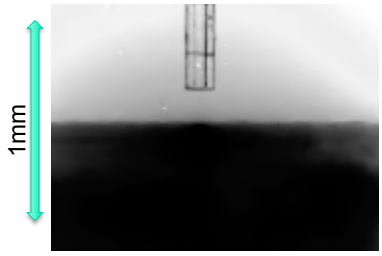
M. Balicki, J. Han, X. Liu, I. Iordachita, P. Gehlbach, J. Handa, R. Taylor, J. Kang.

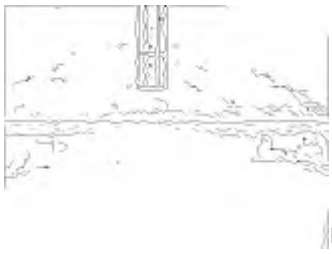
- Fourier Domain Common Path OCT (FD CPOCT)
- Combined Superluminescent Diodes
- Functional and structural images

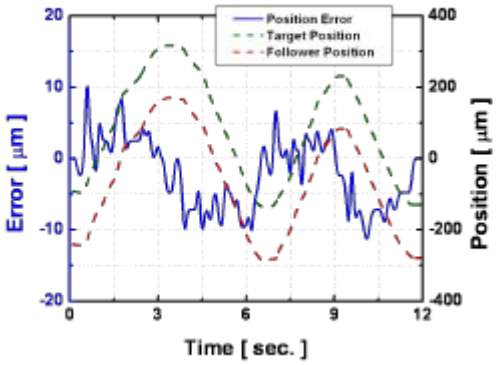


Autonomous Surface Following

M. Balicki, J.-H. Han, I. Iordachita, P. Gehlbach, J. Handa, R. H. Taylor, and J. Kang, *MICCAI 2010*



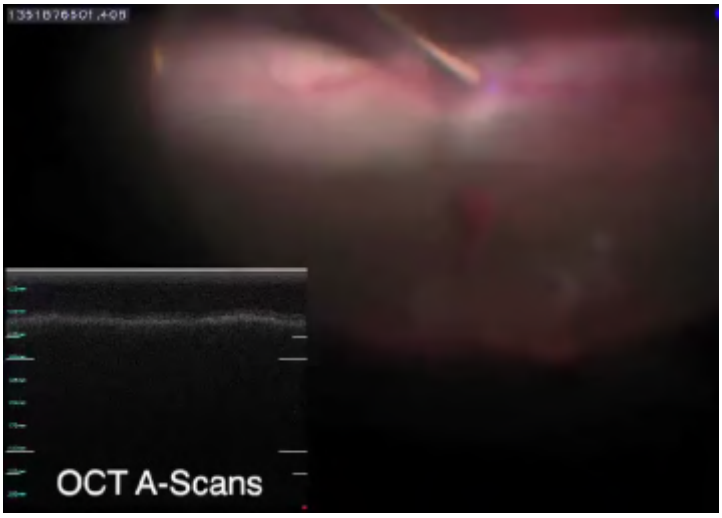




* 500 µm/s Velocity Limit

Noise Rem. /Thresholded/Canny

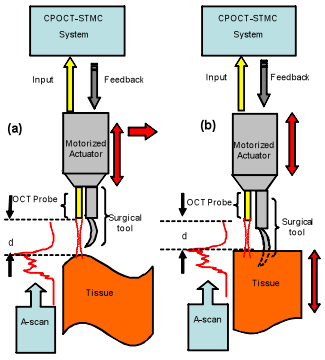
OCT of Rabbit Retina with Micron-held Probe

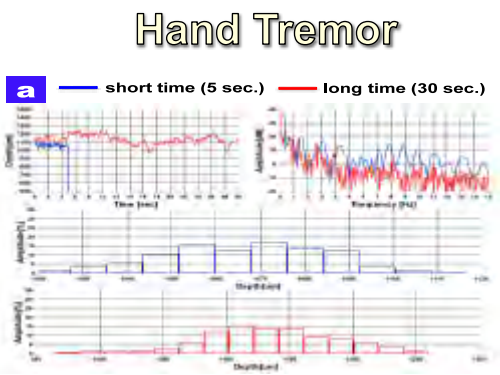


X. Liu, M. Balicki, C. Riviere, R. MacLaughlin, *et al.*

OCT-Guided Motion Control and Compensation with a One Degree-of-Freedom Hand-Held Robot

J. Kang, P. Gehlbach, C. Song, *et al.*



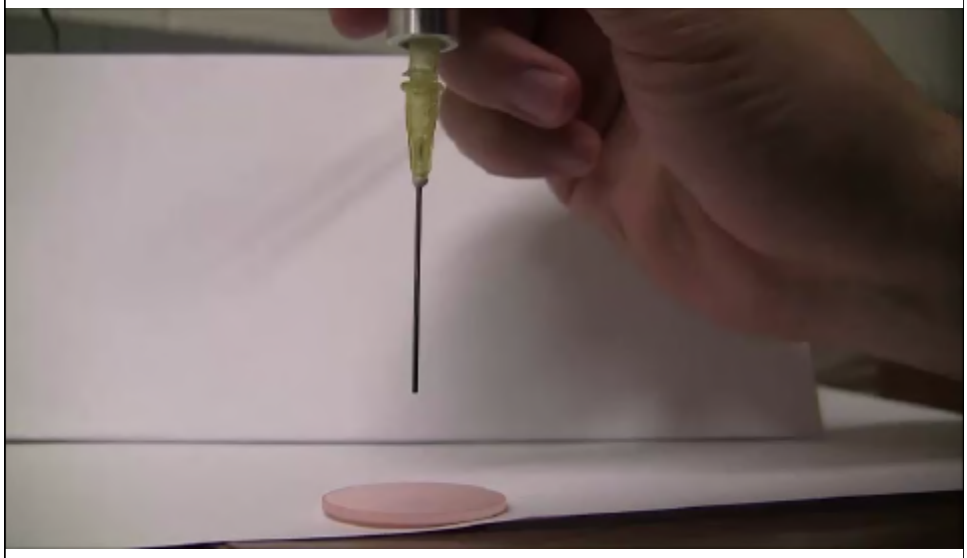


Two basic functions
of the CPOCT-STMC system:
(a) Topological and motion compensation (Safety Barrier),
(b) Targeting and surgical intervention

NIH R01 EY021540

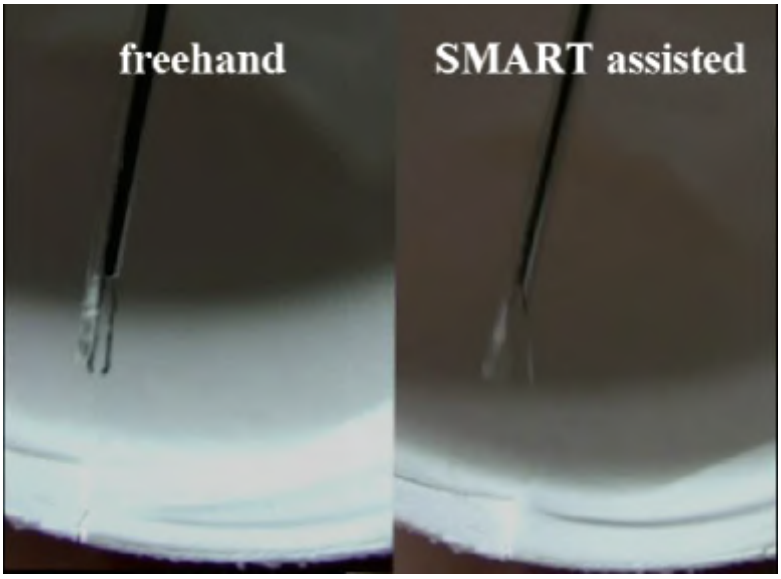
Safety Barrier

J. Kang, P. Gehlbach, C. Song, *et al.*

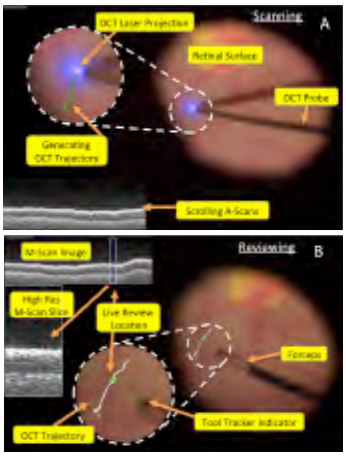


Smart Micro-Forceps

J. Kang, P. Gehlbach, C. Song, *et al.*

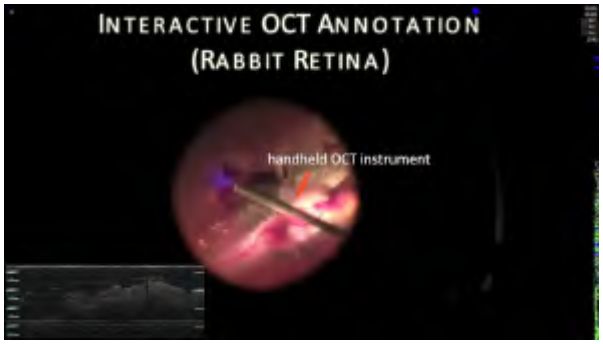


M-Scan



M. Balicki, R. Richa, B. Vagvolgyi, J. Handa, P. Gehlbach, J. Kang, P. Kazanzides, and R. Taylor, "Interactive OCT Annotation and Visualization System for Vitreoretinal Surgery", Medical Image Computing and Computer-Assisted Interventions (MICCAI), Nice, October, 2012

M-Scan: *in vivo*



M. Balicki, R. Richa, B. Vagvolgyi, J. Handa, P. Gehlbach, J. Kang, P. Kazanzides, and R. Taylor, "Interactive OCT Annotation and Visualization System for Vitreoretinal Surgery", Medical Image Computing and Computer-Assisted Interventions (MICCAI), Nice, October, 2012

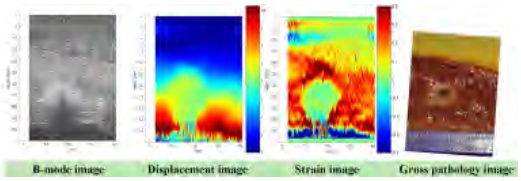
Closed Loop Interventional Medicine

Information

Patient-specific Information (Images, lab results, genetics, etc.)

General information (anatomic atlases, statistics, rules)

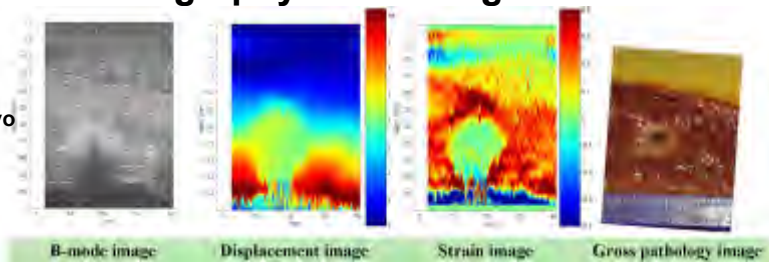
Model → Plan → Evaluation → Action → **Patient-specific Evaluation**

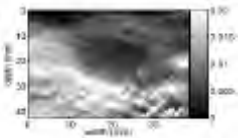
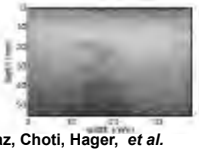
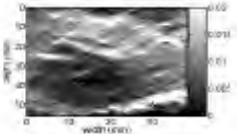
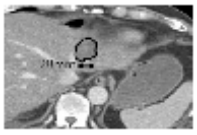


EUS images: E. Boctor

Elastography monitoring of ablations

Ex vivo

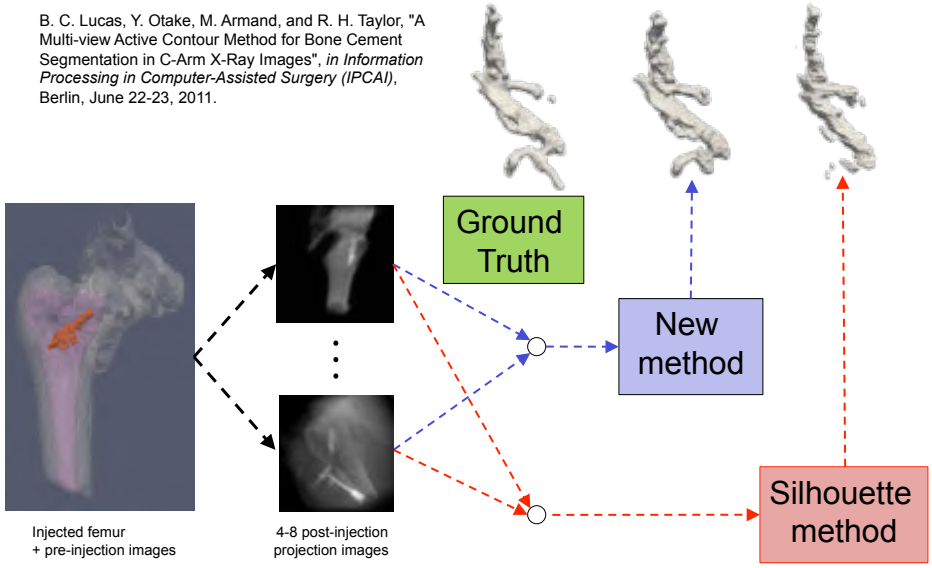


	ultrasound	elasticity	post-operation CT
patient 1			
patient 2			

Credit: Boctor, Rivaz, Choti, Hager, *et al.*

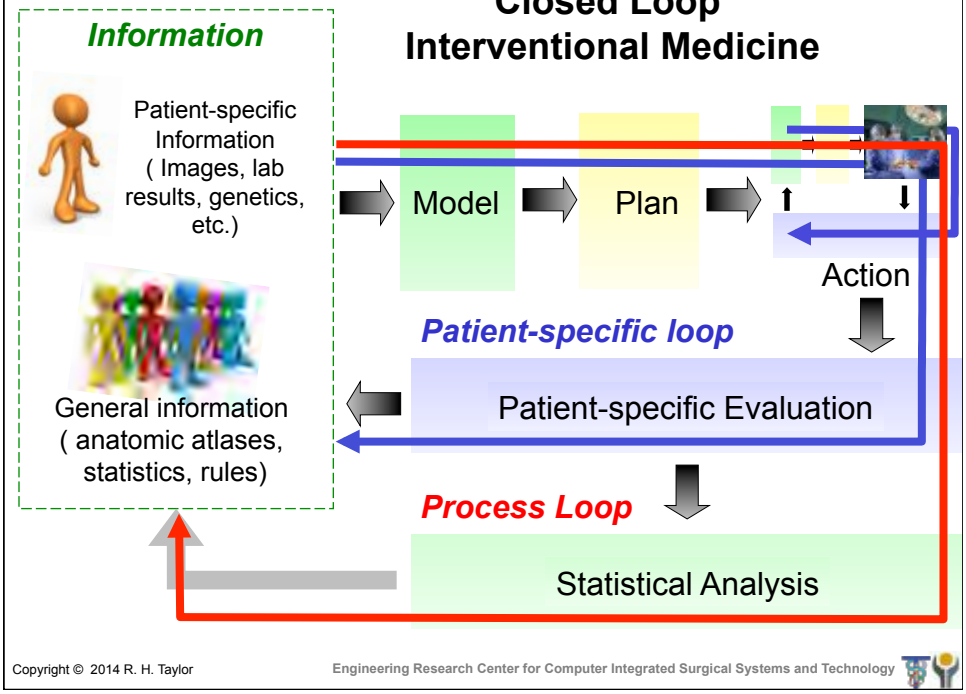
Reconstruction of injected cement from sparse x-rays

B. C. Lucas, Y. Otake, M. Armand, and R. H. Taylor, "A Multi-view Active Contour Method for Bone Cement Segmentation in C-Arm X-Ray Images", *in Information Processing in Computer-Assisted Surgery (IPCAI)*, Berlin, June 22-23, 2011.



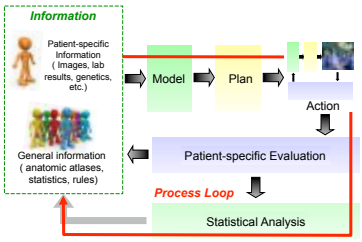
Example: Cadaver study with soft tissue and 4difference images

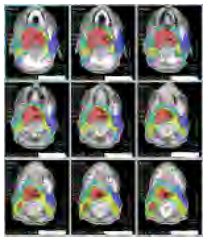
Closed Loop Interventional Medicine



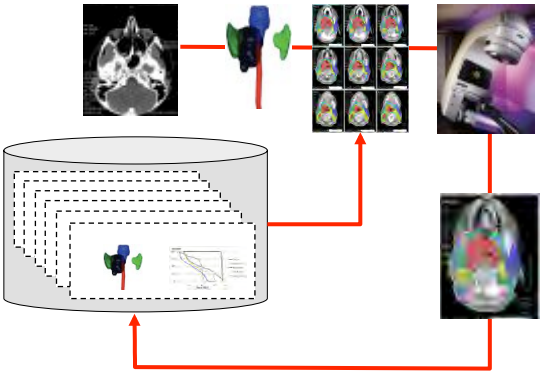
Information-Integrated Process Learning

- **Key idea**
  - Medical robots and CAI systems inherently generate data and promote consistency
  - Eventually, outcomes are known
  - Combine this information over many patients to improve treatment plans / processes
- **Issues / Themes**
  - Very large data bases combining heterogeneous data
  - Statistical modeling of patients, procedures, and outcomes
  - Online tracking of procedures





Credit: Todd McNutt



Statistical process control for radiation therapy

Overall Goal: Use a database of previously treated patients to improve radiation therapy planning for new patients

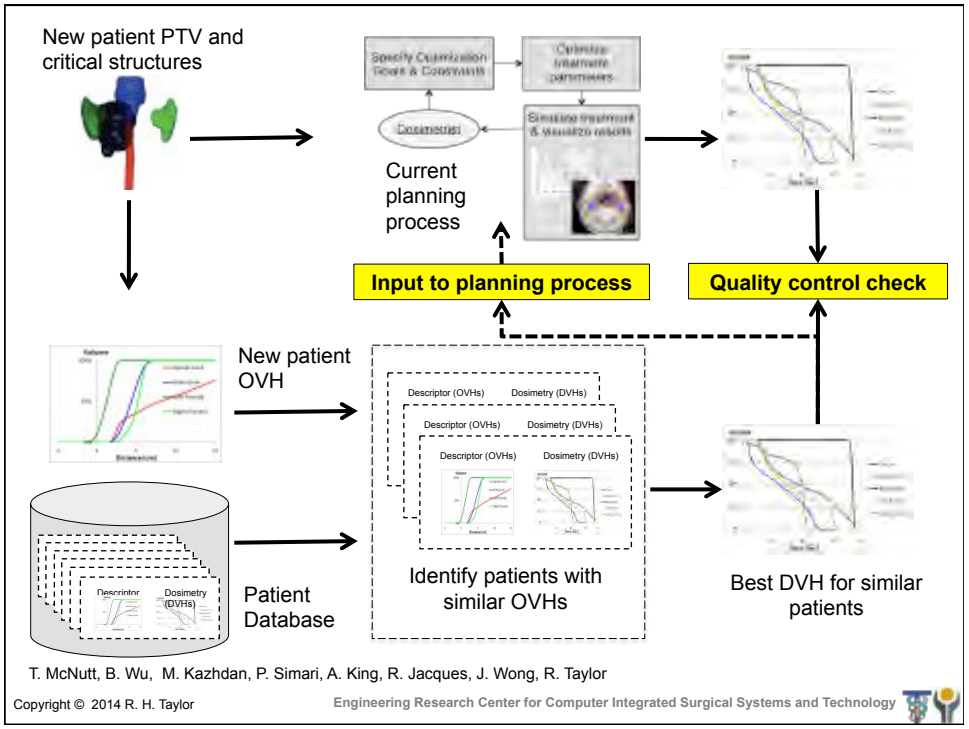
Team:

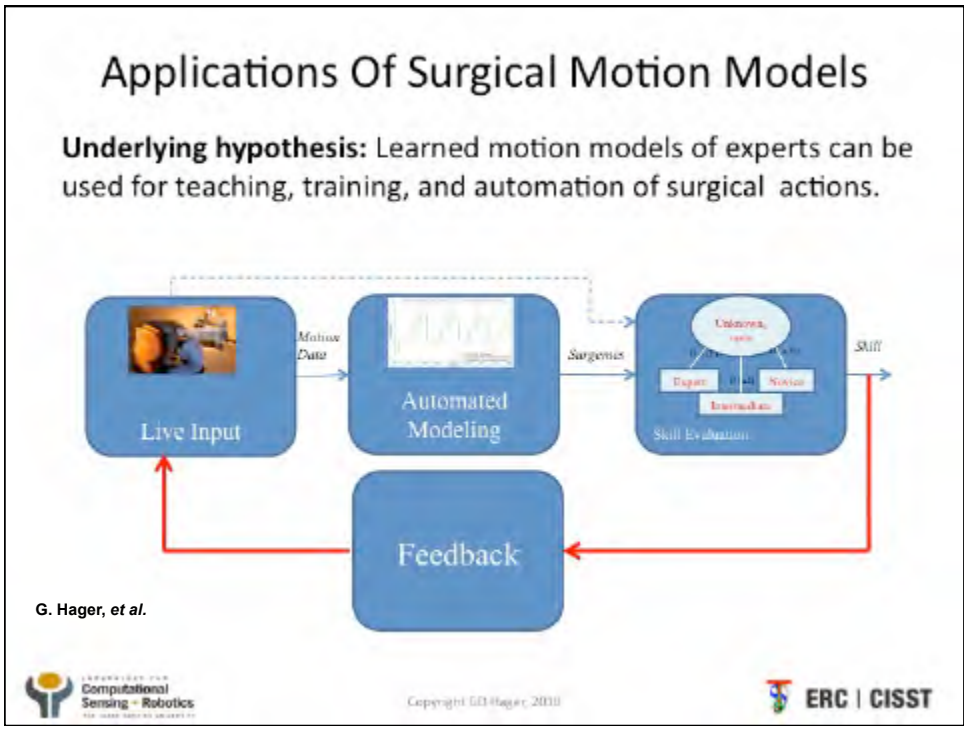
CS: R. Taylor, M. Kazhdan, P. Simari, A. King

BME: R. Jacques

Rad. Oncology: T. McNutt, J. Wong, B. Wu, G. Sanguinetti (MD)

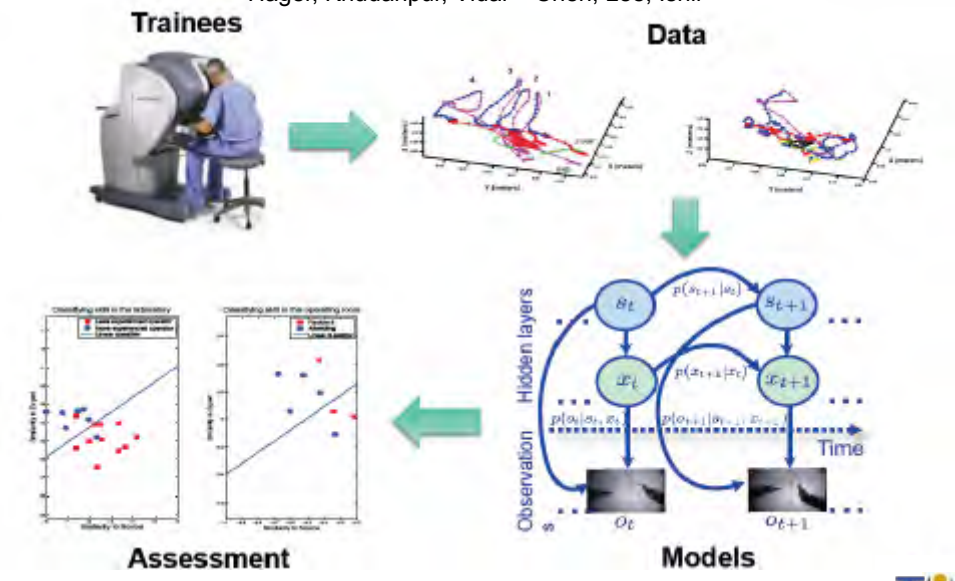
Support: Paul Maritz, Philips, JHU internal funds


New patient PTV and critical structures
Current planning process
Input to planning process
Quality control check
New patient OVH
Descriptor (OVHs)
Dosimetry (DVHs)
Patient Database
Identify patients with similar OVHs
Best DVH for similar patients
T. McNutt, B. Wu, M. Kazhdan, P. Simari, A. King, R. Jacques, J. Wong, R. Taylor
Copyright © 2014 R. H. Taylor
Engineering Research Center for Computer Integrated Surgical Systems and Technology

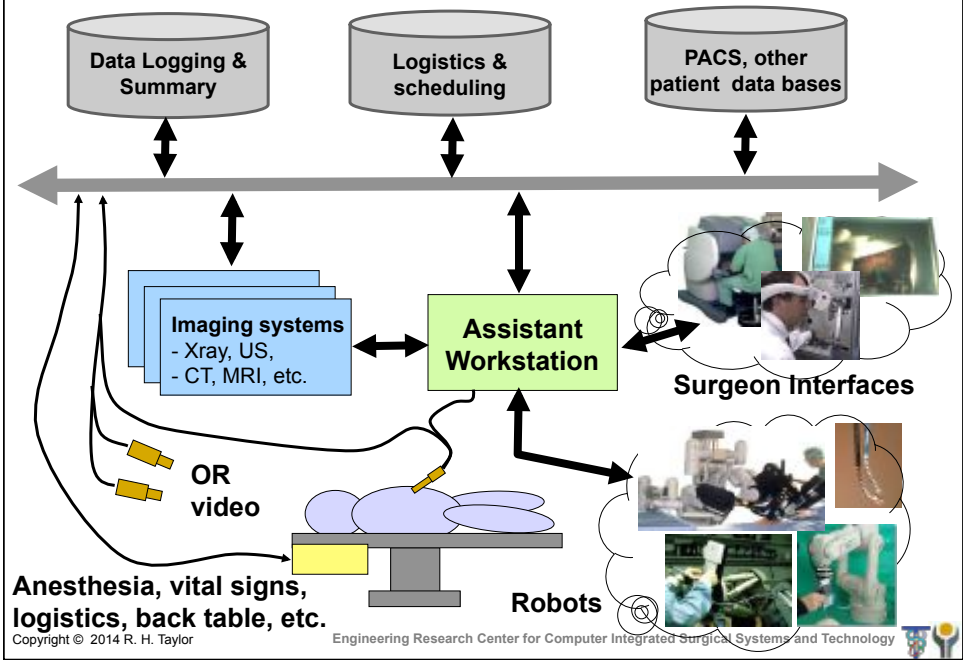

Applications Of Surgical Motion Models
Underlying hypothesis: Learned motion models of experts can be used for teaching, training, and automation of surgical actions.
Live Input
Motion Data
Automated Modeling
Surgemes
Skill
Feedback
G. Hager, et al.
Computational Sensing + Robotics
ERC | CISST

The Language of Surgery

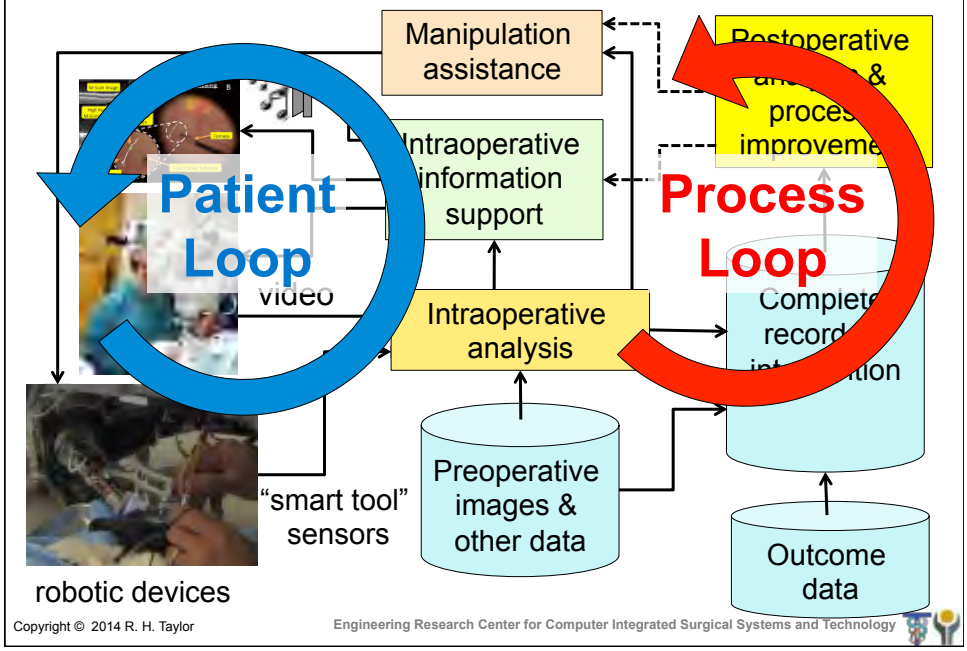
Hager, Khudanpur, Vidal + Chen, Lee, Ishii



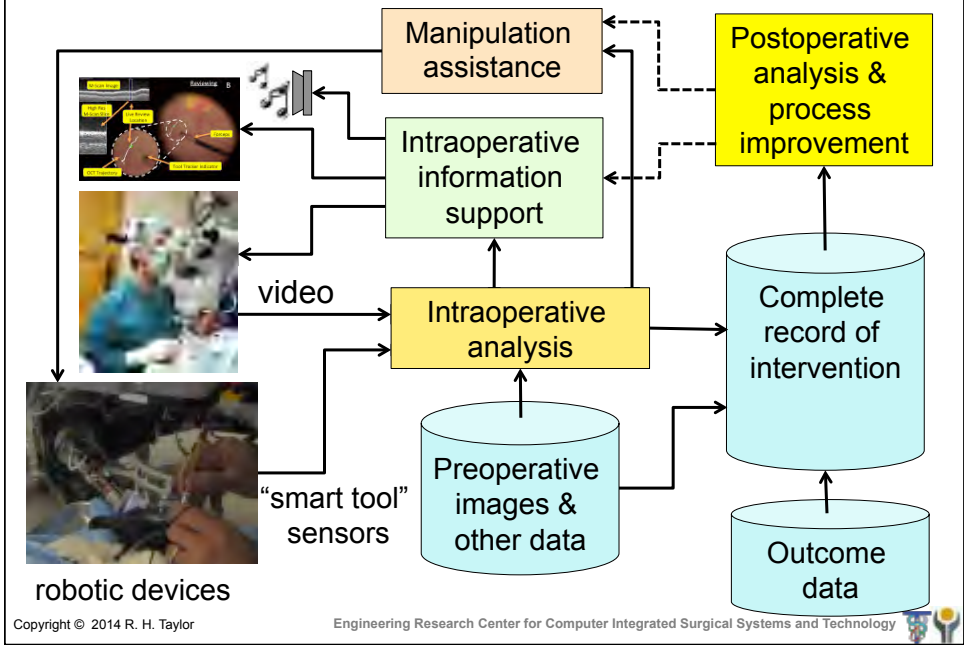
Information-Intensive Interventional Suite



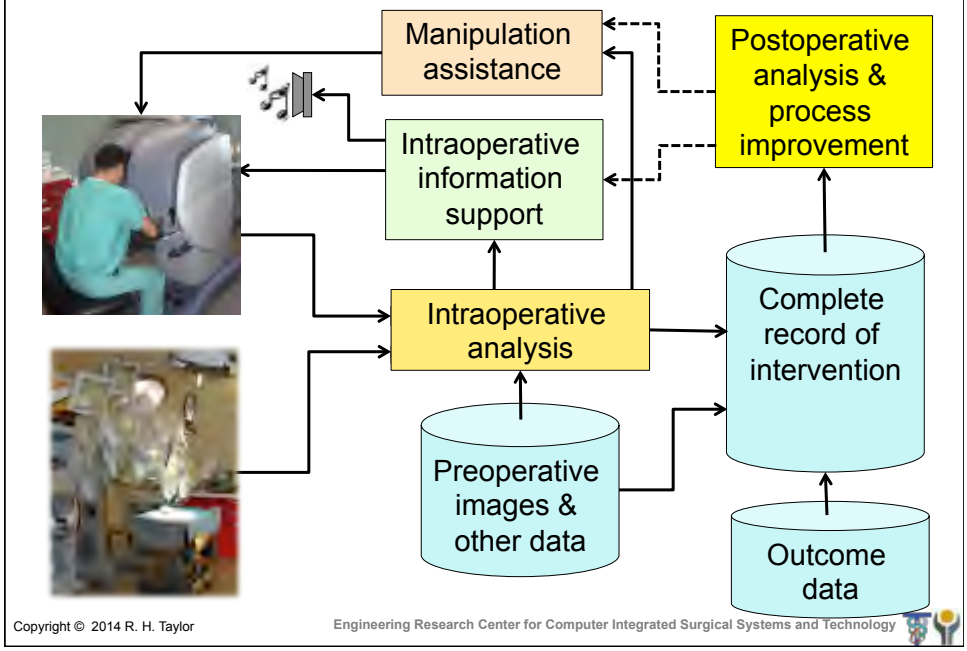
The computer-integrated operating room



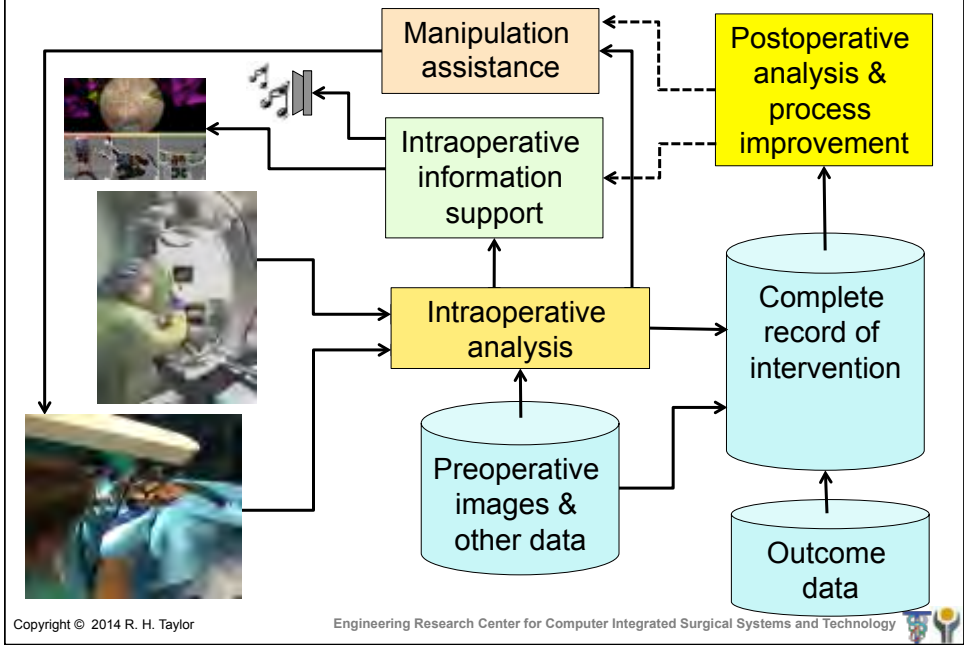
The computer-integrated operating room



The computer-integrated operating room

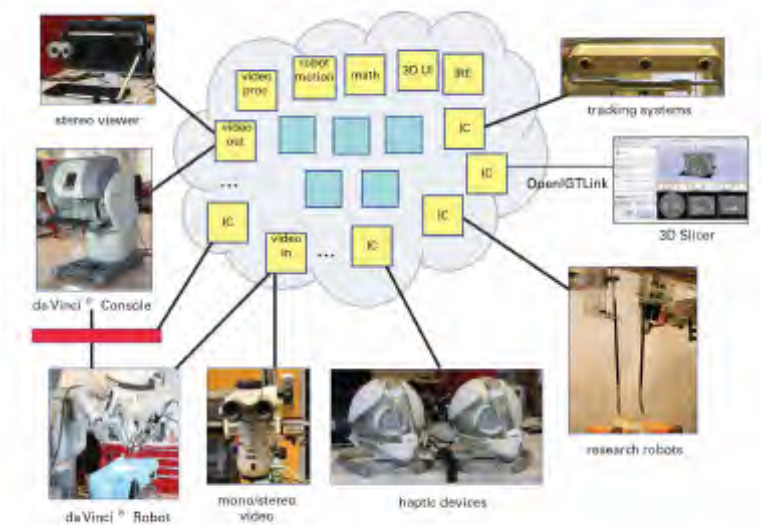


The computer-integrated operating room



cisst libraries and Surgical Assistant Workstation

https://trac.lcsr.jhu.edu/cisst



Peter Kazanzides, Simon P. DiMaio, Anton Deguet, and many more

Use Case: da Vinci Research Kit

- Mechanical components from da Vinci "classic" systems
- Donated by Intuitive Surgical to selected university labs
- Consortium to provide "open source" engineering and support
  - Software – JHU (CISST/SAW)
  - Controller electronics –JHU
  - Interface electronics – ISI
  - Controller power/packaging – WPI
- Controllers and software also adapted for use with complete recycled da Vinci "classic" systems
- **http://research.intusurg.com/dvrkwiki/**

Development History

cisst/SAW Software

EEC 9731748, EEC 0646678

Open source mechatronics

MRI 0722943

da Vinci
Research Kit

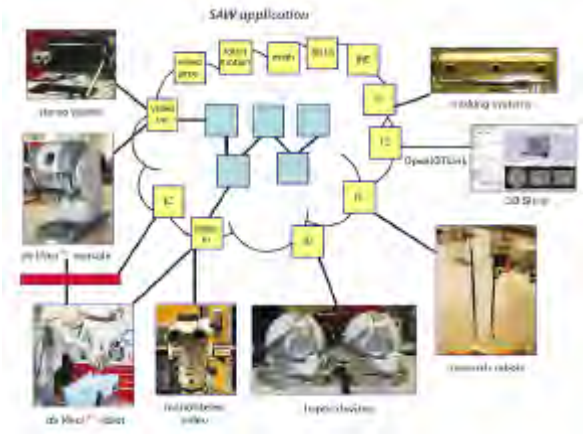
NRI 1208540
NRI 1327657

SAW Value Proposition

Component Viewer

Python shell

General System
Tools



Data collection /
replay

User Community

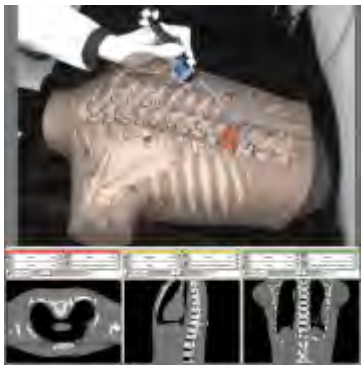
First DVRK User Group Meeting

Johns Hopkins University, March 20-21, 2014

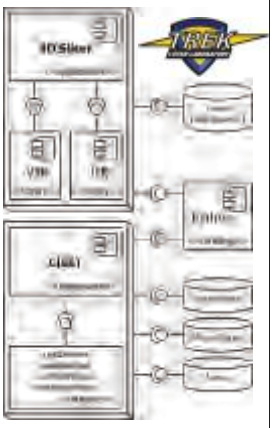
Use Case: Cone-Beam CT-Guided Surgical Navigation

I-STAR Lab

C-arm Setup in the JHU Minimially Invasive Surgical Training and Innovation Center (MISTIC)



Integrated Tracking and Video Augmentation with the Claron MicronTracker

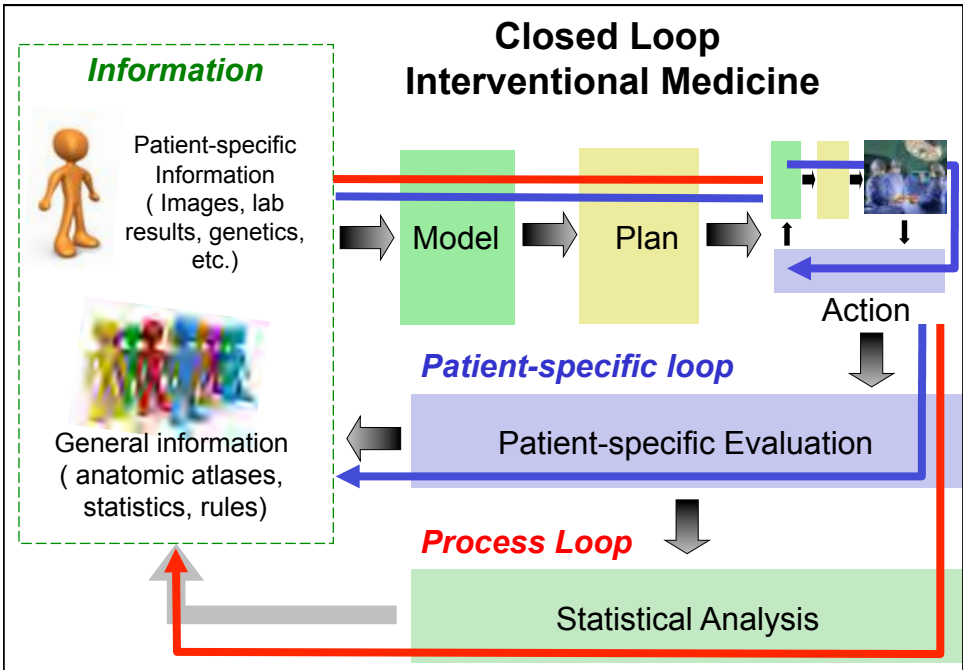


Open-Source Architecture for System Integration

Slide courtesy of J.H. Siewerdsen, Johns Hopkins University

SAW Beyond Surgery

- SAW = Space Assistant Workstation?
- Perform “image-guided surgery” on satellites
  - CT/MRI Image → CAD Model
- Added challenge: time delay (5-10 seconds)
  - Virtual fixtures, semi-autonomous motions, shared control



The real bottom line: patient care

- Provide new capabilities that **transcend human limitations** in surgery
- Increase **consistency and quality** of surgical treatments
- Promote **better outcomes** and more **cost-effective** processes in surgical practice

Discussion