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Autonomy and Semi-Autonomous Behavior in Surgical Robot Systems

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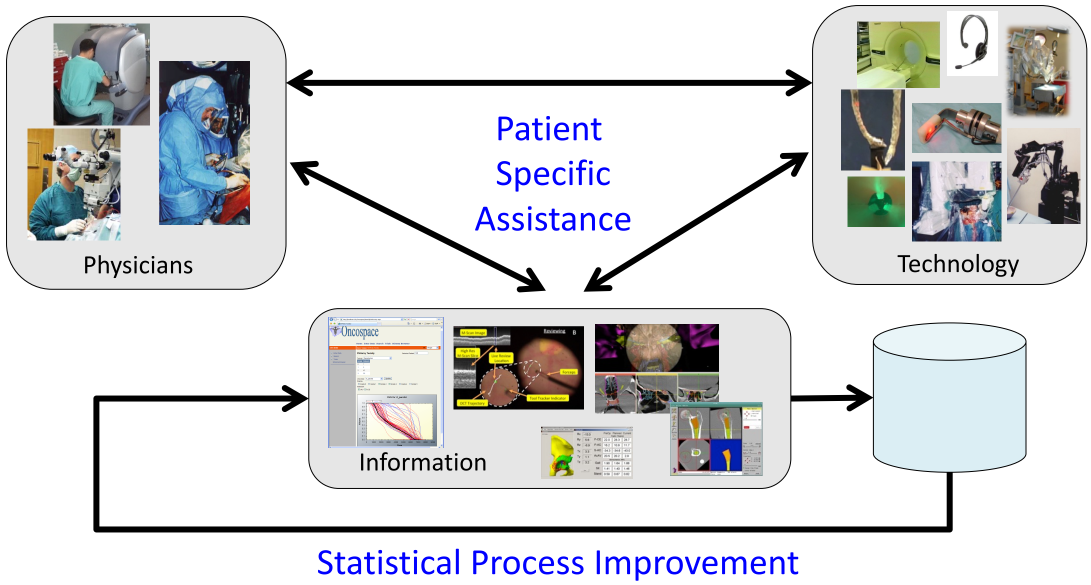
Human-machine partnership to fundamentally improve interventional medicine



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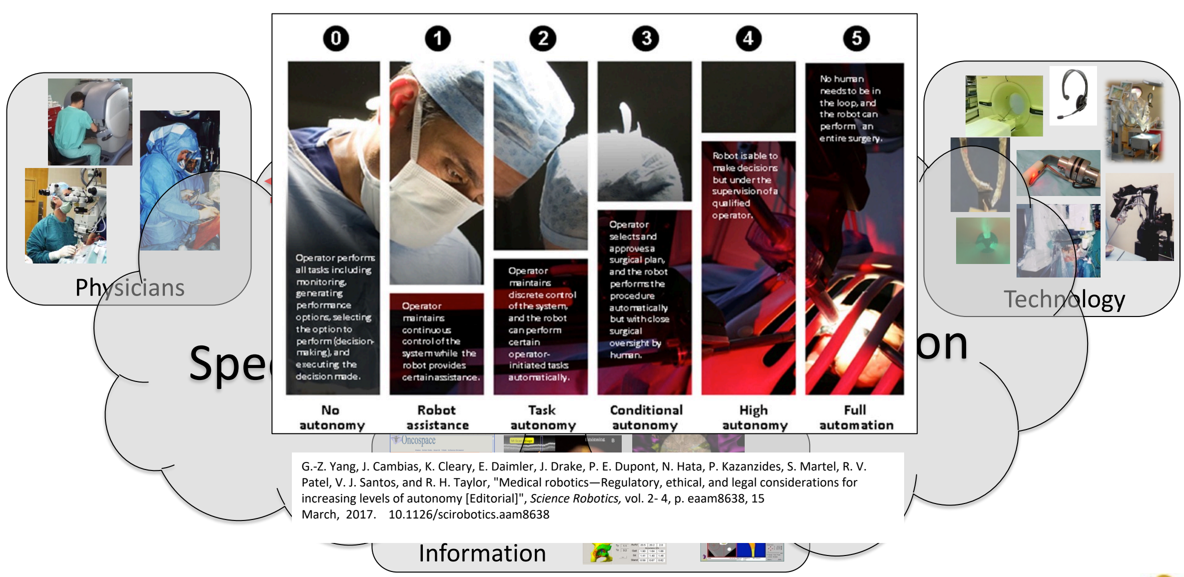
The key issue: mediating between human intention and action



G.-Z. Yang, J. Cambias, K. Cleary, E. Daimler, J. Drake, P. E. Dupont, N. Hata, P. Kazanzides, S. Martel, R. V. Patel, V. J. Santos, and R. H. Taylor, "Medical robotics—Regulatory, ethical, and legal considerations for increasing levels of autonomy [Editorial]", *Science Robotics,* vol. 2- 4, p. eaam8638, 15 March, 2017. 10.1126/scirobotics.aam8638

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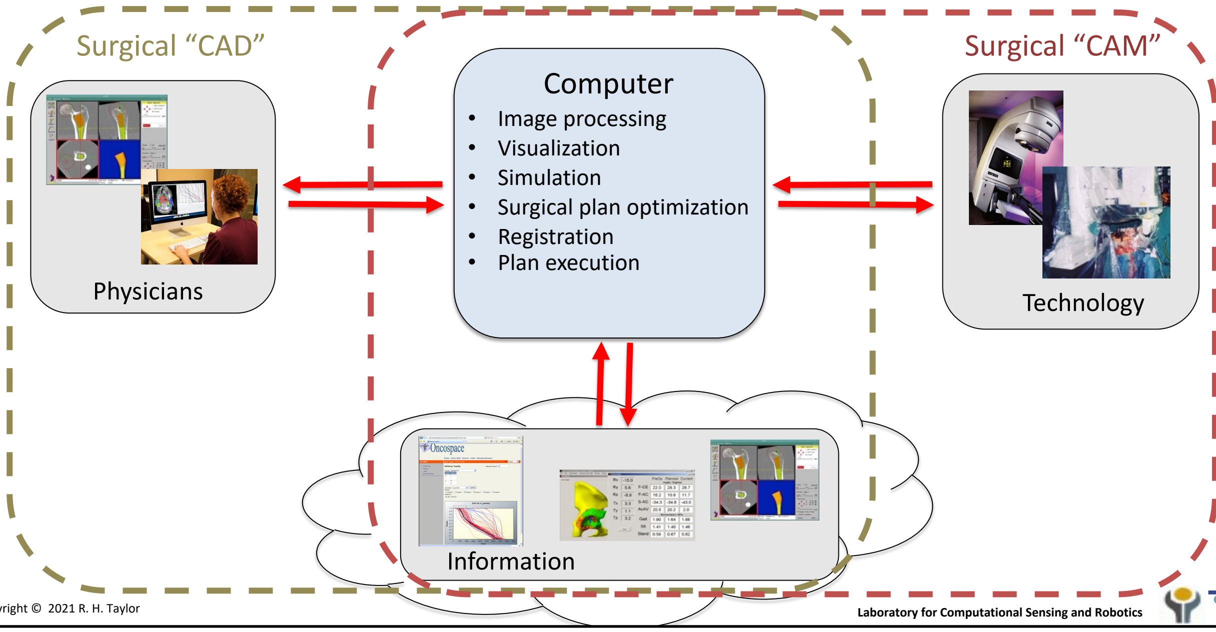
Surgical "CAD/CAM"



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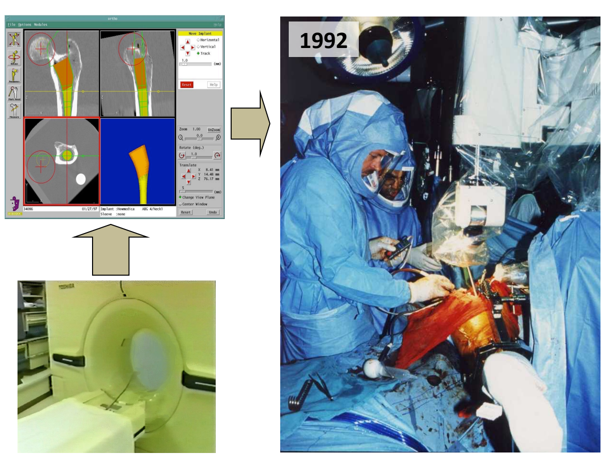
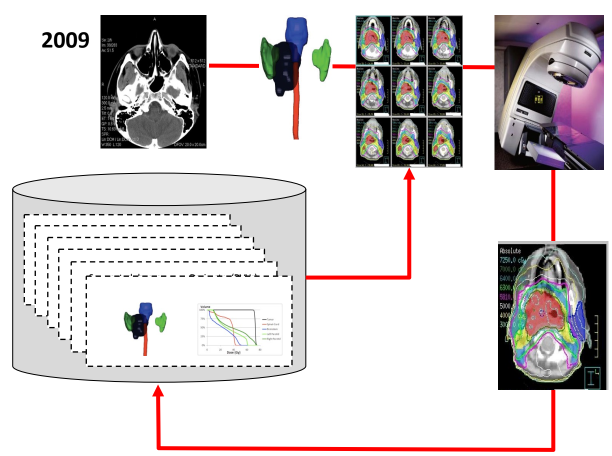
Early Examples of Surgical "CAD/CAM" with Robots

Robodoc Total Joint Replacement



Taylor, Paul, Kazanzides, *et al.*

Radiation Therapy Systems



Taylor, McNutt, Kazhdan, Patrucio, Wu, *et al.*

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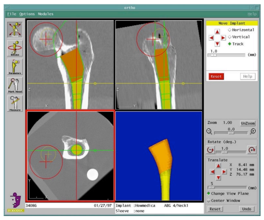
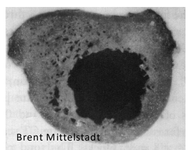
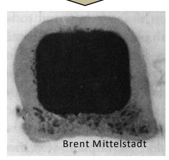
Robotic Joint Replacement Surgery





Manual Surgery



Robotic Surgery

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

Planning:
- Initially interactive graphics with CT images
- Subsequently
  - Automate segmentation
  - Statistics based planning

Execution
- Combination of hand guiding and autonomous machining bones
- Initially mechanical location of fiducials for registration
- Subsequently
  - ICP-based registration
  - Image-based registration

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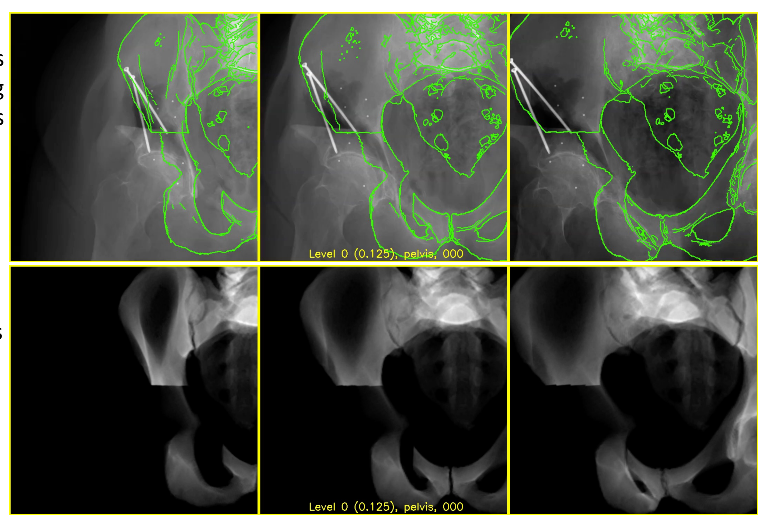
3D-2D Registration of Osteotomy Fragments

$$\underset{\theta_1,\ldots,\theta_N \in SE(3)}{\arg\min} \sum_{m=1}^{M} \mathcal{S}\left(I_m, \sum_{n=1}^{N} \mathcal{P}_m\left(I_{CT};\theta_n\right)\right)$$

Fixed Images with Moving Image Edges

Moving Images



R. Grupp, R. Murphy, M. Armand, R. Taylor

Slide credit: Robert Grupp

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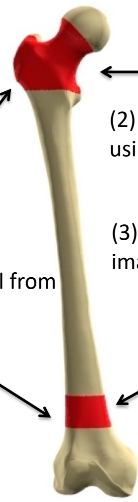
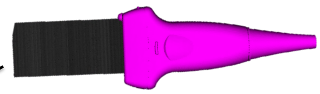
Ultrasound-assisted Registration



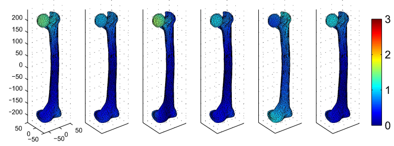
(1) Generate surface model from CT

(2) Digitize proximal bone using tracked pointer

(3) Collect tracked US images of distal bone



(4) Register points/contours to surface model



S. Billings, H. J. Kang, A. Cheng, E. Boctor, P. Kazanzides, and R. Taylor, "Minimally invasive registration for computer-assisted orthopedic surgery: combining tracked ultrasound and bone surface points via the P-IMLOP algorithm", Int. J. Computer Assisted Radiology and Surgery, p. (epub ahead of print), 2015. http://dx.doi.org/10.1007/s11548-015-1188-z DOI 10.1007/s11548-015-1188-z

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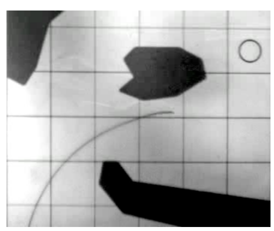
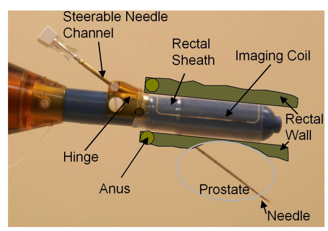
9

Image-guided needle placement

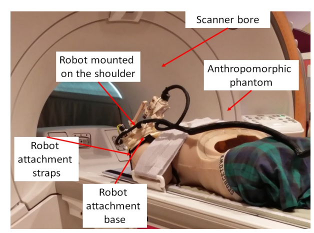
Masamune, Fichtinger, Iordachita, …



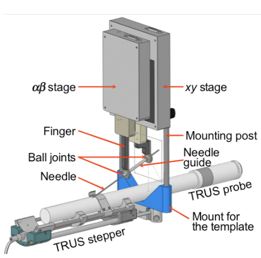
Okamura, Webster, …



Krieger, Fichtinger, Whitcomb, …

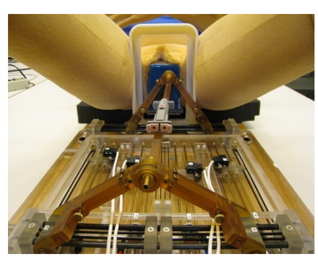


Monfaredi, Sharma, Kim, Iordachita, Cleary



Fichtinger, Kazanzides, Burdette, Song …

Taylor, Masamune, Susil, Patriciu, Stoianovici,…



Iordachita, Fischer, Hata…

Iordachita, Fischer, Hata…

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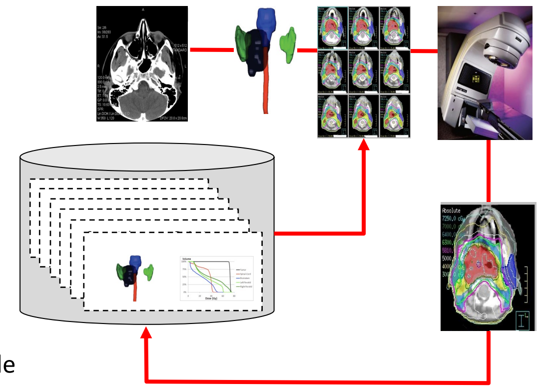
11

Example: External Beam Radiation Therapy Systems

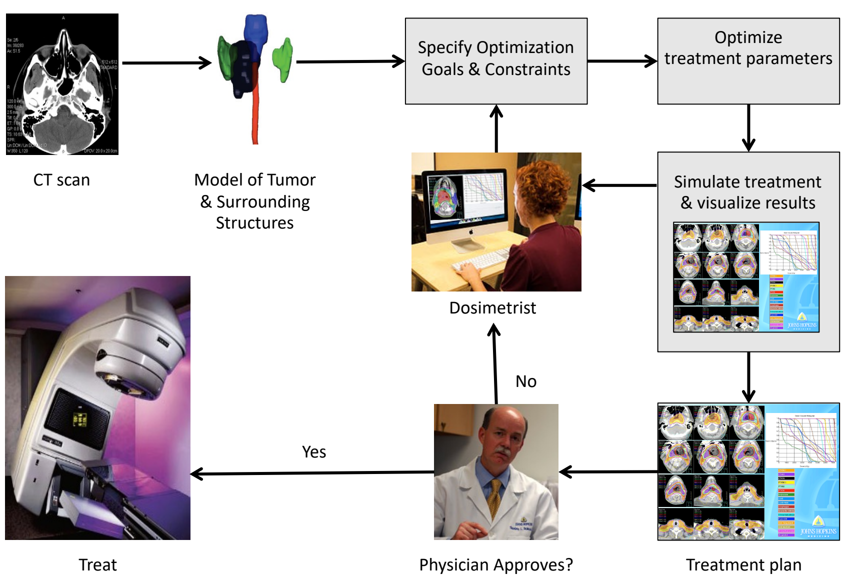
- "Robotic" systems since at least 1980s
- Task Specification
  - Planning of radiation pattern from CT
  - Typically human-machine process involving optimization + simulation
- Task Execution
  - Very careful and accurate machine calibration & verification
  - Registration to patient
  - Machine delivers beams of radiation from multiple angles
- Challenges/Opportunities
  - Adaptation to patient changes/motion
  - Experience-based planning to optimize outcomes
  - The "usual" (system integrity, etc.)



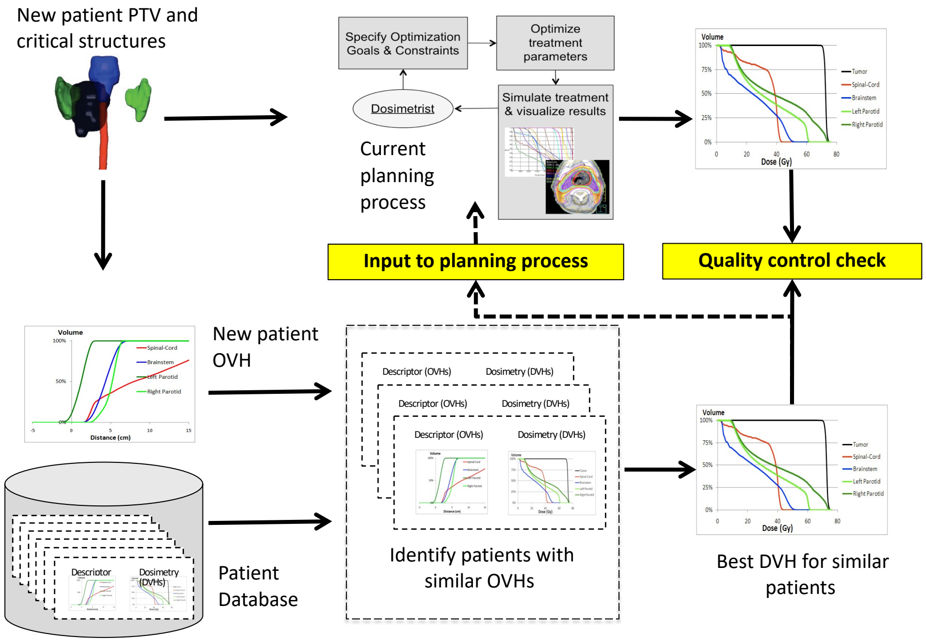
JHU Faculty: Todd McNutt, Russell Taylor, Mischa Kazhdan, Ilya Shpitser, Sauleh Siddiqui

12

Conventional Radiation Therapy Planning



13



T. McNutt, B. Wu, M. Kazhdan, P. Simari, A. King, R. Jacques, J. Wong, R. Taylor

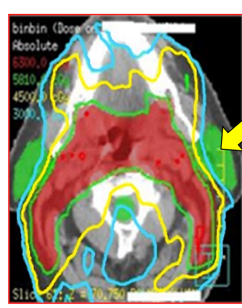
14

Sample automated radiation planning result

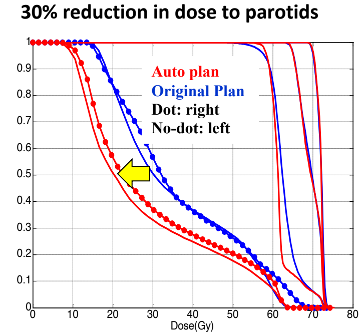
T. McNutt, A. Patriciu, B. Wu, R.. Taylor *et al.*

Original plan

Automated plan



30% reduction in dose to parotids

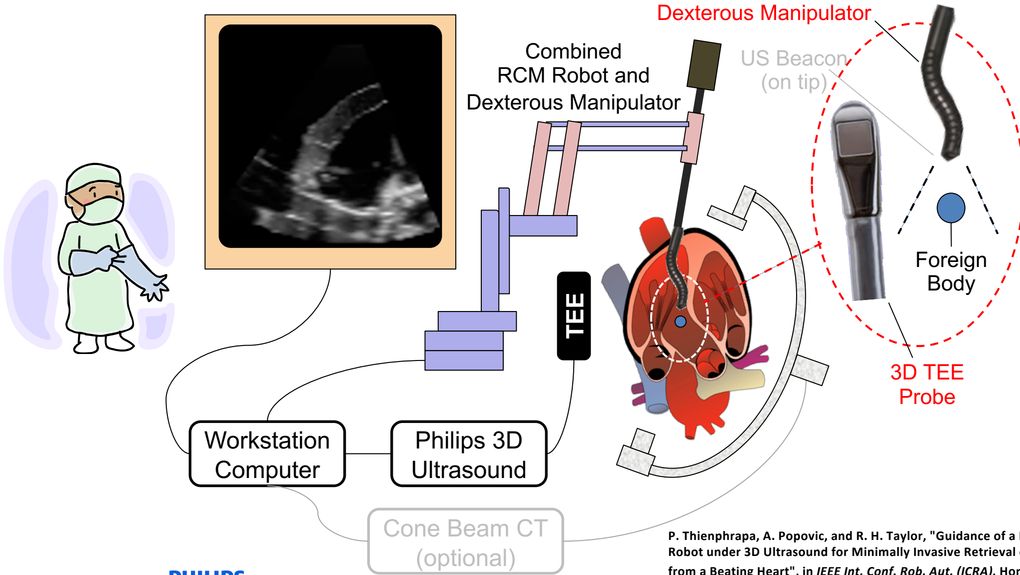


	brain (Gy) (max)	Brainstem (Gy) (max)	Cord4mm (Gy) (max)	L inner ear (Gy)(mean)
original	61.25	54.58	41.75	57.18
re-plan	56.33	46.48	37.89	43.72
	R inner ear (Gy) (mean)	**mandible (Gy) (max)**	**larynx for edema (V50)**	**esophagus (Gy)(max)**
original	40.57	66.58	61%	63.74
re-plan	38.38	63.78	59%	61

15

Beating Heart MIS with 3D US Guidance

Paul Thienphrapa, Aleksandra Popovic, Russell Taylor



PHILIPS

P. Thienphrapa, A. Popovic, and R. H. Taylor, "Guidance of a High Dexterity Robot under 3D Ultrasound for Minimally Invasive Retrieval of Foreign Bodies from a Beating Heart", in *IEEE Int. Conf. Rob. Aut. (ICRA),* Hong Kong, May 31-Jun 6, 2014. pp. 4869-4874.

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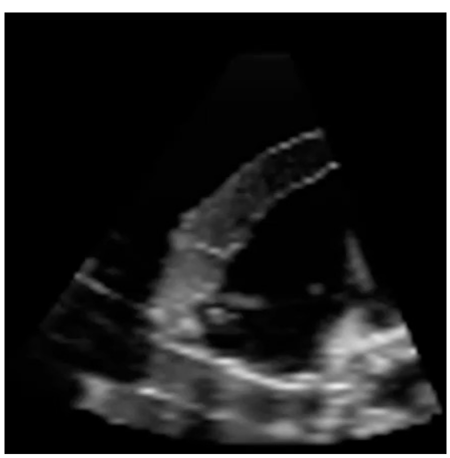
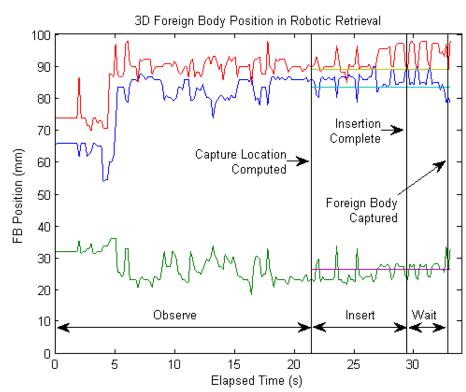
16

Retrieval Experiment Results





PHILIPS

Thienphrapa *et al.* 2013

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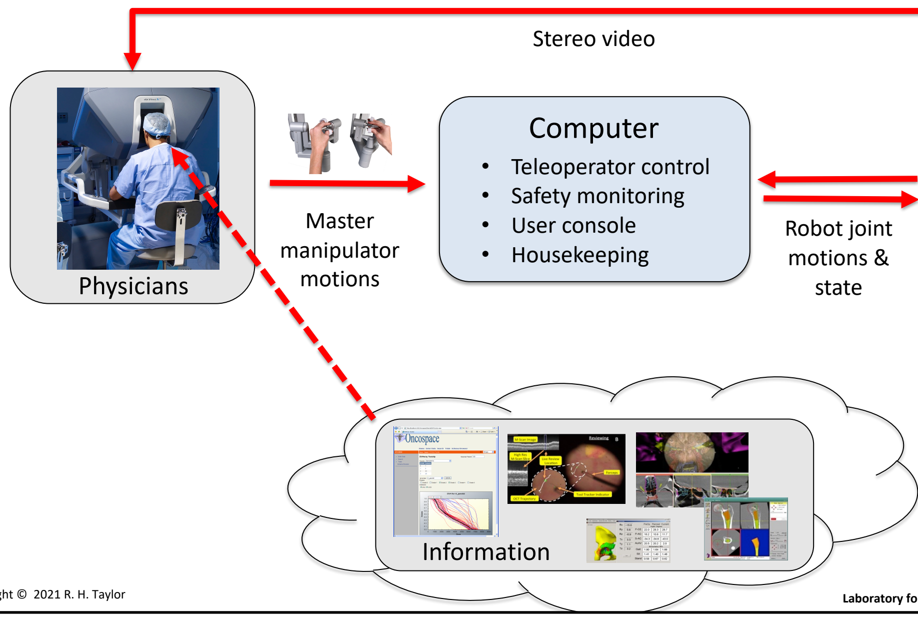
18

Current dominant paradigm for interactive surgery



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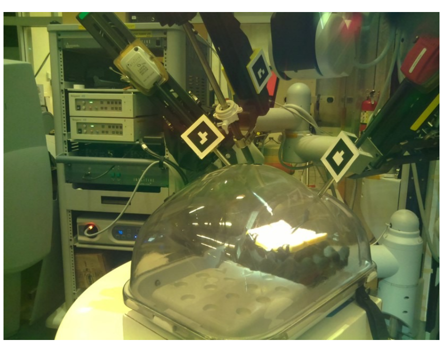
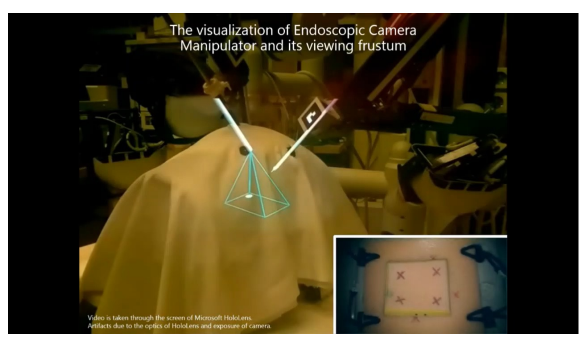
19

Augmented Reality: da Vinci Patient-Side Assistant

L. Qian, A. Deguet, Z. Wang, Y. Liu, P. Kazanzides



Setup with transparent abdominal phantom



View through HMD (HoloLens)

L. Qian, A. Deguet, P. Kazanzides, "ARssist: Augmented Reality on a Head-Mounted Display for the First Assistant in Robotic Surgery", *IET Healthcare Technology Letters*, Oct. 2018
L. Qian, A. Deguet, Z. Wang, Y. Liu, P. Kazanzides, "Augmented Reality Assisted Instrument Insertion and Tool Manipulation for the First Assistant in Robotic Surgery", *IEEE ICRA*, May 2019.

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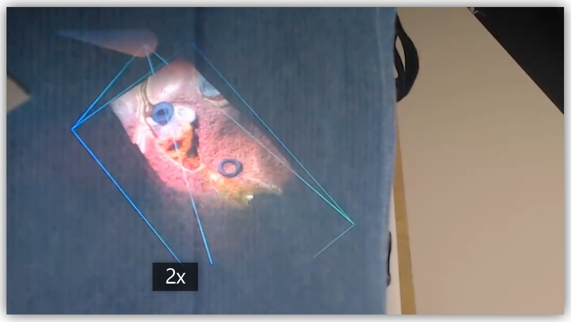
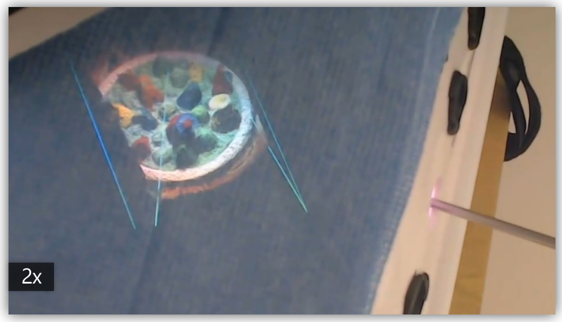
20

Augmented Reality: Laparoscopic Guidance

L. Qian, X. Zhang, A. Deguet, P. Kazanzides

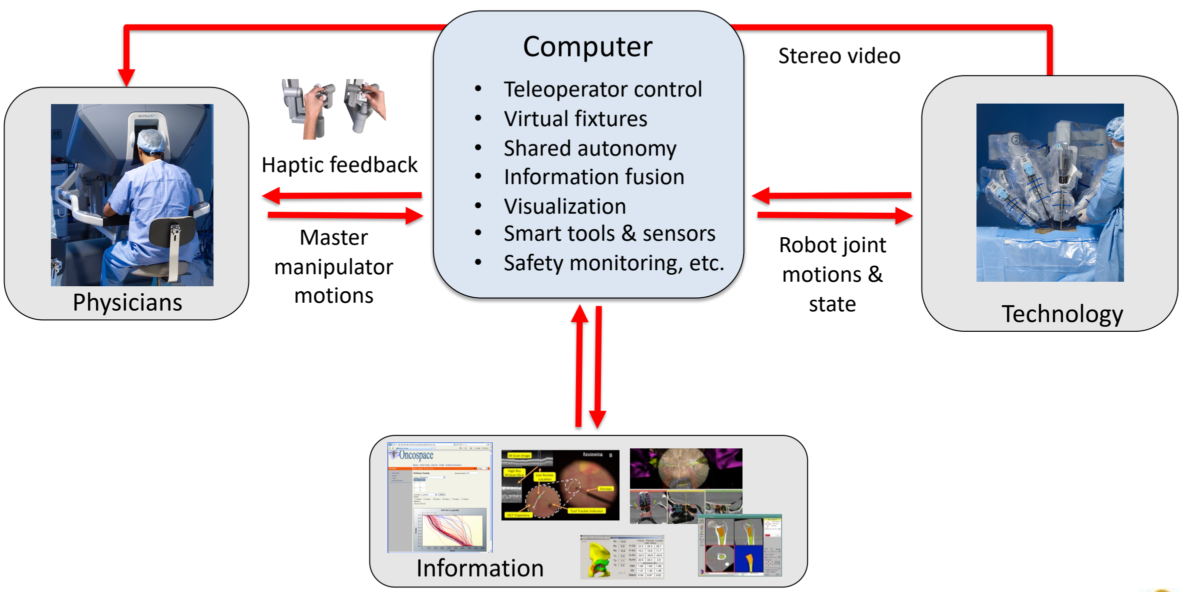




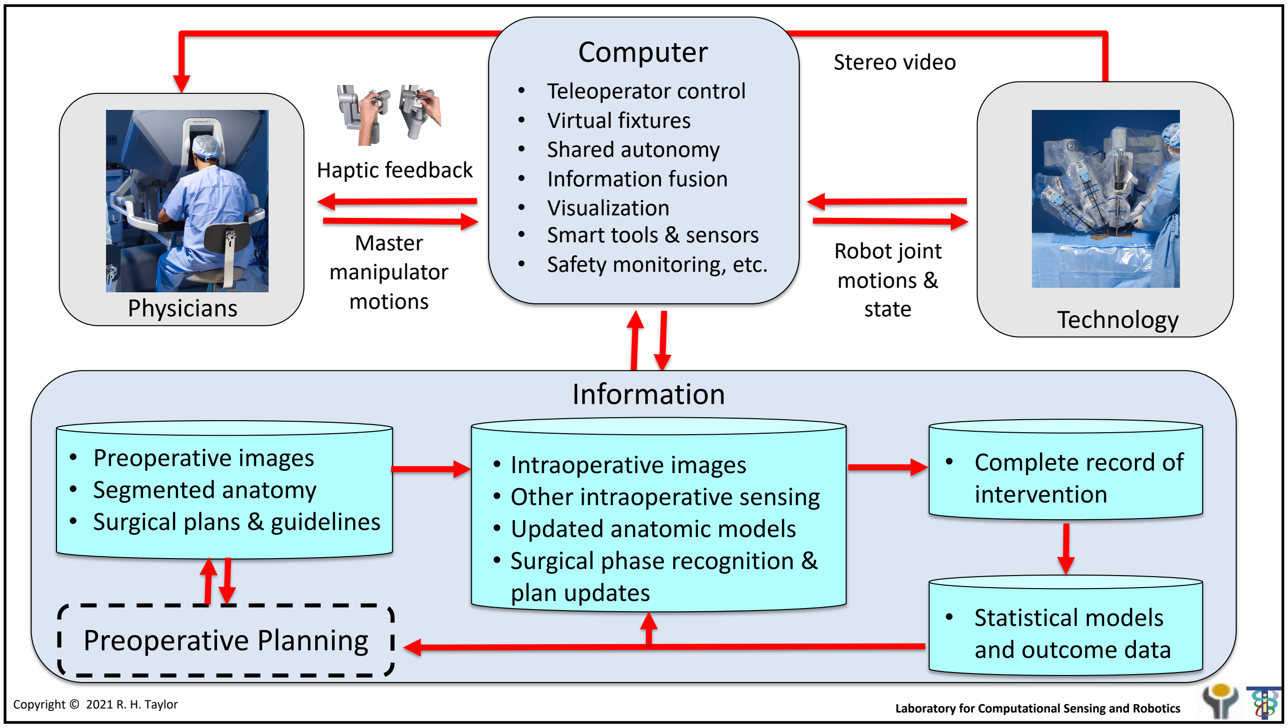
L. Qian, X. Zhang, A. Deguet, P. Kazanzides. "ARAMIS: Augmented Reality Assistance for Minimally Invasive Surgery Using a Head-Mounted Display." *MICCAI* 2019.

21

Emerging paradigm (shared autonomy & assistant modes)



22


Computer
Teleoperator control
Virtual fixtures
Shared autonomy
Information fusion
Visualization
Smart tools & sensors
Safety monitoring, etc.
Stereo video
Haptic feedback
Master manipulator motions
Physicians
Robot joint motions & state
Technology
Information
Preoperative images
Segmented anatomy
Surgical plans & guidelines
Intraoperative images
Other intraoperative sensing
Updated anatomic models
Surgical phase recognition & plan updates
Complete record of intervention
Statistical models and outcome data
Preoperative Planning
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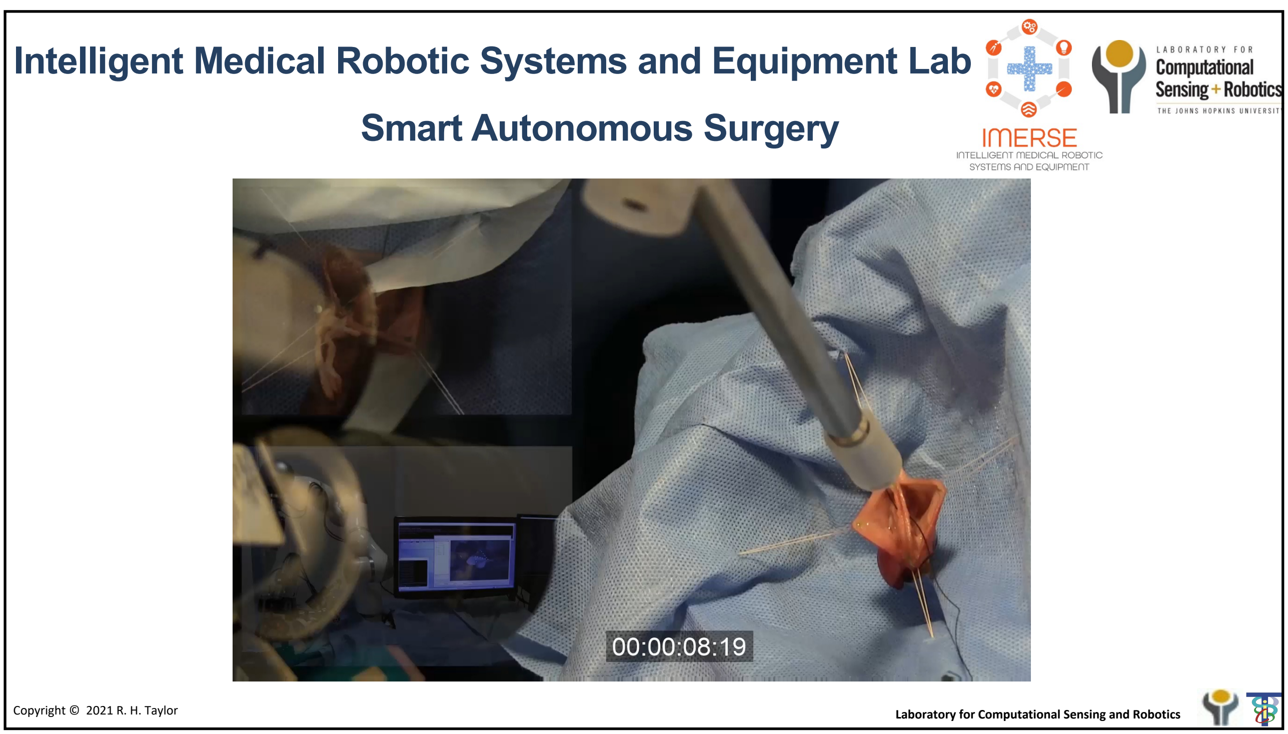
23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Smart Autonomous Surgery
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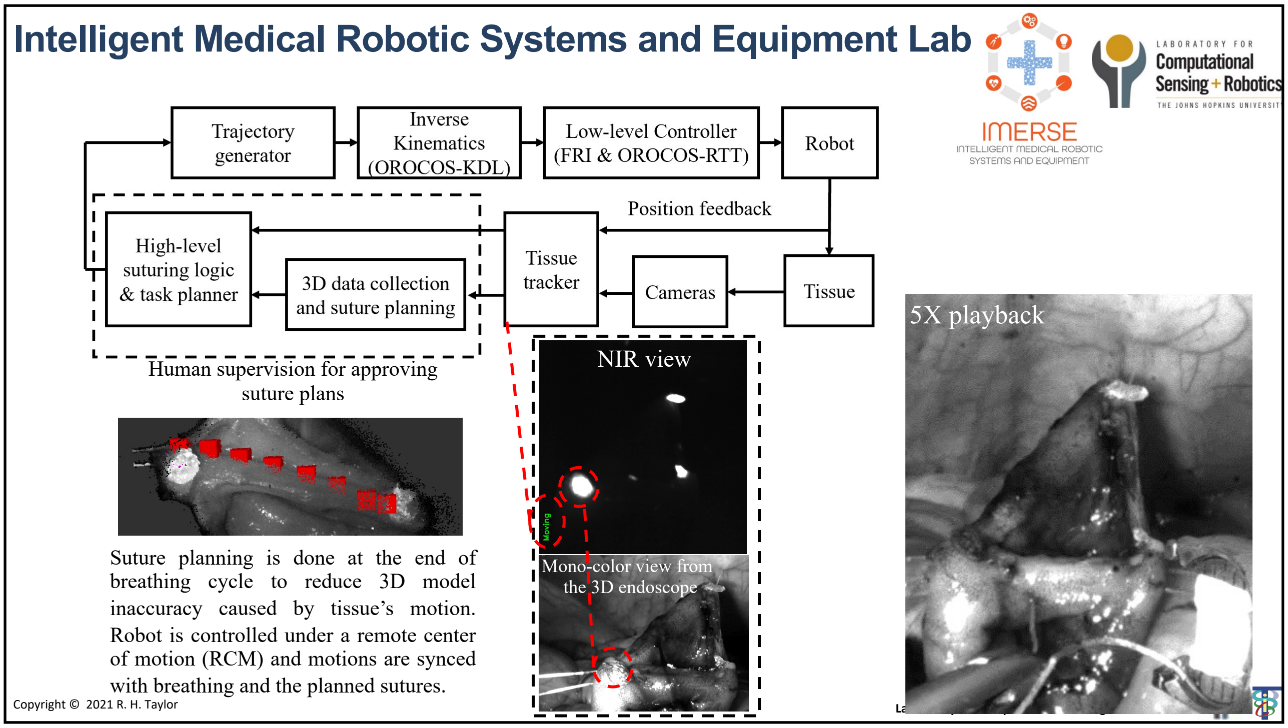
25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Trajectory generator
Inverse Kinematics (OROCOS-KDL)
Low-level Controller (FRI & OROCOS-RTT)
Robot
Position feedback
High-level suturing logic & task planner
3D data collection and suture planning
Tissue tracker
Cameras
Tissue
Human supervision for approving suture plans
NIR view
Moving
Mono-color view from the 3D endoscope
5X playback
Suture planning is done at the end of breathing cycle to reduce 3D model inaccuracy caused by tissue's motion. Robot is controlled under a remote center of motion (RCM) and motions are synced with breathing and the planned sutures.
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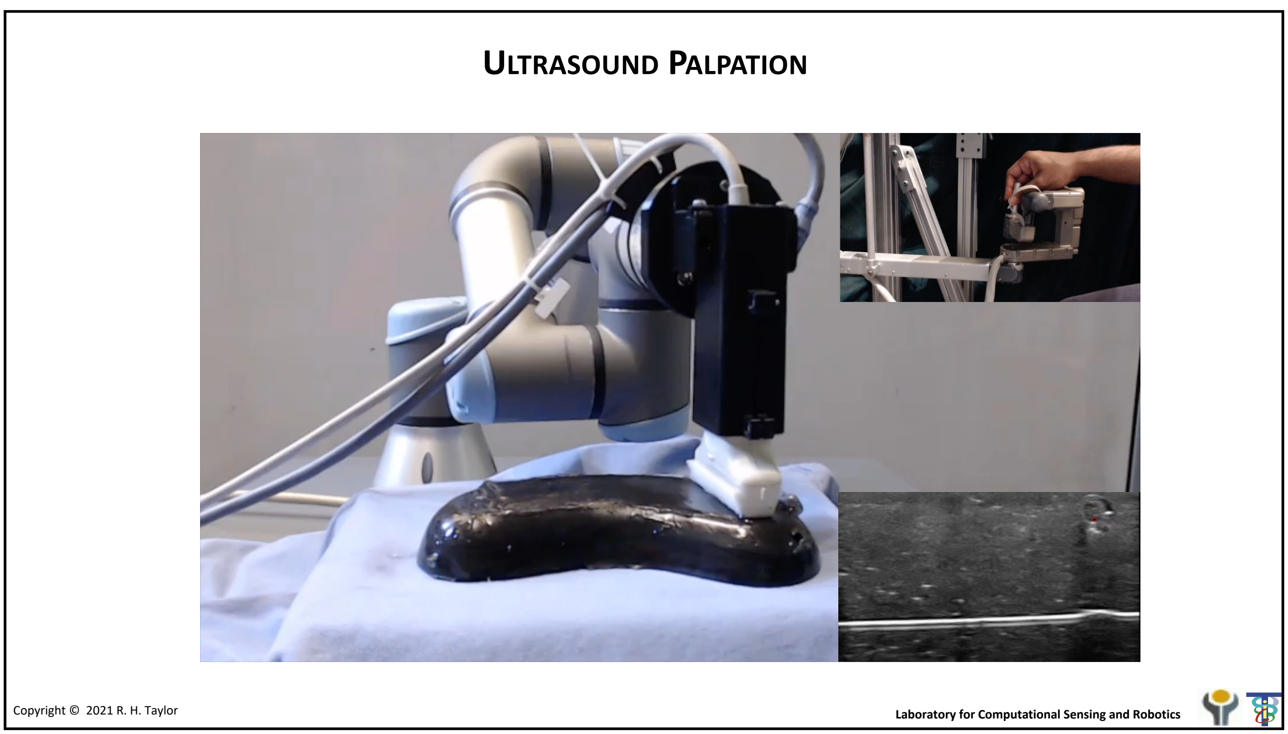
26


ULTRASOUND PALPATION
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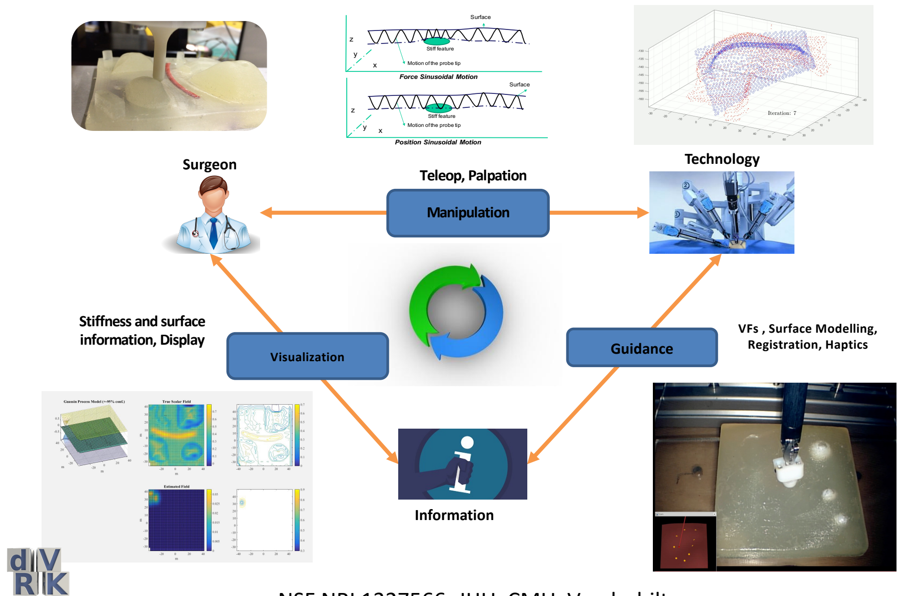
27

Complementary Situational Awareness in a Robotic Surgical Assistant



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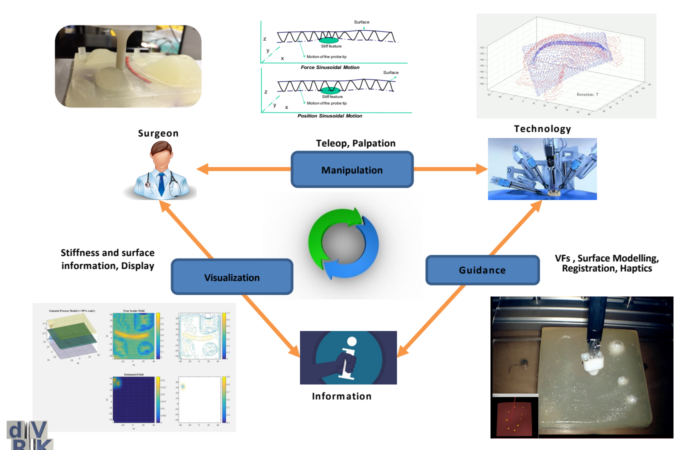
28

Complementary Situational Awareness in a Robotic Surgical Assistant



NSF NRI 1327566: JHU, CMU, Vanderbilt

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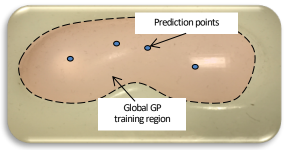
29

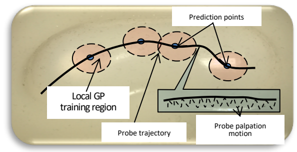
Continuous Stiffness and Geometry Update

Preetham Chalasani, Russell Taylor



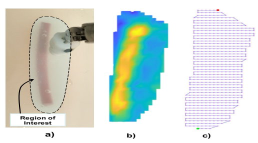
Offline Estimation

Chalasani et. al, ICRA 2016

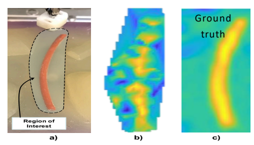


Online Estimation

Chalasani et. al, RAL 2018



Results from automated Sinusoidal palpation

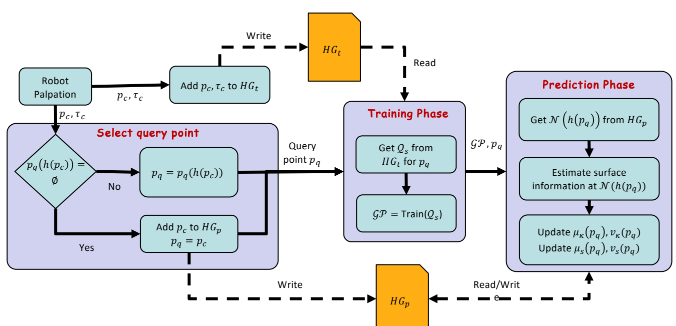


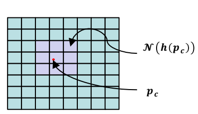
Teleoperated palpation w. superimposed motion

Automated Sinusoidal Palpation

30

Online Geometry and Stiffness Update





P. Chalasani, L. Wang, R. Yasin, N. Simaan, and R. H. Taylor, "Preliminary Evaluation of an Online Estimation Method for Organ Geometry and Tissue Stiffnes", *IEEE Robotics and Automation Letters*, p. [early access online version], 2018. 10.1109/LRA.2018.2801481

31

Semi-Autonomous Palpation Example

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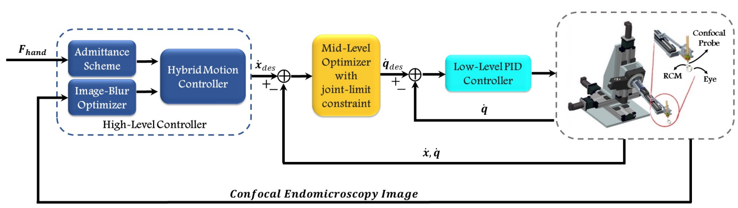
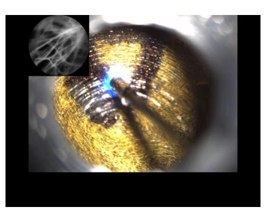
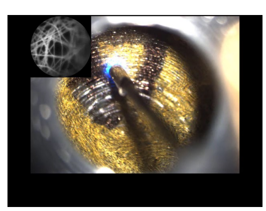
32

Robot-assisted confocal endoscopic imaging for retinal surgery



Simple hand guiding with robot (5 DoF)





Hybrid control:

- Hand-guided lateral motion
- Image-based depth/focus control

Z. Li, M. Shahbazi, M. Patel, P. Chalasani, E. O'Sullivan, H. Zhang, K. Vyas, A. Deguet, P. Gehlbach, I. Iordachita, G. Z. Yang, R. H. Taylor, "A Comparison of Cooperative vs. Teleoperated Robot-Assisted Frameworks for Confocal Endomicroscopy Scanning of the Retina", ***IEEE TMRB*****, in submission.**

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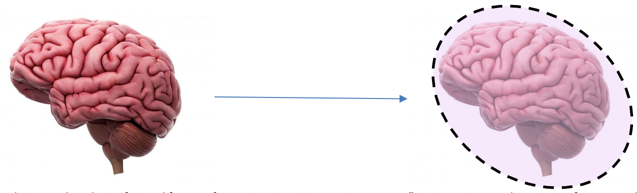
33

Anatomy-Based Virtual Fixtures: An Additional Complication

Virtual fixture is often used for increased efficiency and operation safety.

However, it is challenging to automatically generate virtual fixture for complex anatomies.

Existing researches usually approximate the anatomical shape when using parametric forms such as ellipsoid [4][5][6], or using sparse level-set functions [7]. The process is labor intensive, and the virtual fixture cannot accurately reflect the anatomical shape.

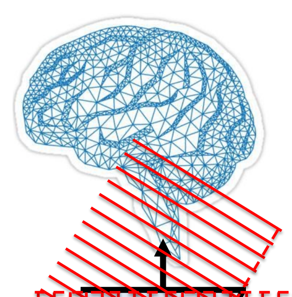


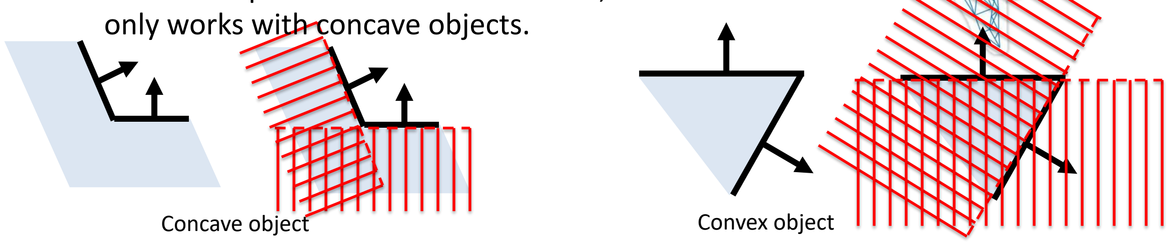
Virtual fixture approximates the anatomy as an ellipsoid

[4] R. Prada and S. Payandeh, "A study on design and analysis of virtual fixtures for cutting in training environments," in First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environ-ment and Teleoperator Systems. World Haptics Conference.IEEE,2005, pp. 375–380.
[5] S. Park, R. D. Howe, and D. F. Torchiana, "Virtual fixtures for robotic cardiac surgery," in International Conference on Medical Image Computing and Computer-Assisted Intervention.Springer,2001, pp. 1419–1420.
[6] M. M. Marinho, B. V. Adorno, K. Harada, and M. Mitsuishi, "Dynamic active constraints for surgical robots using vector-field inequalities," IEEE Transactions on Robotics, vol. 35, no. 5, pp. 1166–1185, 2019.
[7] J. Ren, R. V. Patel, K. A. McIsaac, G. Guiraudon, and T. M. Peters, "Dynamic 3-d virtual fixtures for minimally invasive beating heart procedures," IEEE transactions on medical imaging, vol. 27, no. 8,pp. 1061–1070, 2008.

Challenges

- Mesh is an intuitive representation of 3D objects, which is widely used in medical imaging.
- Prior work [8] proposes to treat triangles in mesh as plane constraints. However, it only works with concave objects.





[8] M. Li, M. Ishii, and R. H. Taylor, "Spatial motion constraints using virtual fixtures generated by anatomy," IEEE Transactions on Robotics,vol. 23, no. 1, pp. 4–19, 2007.

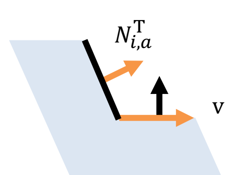
Virtual Fixture Formulation

- In this work, an anatomical mesh-based virtual fixture is proposed
  - Generates virtual fixture for complex anatomy automatically
  - Implements an efficient and dynamic formulation

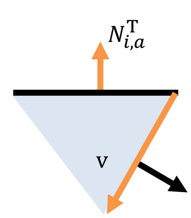
Virtual Fixture Formulation

- Mesh-based constraint formulation algorithm is based on closest point (CP) and local geometry
  - Store mesh as principle-direction tree (PD-Tree) [9] and define a motion sphere
  - Determine the closest point on triangles
  - Determine the local geometry

- $\text{geometry} = \begin{cases} \text{concave if } N_{i,a}^{\mathrm{T}}\mathrm{v} > 0 \\ \text{concex if } N_{i,a}^{T}\mathrm{v} < 0 \end{cases}$



Concave object



Convex object

[9] Williams, R. Taylor, and L. Wolff, "Augmented kd techniques for accelerated registration and distance measurement of surfaces,"Computer Aided Surgery: Computer-Integrated Surgery of the Headand Spine, pp. 1–21, 1997.

Virtual Fixture Formulation

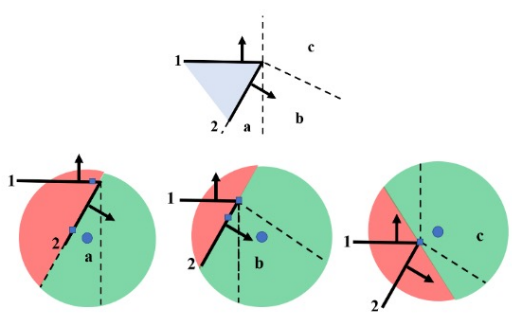
- Mesh-based constraint formulation algorithm is based on closest point (CP) and local geometry

Algorithm 1: Polygon Mesh Constraint

Input: PD-Tree, Current Position x
Result: List of Active Plane Constraints $\mathcal{L}$
Find intersected triangles $\mathcal{T}$, corresponding closest points $\mathcal{CP}$ and face normals $\mathcal{N}$;
for *triangle* $\mathcal{T}_i \in \mathcal{T}$ **do**
  if $\mathcal{CP}_i$ *in-triangle* & $\mathcal{N}_i^T(x - \mathcal{CP}_i) \geq 0$ **then**
    add $\{\mathcal{N}_i, \mathcal{CP}_i\}$ to $\mathcal{L}$;
  else if $\mathcal{CP}_i$ *on-edge* **then**
    Find adjacent triangle(s) $\mathcal{T}_{i,a}$;
    if $\mathcal{CP}_i == \mathcal{CP}_{i,a}$ & *locally convex* **then**
      add $\{x - \mathcal{CP}_i, \mathcal{CP}_i\}$ to $\mathcal{L}$;
    else if $\mathcal{N}_i^T(x - \mathcal{CP}_i) \geq 0$ & *locally concave* **then**
      add $\{\mathcal{N}_i, \mathcal{CP}_i\}$ to $\mathcal{L}$;
end

Virtual Fixture Formulation

- Mesh-based constraint formulation algorithm is based on closest point (CP) and local geometry

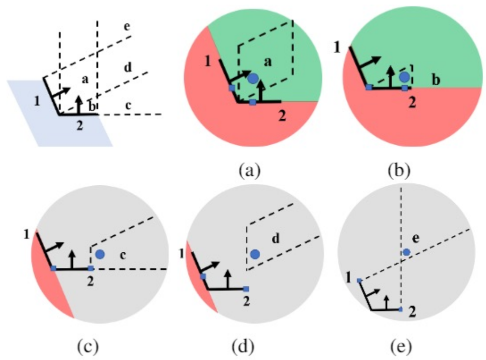


(a) (b) (c)

●: tool position
■: closest point
Green region: allowable
Red region: forbidden

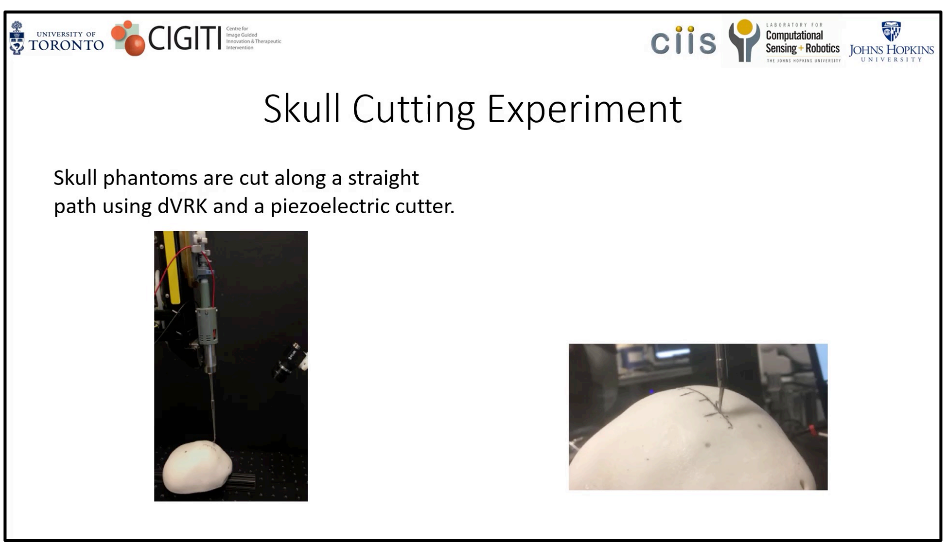
Virtual Fixture Formulation

- Mesh-based constraint formulation algorithm is based on closest point (CP) and local geometry



●: tool position
■: closest point
Green region: allowable
Red region: forbidden

Virtual Fixtures for Craniosynostosis



Z. Li, A. Gordon, T. Looi, J. Drake, C. Forrest, and R. H. Taylor, "Anatomical Mesh-Based Virtual Fixtures for Surgical Robots", in International Conference on Intelligent Robots and Systems (IROS), Las Vegas, Oct. 25-29, 2020.

Emerging paradigm (shared autonomy & assistant modes)

Physicians

Technology

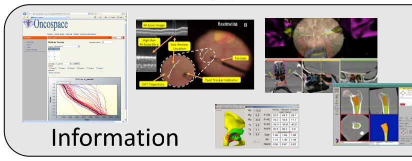
Haptic feedback

Surgeon
Hand Forces

Computer

- Cooperative control
- Virtual fixtures
- Shared autonomy
- Information fusion
- Visualization
- Smart tools & sensors
- Safety monitoring, etc.

Robot joint
motions & state



Information

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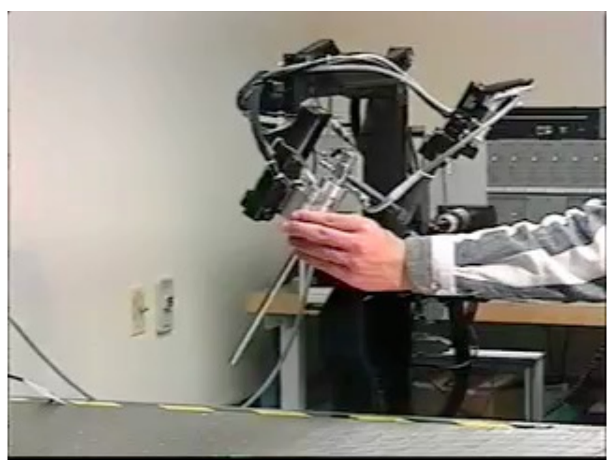
Steady Hand Manipulation

Robodoc Canine Surgery, 1990



LARS Robot in IBM Lab, *ca.* 1993

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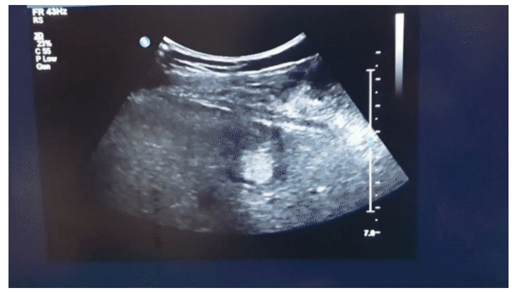
45

Image-based automated tracking of lesion to stabilize view in biopsy

- **Robotic arm:**
  - force control, accuracy, repeatability
- **Co-robotic ultrasound**

In a biopsy procedure, **physiological motions** of the target is another problem to solve.

"Hand-over-hand control"



Respiratory motion

T. Xie, M. Shahbazi, Y. Wu, R. H. Taylor, and E. M. Boctor, "Stabilized ultrasound imaging of a moving object using 2D B-mode images and convolutional neural network", in *Proc.SPIE*, 2020 https://doi.org/10.1117/12.2550198 10.1117/12.2550198.

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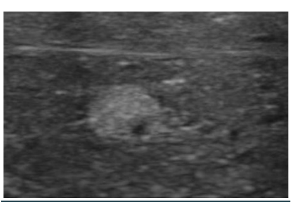
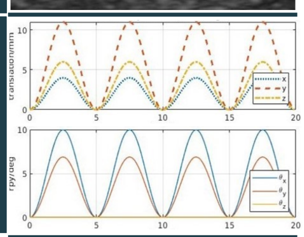
Image-based automated tracking of lesion to stabilize view in biopsy

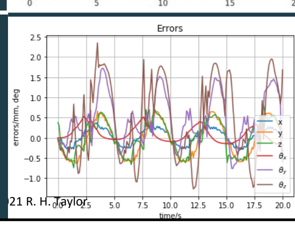
Target view



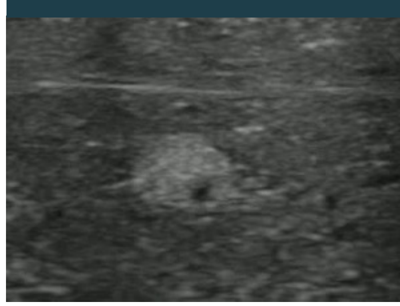
Target motion



Errors over time



- **Target motion:**
  - 4, 11 and 6 mm along axial, lateral and elevational axes
  - 10 and 6 degree about x and y axes (w/o in-plane rotation)
- **Error:**
  - Translations: less than 0.7 mm
  - Rotations: less than 2 degree
- No fine tuning. Same linear probe used for CNN training.

No tracking	With tracking
	

T. Xie, M. Shahbazi, Y. Wu, R. H. Taylor, and E. M. Boctor, "Stabilized ultrasound imaging of a moving object using 2D B-mode images and convolutional neural network", in *Proc.SPIE*, 2020 https://doi.org/10.1117/12.2550198 10.1117/12.2550198.

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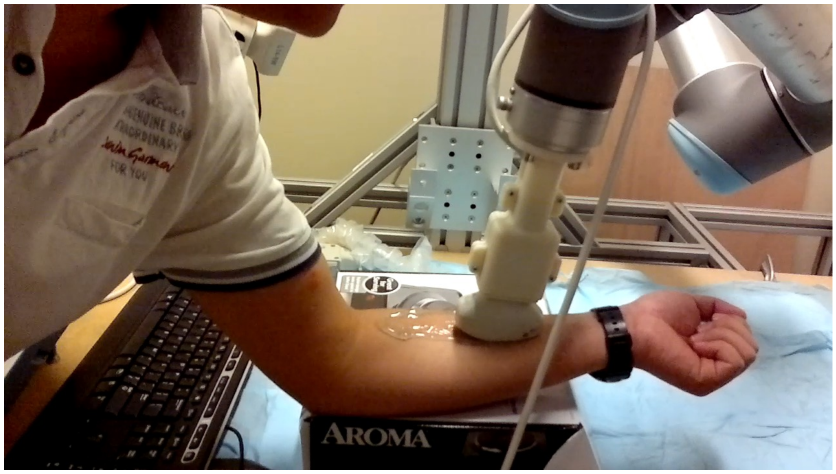
48

Synthetic-Tracked Aperture Ultrasound (STrAtUS) Imaging Using Robotic Guidance

Emad Boctor, *et al.*



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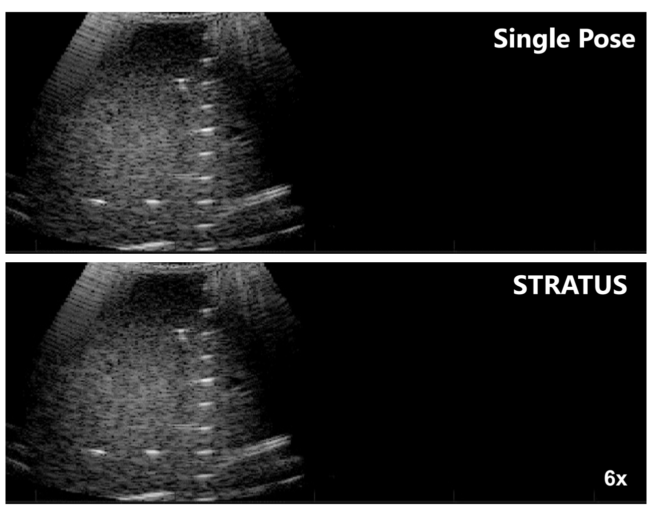
49

Synthetic-Tracked Aperture Ultrasound (STrAtUS) Imaging Using Robotic Guidance & Virtual Fixtures

Emad Boctor, *et al.*



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50

Cadaver Study: Sinus Surgery with Virtual Fixtures

K. Olds, M. Balicki, M. Ishii, R. Taylor

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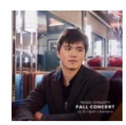
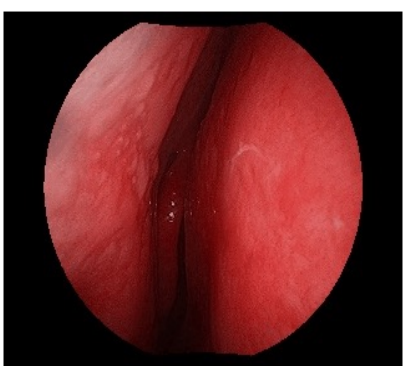
51

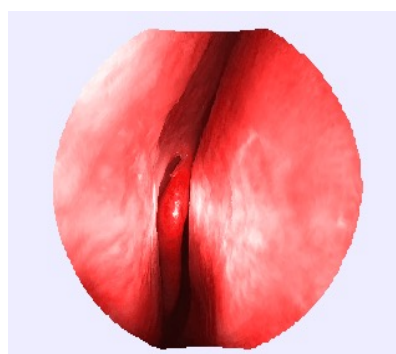
3D airway reconstruction during nasal endoscopic procedures without external tracking devices



Xingtong Liu



Monoscopic Endoscope Video



Dense Point Cloud Reconstruction

X. Liu, A. Sinha, M. Unbareth, M. Ishii, G. D. Hager, R. H. Taylor, and A. Reiter, "Self-Supervised Learning for Dense Depth Estimation in Monocular Endoscopy", (best paper) in MICCAI Computer Assisted and Robotic Endoscopy (CARE), Grenada, Spain, September 16, 2018.

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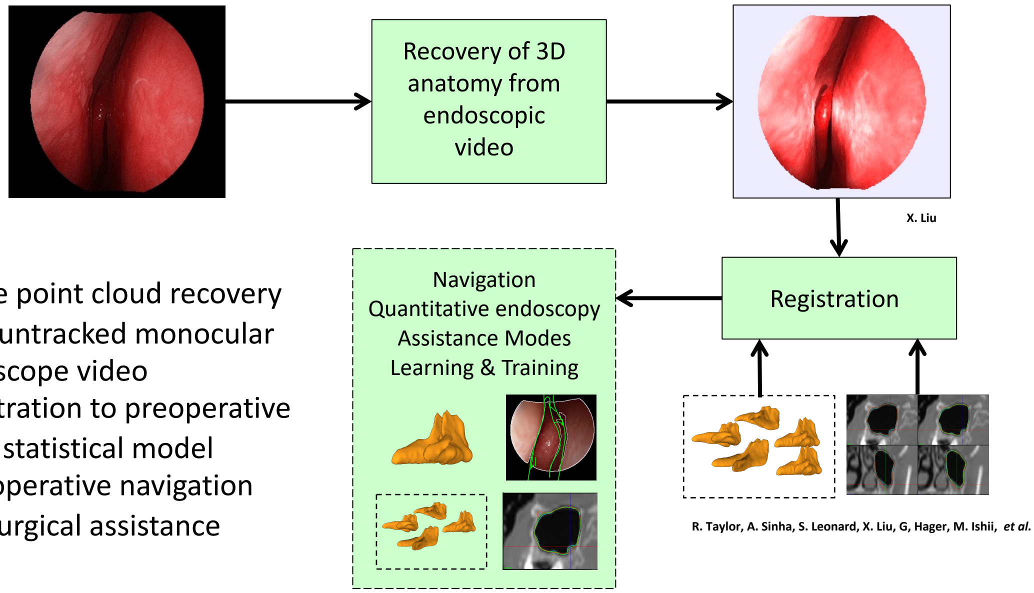
53

A "smart" sinus endoscopy assistant



- Dense point cloud recovery from untracked monocular endoscope video
- Registration to preoperative CT or statistical model
- Intraoperative navigation and surgical assistance

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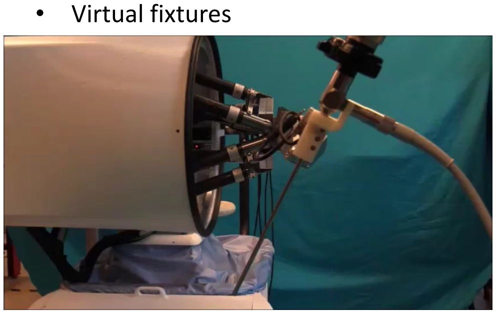
57

The Galen Platform

GALEN ROBOTICS

Technology:

- Custom 5-DOF architecture
- "Steady Hand" cooperative control
- Hand tremor cancellation
- Virtual fixtures



Ease of Use:

- Same footprint as a person
- Accommodates standard instruments
- Minimal change to existing surgical workflow

Broad Applications:

- ENT, spine, brain, trauma, ...

Disclosure: Under a license agreement between Galen Robotics, Inc. and the Johns Hopkins University, Dr. Taylor and the University are entitled to royalty distributions on technology related to technology described in the study discussed in this publication. Dr. Taylor also is a paid consultant to and owns equity in Galen Robotics, Inc. This arrangement has been reviewed and approved by the Johns Hopkins University in accordance with its conflict-of-interest policies.

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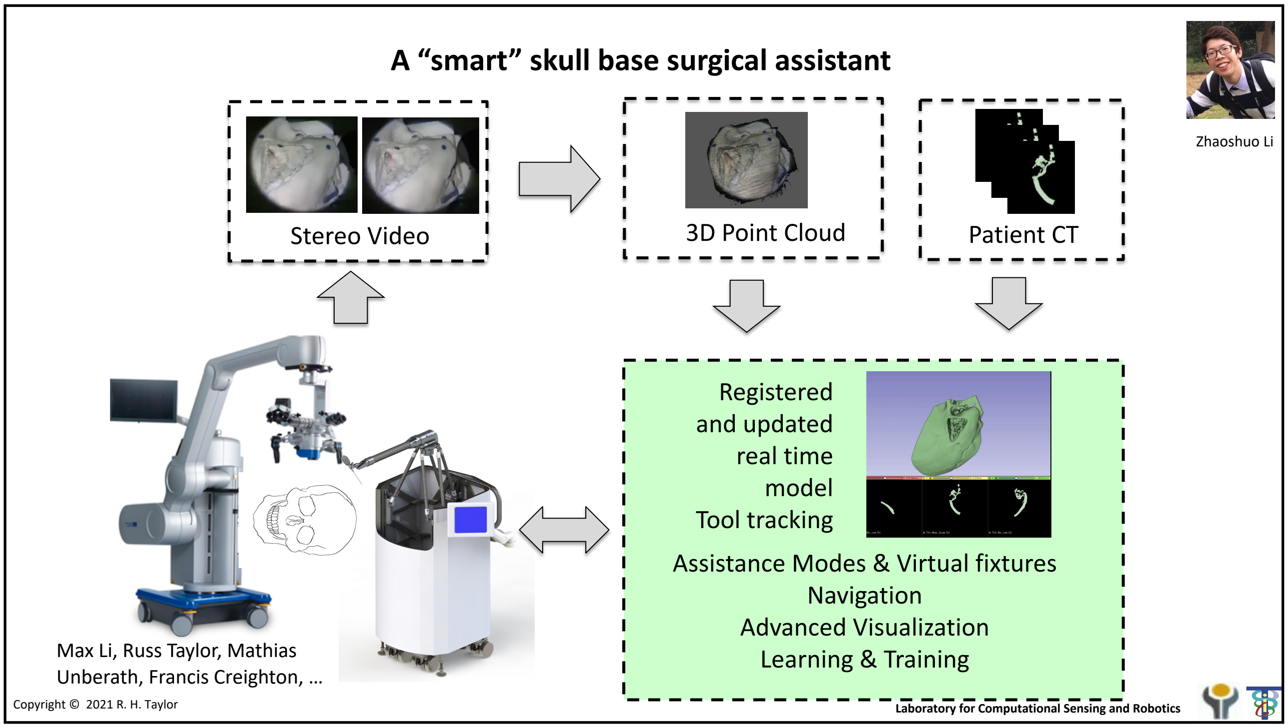
60


A "smart" skull base surgical assistant
Zhaoshuo Li
Stereo Video
3D Point Cloud
Patient CT
Registered
and updated
real time
model
Tool tracking
Assistance Modes & Virtual fixtures
Navigation
Advanced Visualization
Learning & Training
Max Li, Russ Taylor, Mathias
Unberath, Francis Creighton, …
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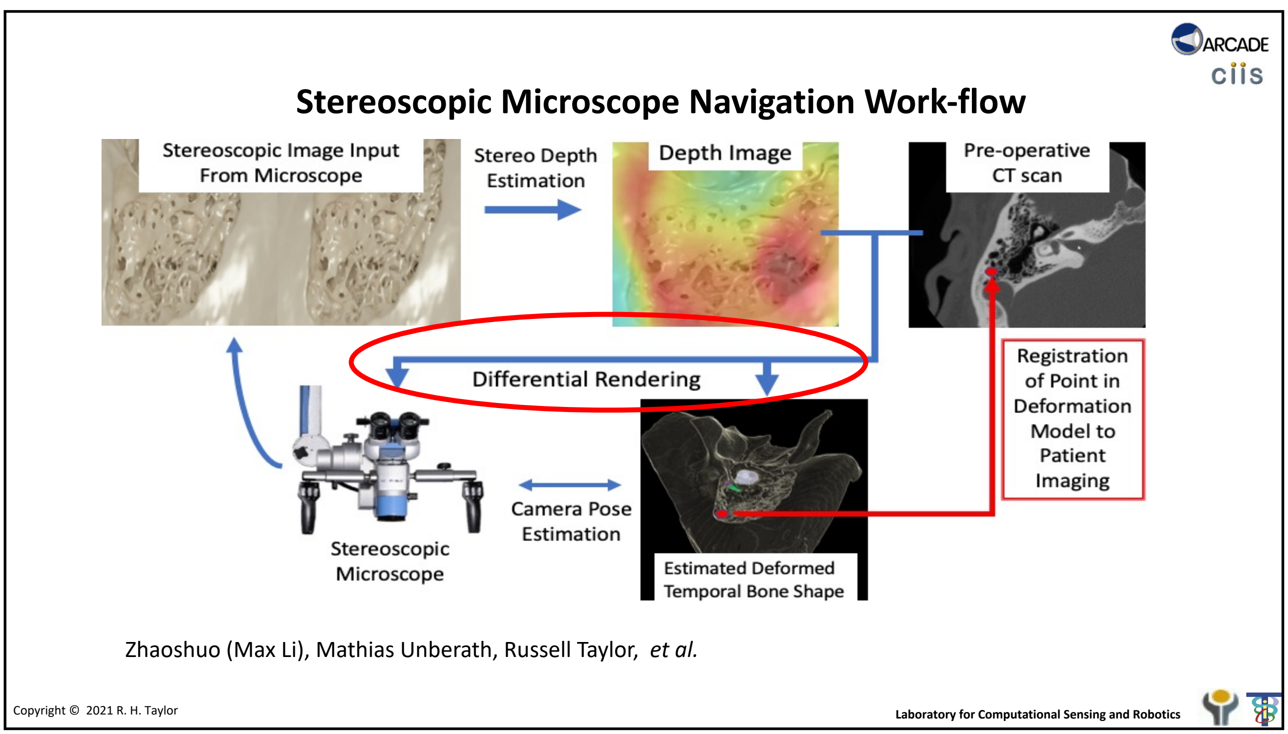
61


ARCADE
ciis
Stereoscopic Microscope Navigation Work-flow
Stereoscopic Image Input
From Microscope
Stereo Depth
Estimation
Depth Image
Pre-operative
CT scan
Differential Rendering
Registration
of Point in
Deformation
Model to
Patient
Imaging
Camera Pose
Estimation
Stereoscopic
Microscope
Estimated Deformed
Temporal Bone Shape
Zhaoshuo (Max Li), Mathias Unberath, Russell Taylor, *et al.*
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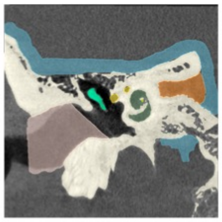
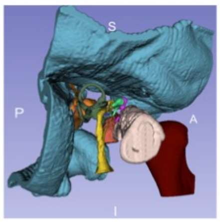
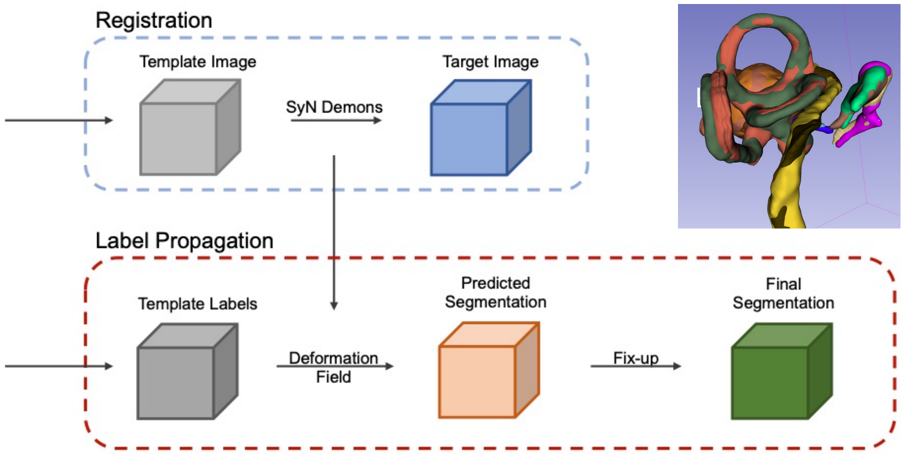
63

Automated Segmentation of Temporal Bone Structures



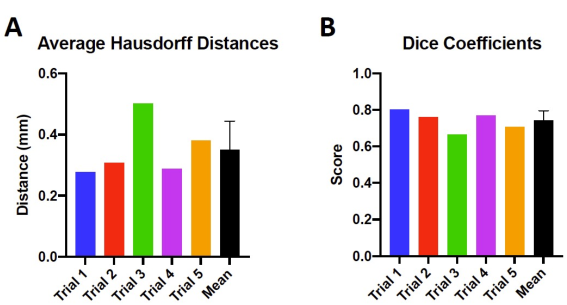


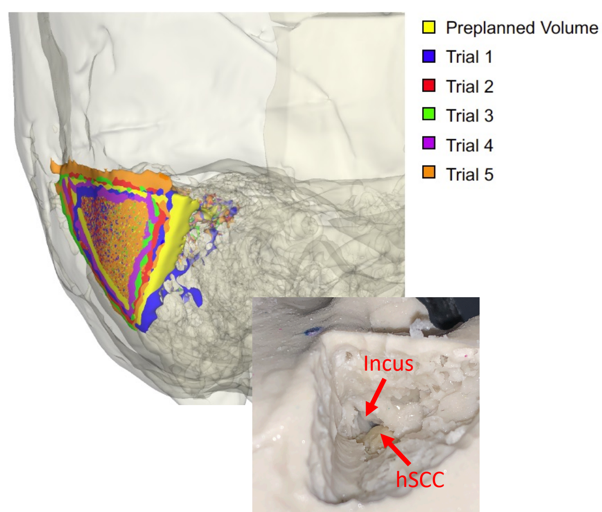


Andy Ding, Alex Lu, Francis Creighton, Russ Taylor

Results

- Mean time to completion: 221 +/- 35 seconds (3.6 min)
- Average Hausdorff Distance ~0.3mm

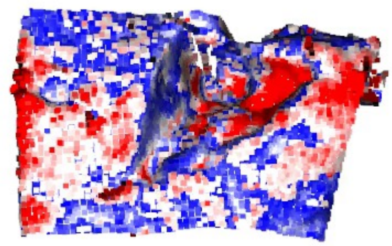




Andy Ding, Alex Lu, Francis Creighton, Russ Taylor

Registration Result

	Inlier RMSE	# of Correspondence
Direct generalization	1.152 mm	6946
Self supervision	1.147 mm	6928



Zhaoshuo (Max Li), Mathias Unberath, Russell Taylor, *et al.*

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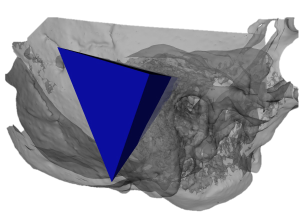
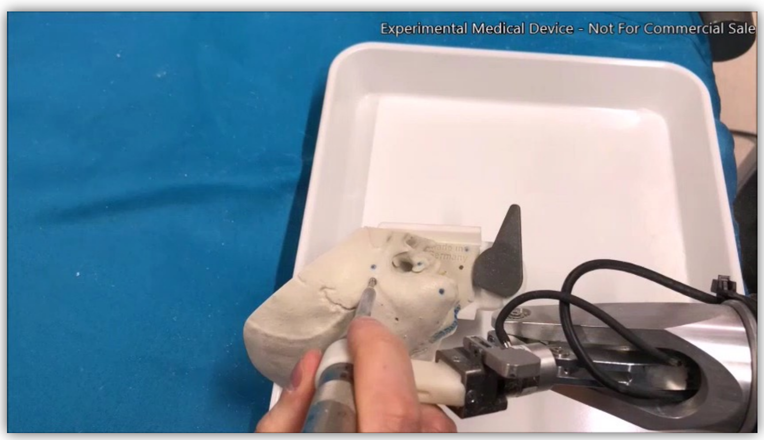
66

Virtual Fixtures for Mastoidectomy

GALEN ROBOTICS

- 5 identical phantoms
- 3 plane virtual fixture planned from CT
- Engineer with no surgical training
- Robot enforces constraints
- Results assessed using postoperative CT





Francis X. Creighton, Christopher R. Razavi, Paul R. Wilkening, Rui Yin, Nicholas Lamaison, Russell H. Taylor, John P. Carey, "Image-Guided Mastoidectomy with the Robotic ENT Microsurgery System (REMS)", *AAO Conference*, October 7, 2018.

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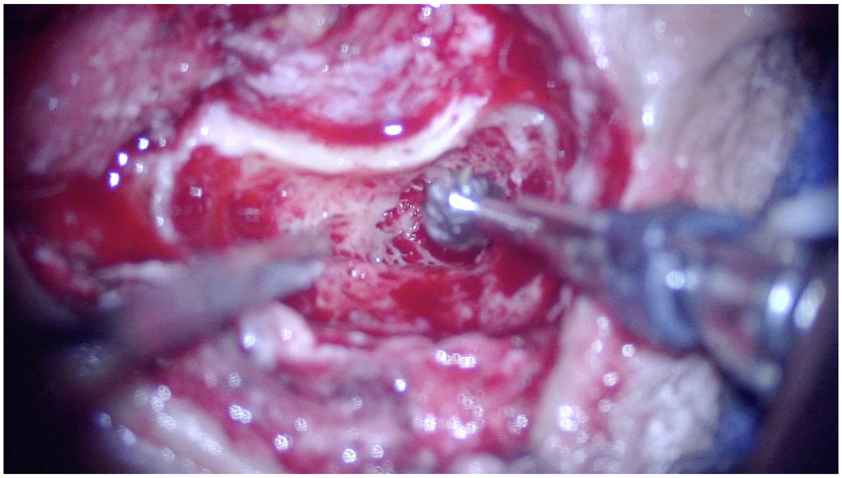
67

Next Steps: Incorporate Instrument Tracking



Sue-Min Cho, Zhaoshuo (Max Li), Mathias Unberath, Russell Taylor, *et al.*

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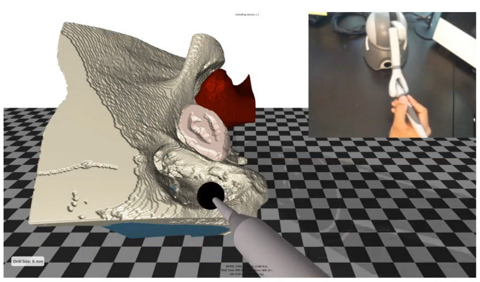
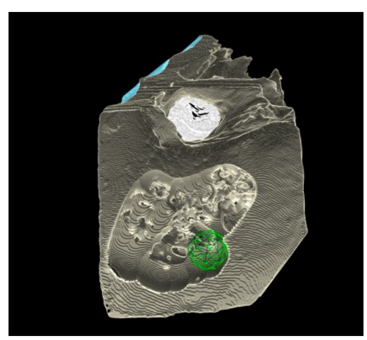
68

Virtual Reality for Synergistic Surgical Training and Data Generation

Demo of virtual drilling simulator





- Simulator for training otology and lateral skullbase surgeons
- Data for transfer learning for stereo

Adnan Munawar, Francis Creighton, Mathias Unberath, Zhaoshuo (Max Li), Russell Taylor, *et al.*

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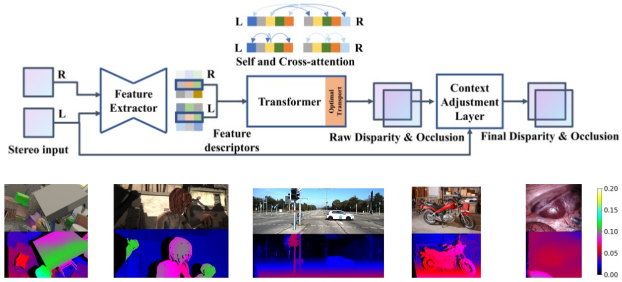
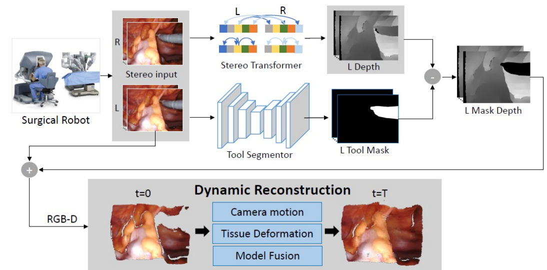
69

Surgical Scene Depth Estimation and Reconstruction

Surgical vision: depth estimation and 3D reconstruction from robotic stereo videos



[Li et al. ICCV 2021]



[Long et al. MICCAI 2021]

Revisiting Stereo Depth Estimation From a Sequence-to-Sequence Perspective with Transformers

Zhaoshuo Li, Xingtong Liu, Nathan Drenkow, Andy Ding, Francis X. Creighton, Russell H. Taylor, and Mathias Unberath

Johns Hopkins University

E-DSSR: Efficient Dynamic Surgical Scene Reconstruction with Transformer-based Stereoscopic Depth Perception

Yonghao Long*[1✉], Zhaoshuo Li*[2], Chi Hang Yee[3], Chi Fai Ng[3], Russell H. Taylor[2], Mathias Unberath[2], and Qi Dou[1,4]

[1] Dept. of Computer Science and Engineering, The Chinese University of Hong Kong
[2] Department of Computer Science, Johns Hopkins University
[3] SH Ho Urology Centre, Dept. of Surgery, The Chinese University of Hong Kong
[4] T Stone Robotics Institute, The Chinese University of Hong Kong

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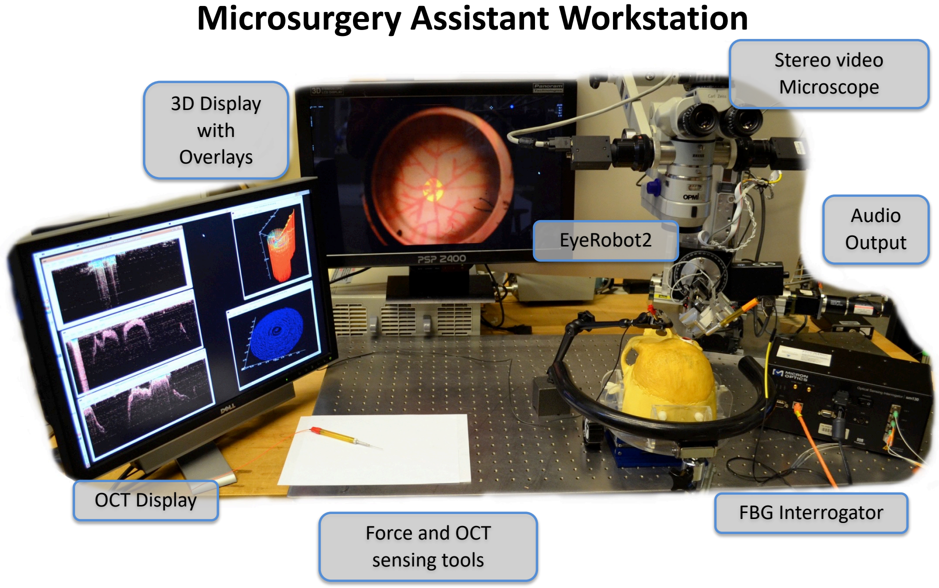
71

Microsurgery Assistant Workstation



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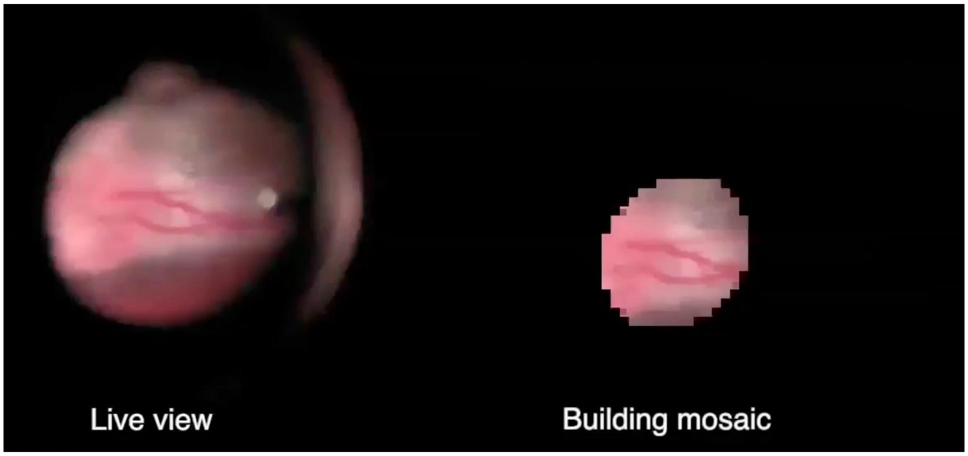
72

Retina Mosaicking, Annotation, and Registration



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

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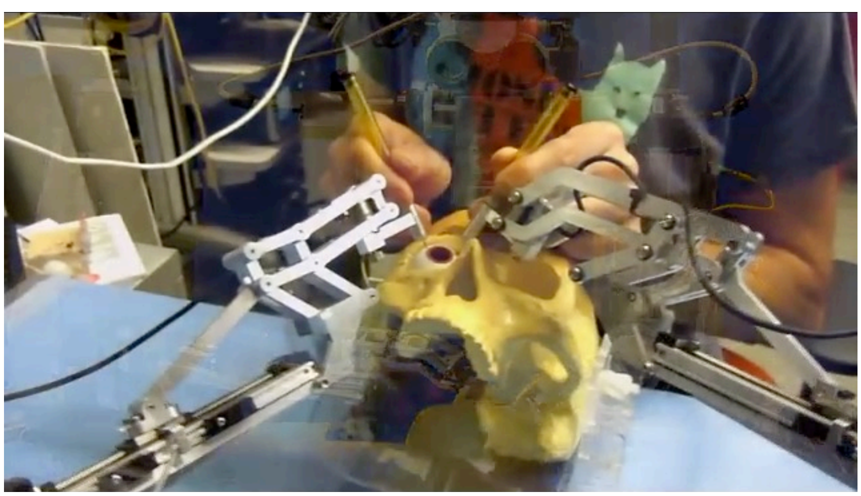
73

Bilateral Robot-Assisted Retinal Surgery

Iulian Iordachita, *et al.*



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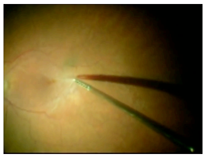
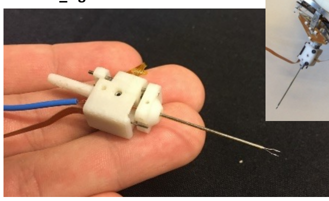
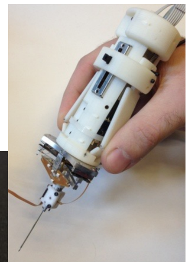
74

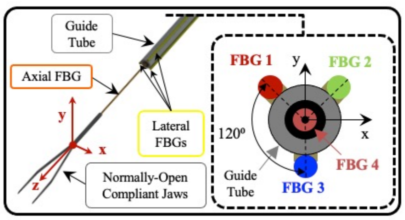
Example: Force-limited Retinal Membrane Peeling

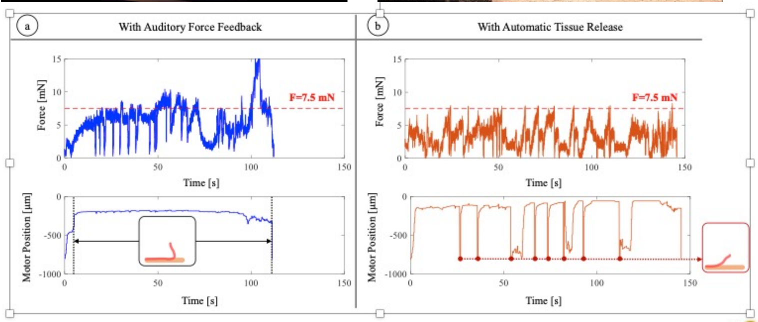


https://www.youtube.com/watch?v=JCpZ255_YVI&feature=emb_logo









Berc Gonenc, I. Iordachita, *et al.*

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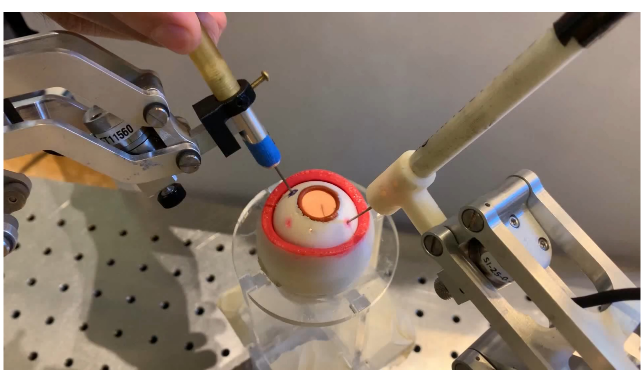
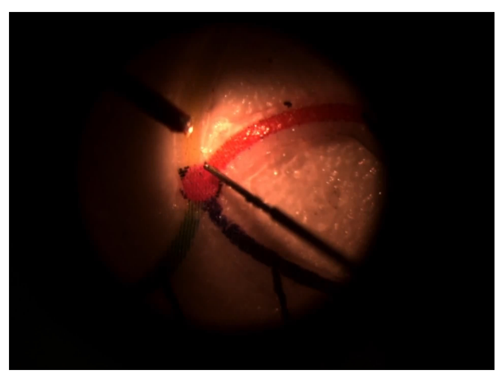
75

Automatic Light Pipe Actuating System in Bilateral Surgery

Automatic light pipe actuation



Microscope view



Changyan He, et al. *IEEE Trans. on Mechatronics*, 2020

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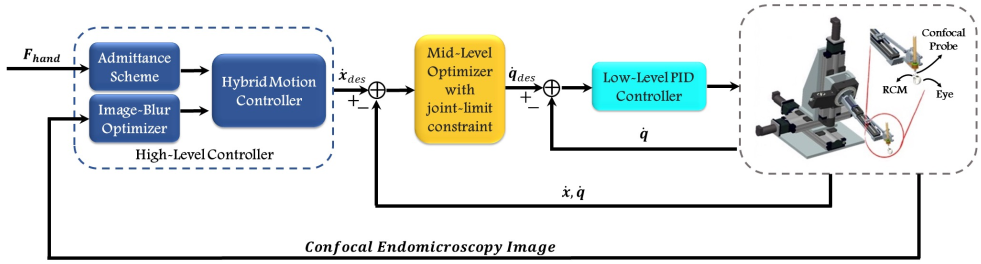
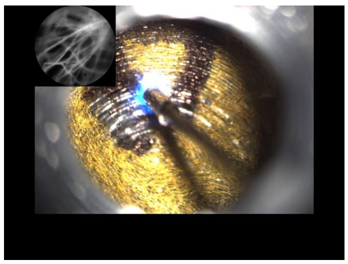
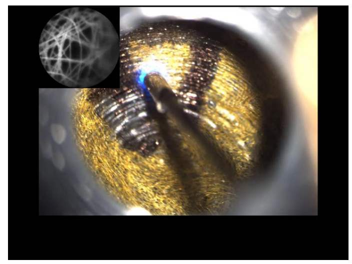
Robot-assisted confocal endoscopic imaging for retinal surgery



Simple hand guiding with robot (5 DoF)





Hybrid control:
- Hand-guided lateral motion
- Image-based depth/focus control

Z. Li, M. Shahbazi, M. Patel, P. Chalasani, E. O'Sullivan, H. Zhang, K. Vyas, A. Deguet, P. Gehlbach, I. Iordachita, G. Z. Yang, R. H. Taylor, "A Comparison of Cooperative vs. Teleoperated Robot-Assisted Frameworks for Confocal Endomicroscopy Scanning of the Retina", *IROS 2019*.

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77

Intelligent Medical Robotic Systems and Equipment Lab

Smart Autonomous Surgery

IMERSE
INTELLIGENT MEDICAL ROBOTIC SYSTEMS AND EQUIPMENT

LABORATORY FOR Computational Sensing + Robotics
THE JOHNS HOPKINS UNIVERSITY

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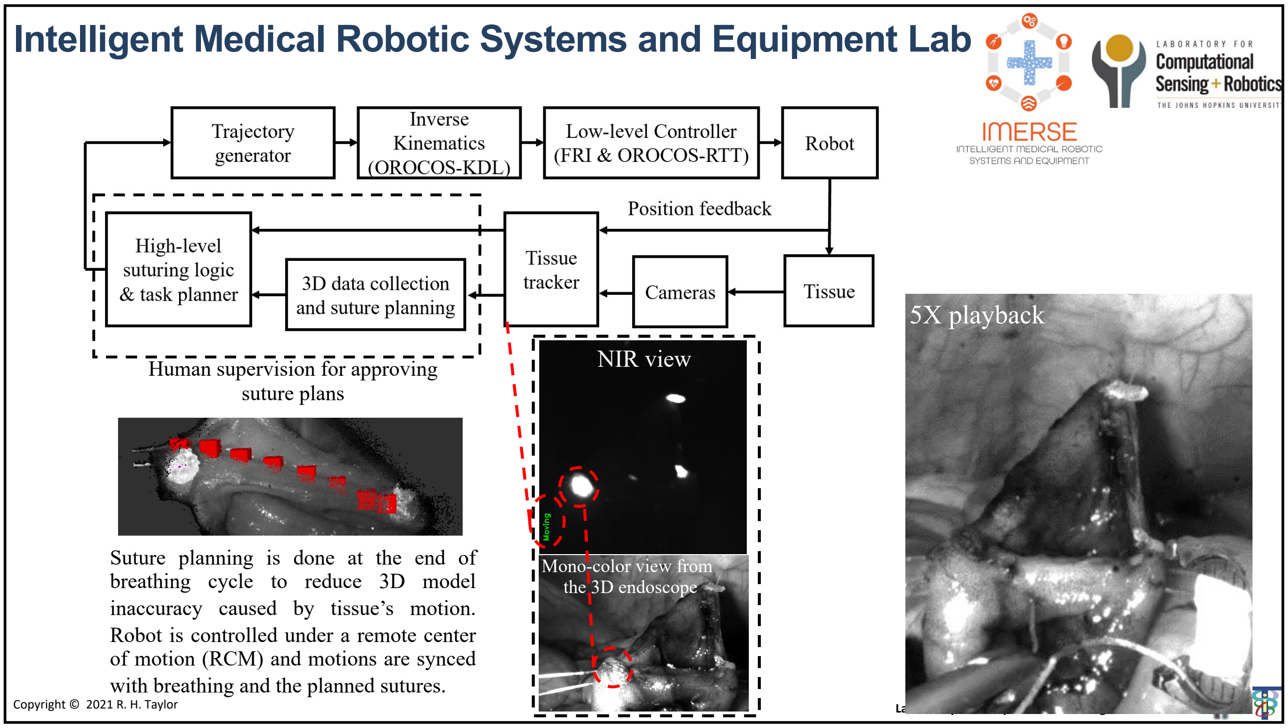
78


Intelligent Medical Robotic Systems and Equipment Lab
IMERSE
INTELLIGENT MEDICAL ROBOTIC SYSTEMS AND EQUIPMENT
LABORATORY FOR Computational Sensing + Robotics
THE JOHNS HOPKINS UNIVERSITY
Trajectory generator
Inverse Kinematics (OROCOS-KDL)
Low-level Controller (FRI & OROCOS-RTT)
Robot
Position feedback
High-level suturing logic & task planner
3D data collection and suture planning
Tissue tracker
Cameras
Tissue
Human supervision for approving suture plans
NIR view
Moving
Mono-color view from the 3D endoscope
5X playback
Suture planning is done at the end of breathing cycle to reduce 3D model inaccuracy caused by tissue's motion. Robot is controlled under a remote center of motion (RCM) and motions are synced with breathing and the planned sutures.
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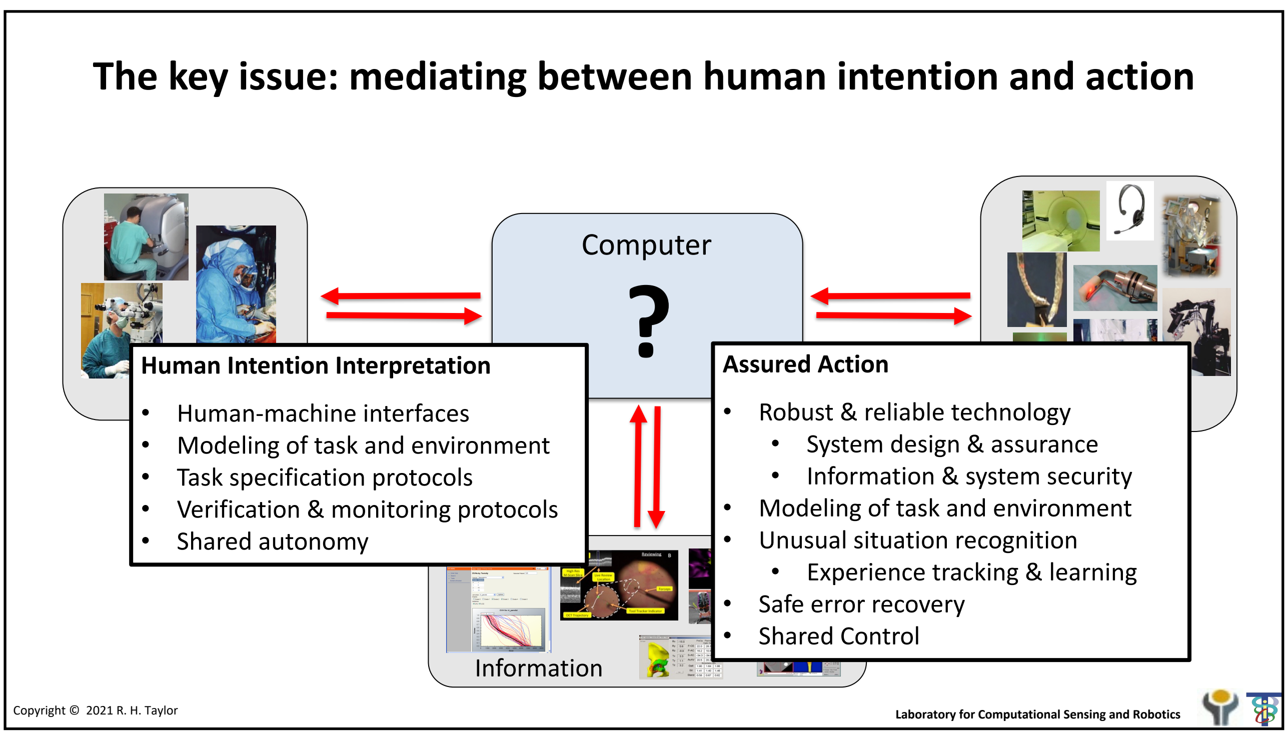
79


The key issue: mediating between human intention and action
Computer
?
Human Intention Interpretation
• Human-machine interfaces
• Modeling of task and environment
• Task specification protocols
• Verification & monitoring protocols
• Shared autonomy
Assured Action
• Robust & reliable technology
• System design & assurance
• Information & system security
• Modeling of task and environment
• Unusual situation recognition
• Experience tracking & learning
• Safe error recovery
• Shared Control
Information
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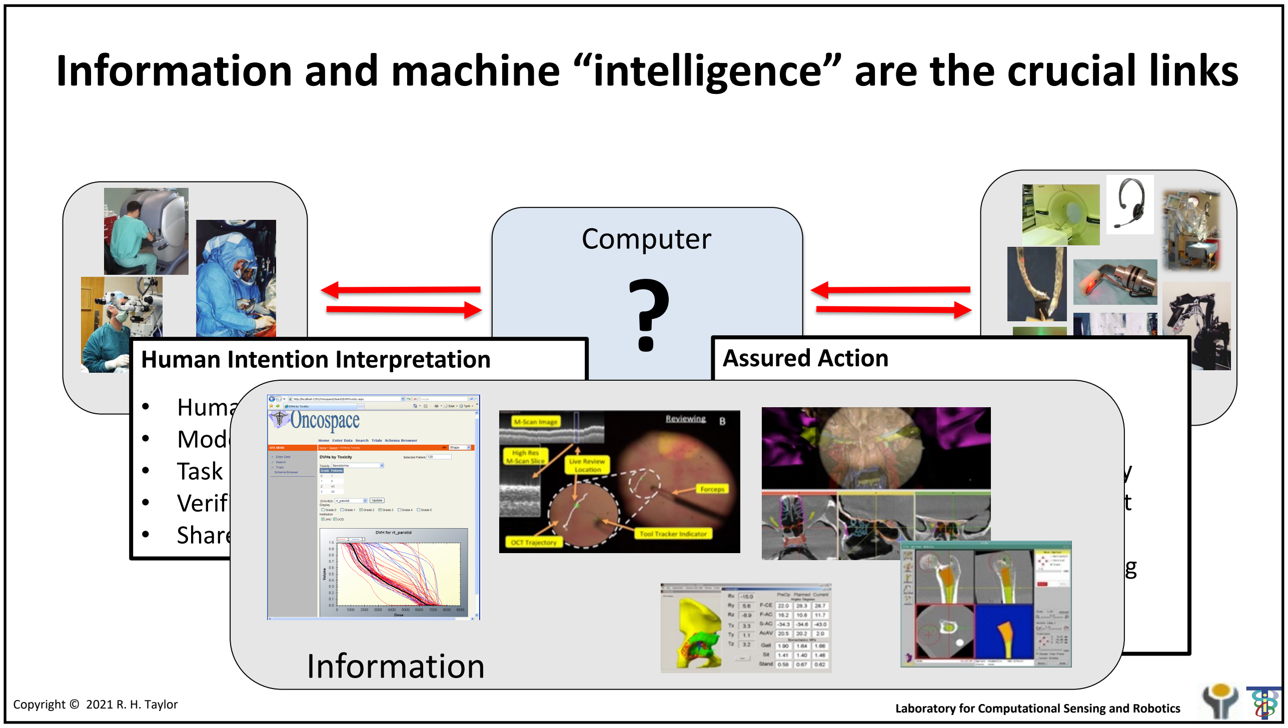
84


Information and machine "intelligence" are the crucial links
Computer
?
Human Intention Interpretation
Huma
Mod
Task
Verif
Share
Assured Action
Information
Oncospace
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85