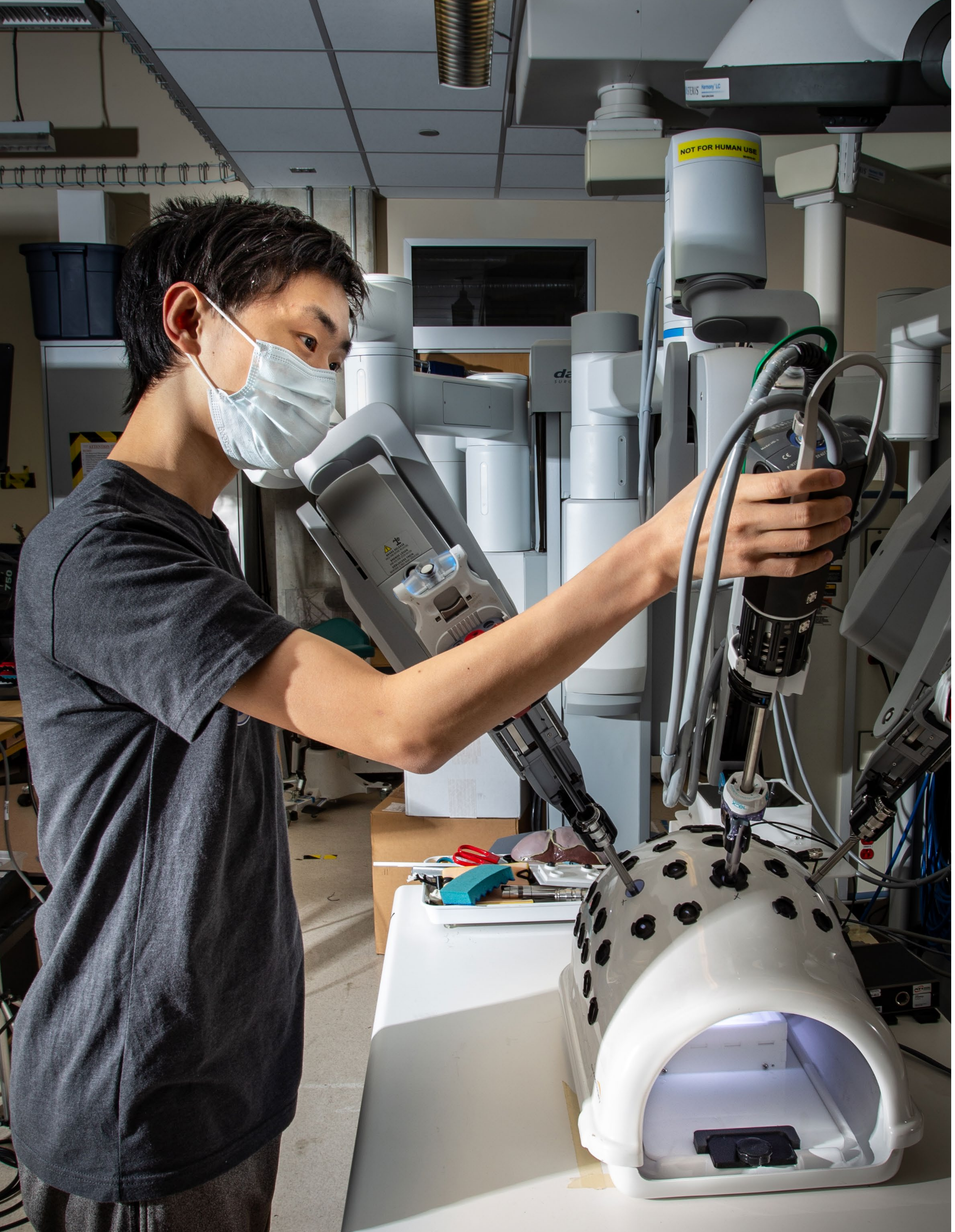
LABORATORY FOR
Computational Sensing & Robotics

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING



LABORATORIES

Medical UltraSound Imaging
and Intervention Collaboration 6

Advanced Medical Instrumentation and Robotics 8

Terradynamics 10

Sensing, Manipulation, and Real-Time Systems 12

Dynamical Systems and Control 14

Autonomous Systems, Control and Optimization 16

Intelligent Medical Robotic Systems & Equipment 18

Computer Integrated Interventional Systems 20

Computational Interaction and Robotics 22

Locomotion In Mechanical and Biological Systems 24

Haptics and Medical Robotics 26

Biomechanical- and Image-Guided Surgical Systems 28

Advanced Robotics and
Computationally Augmented Environments 30

Computer Aided Medical Procedures 32

Photoacoustic & Ultrasonic Systems Engineering 34

Intuitive Computing 36

Photonics and Optoelectronics 38

PROJECTS

Assured Autonomous Control of ICU Ventilators 42
Autonomous Robotic Soft Tissue Surgery 43
Image Guided Interventions and Planning 44
Autonomous Robotic Ultrasound 45
Magnetically Actuated Microrobots 46
Cardiac Planning and Patient Specific Implant Design 47
The Terradynamics of Biological Movement in Complex Terrain 48
Neuromechanics of Legged Locomotion on Energy Landscapes of Complex Terrains 49
Simulation of Multi-Legged Robot Locomotor Transitions to Traverse Rocky Martian Terrain 50
Human-Robot Co-Navigation 51
Human-Machine Teaming for Medical Decision Making 52
Accessible Robot Programming 53
Socially Assistive Robots for Behavioral Interventions 54
Co-Robotic Ultrasound Tomography Framework for In Vivo Prostate Imaging 55
The Language of Surgery Project 56
Machines with Imagination: Learning from Description through Synthesis and Analysis 57
Enabling Technology for Image-Guided Robot-Assisted Sub-Retinal Injections 58
Adaptive Percutaneous Prostate Interventions Using Sensorized Needle 59
MRI Compatible Robot for Improved Pain Injections in Adults and Children 60
Anthropomorphically Driven Upper-Extremity Prosthesis 61
Robot-Assisted Minimally Invasive Surgical Training 62
Neuroergonomic Evaluation on Haptic Feedback in Upper-Extremity Prostheses 63
Sensorimotor-Inspired Control for Upper-Extremity Prostheses 64
Haptic Perception and Task Performance During Non-Transparent Teleoperation 65
Development of Nereid Under-Ice (NUI): An Underwater Robot for Oceanographic Exploration Under Polar Ice 66
Development of a Low-Cost True-North Seeking Fiber Optic Gyrocompass for Precision Underwater Robot Navigation 67
Precision Navigation of Low-Cost Underwater Robotic Vehicles for Ocean Science 68
Robotic Environmental Sampling 69
Autonomous Aerial Manipulation 70
Autonomously Navigating a Surgical Tool Inside the Eye by Learning from Demonstration 71
Task-aware and Autonomous C-arm Imaging 72
3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning 73
Transparent Machine Learning for Healthcare 74
SyntheX: Scaling Up Learning-based X-ray Image Analysis Through in Silico Experiments 75
Mixed Reality for Surgical Guidance 76
Continuum Robots, Tools, and Algorithms for Tissue Manipulation 77
Perceptual Visualization for Surgical Guidance in Orthopaedics Using Augmented Reality 78
Total Body Imaging for Skin Cancer Detection 79
Automated Implant Modification for Neuroplastic Surgery 80
Robot-Assisted Femoroplasty 81
Robot-Assisted Transcranial Magnetic Stimulation 82
Deep Learning Approach to Photoacoustic Visual Servoing 83
Photoacoustic-Guided Hysterectomy 84
Deep Learning COVID-19 Features in Lung Ultrasound Images 85
Interactive Flying Frustums 86
Augmented Mirrors 87
iOCT-Guided Robot-Assisted Sub Retinal Injection 88
A User's Guide to System Identification for Sensorimotor Control 89
Programming Thermobiochemomechanical (TBCM) Multiplex Robot Gels 90
Human Sensory-Motor Control 91
Telerobotic Satellite Servicing 92
Augmented Reality Assistance for Robotic Surgery 93
Force Estimation for Surgical Robotics 94
X-ray Image-based Navigation for Periacetabular Osteotomy with Intraoperative Biomechanical Feedback 95
Robot-assisted Confocal Endoscopic Imaging for Retinal Surgery 96
Automated Mosquito Salivary Gland Removal 97
Steady-Hand Robot for Head-and-Neck Surgery 98
Deformable Registration using Statistical Shape Models 99
Enhanced Navigation for Endoscopic Sinus Surgery through Video Analysis 100
Image-based Modeling and Analysis of Anatomic Structures in the Human Temporal Bone 101
Real-time Modeling and Registration of 3D Surgical Field from Surgical Microscope Data 102
Virtual Reality Simulator for Temporal Bone Surgery 103
Endoscopic Fringe Projection Profilometry 104
Artificial intelligence Optical Coherence Tomography Guided Deep Anterior Lamellar Keratoplasty (AUTO-DALK) 105

ADVANCING DISCOVERY

Robotics at Johns Hopkins Whiting School of Engineering

Johns Hopkins University's Whiting School of Engineering stands at the forefront of technological innovation in robotics, and comprises one of the largest and most technologically advanced robotics research and educational centers in the world. Its faculty and students work collaboratively and across traditional disciplinary boundaries to advance the discoveries that are revolutionizing fields ranging from national security and medicine to manufacturing.

Improving the efficacy and efficiency of health care, making complex surgeries safer and more widely available, reducing risks to first responders, enabling the exploration of outer space and of the ocean's depths, and expanding our understanding of climate change are just some of the ways Johns Hopkins roboticists are addressing critical societal challenges.

Our faculty are world-renowned leaders in the areas of medical robotics, autonomous systems, and bio-inspired robots, and lead collaborations and translational research in partnership with affiliate clinicians and scientists from across Johns Hopkins divisions, including the Johns Hopkins School of Medicine, the Bloomberg School of Public Health, and the Johns Hopkins University Applied Physics Laboratory, as well as with international peer institutions, government, and industry. The power of this truly cross-disciplinary, collaborative approach is profound.

LCSR MISSION AND STRATEGY

Our mission is to create new knowledge and capabilities for intelligent systems and human-centered robotics, to educate a diverse workforce, to extend human reach, and to shape the future of society and the environment in a manner that enables equitable, healthy, and sustainable communities.

OUR STRATEGY

We accomplish this mission by cultivating a diverse and inclusive environment of research and teaching, pursuing interdisciplinary scientific and engineering research, translating science and technology to real-world applications, and fostering synergy and collaborations across Johns Hopkins and worldwide.

By closing the loop between perception, computation, and action, our work focuses on intelligent systems, both engineered and natural, as an essential link between the physical and computational worlds. Our systems operate inside and interact with the living body, on land, undersea, in air, and within outer space. Our research spans next-generation mechatronic design of robotic systems and devices, computational theory and software algorithms for learning, sensing, and control, and experimental robotics for scientific discovery. We develop complete systems embodying the results of our research and discover principles of embodied intelligence in biological systems.

We use real-world applications to drive development of fundamental engineering knowledge and core capabilities in the following areas:

- Surgical and clinical robots
- Medical imaging devices
- Self-driving vehicles and autonomous mobility for everyone
- Space and undersea robotic systems
- Clean energy and sustainable environment

Our core research capabilities include:

- Imaging, Sensing, and Perception
- Computational Modeling and Simulation
- Dynamics and Control
- Motion Planning and Assured Decision Making
- Biological Systems and Natural Intelligence
- Experimental robotics
- Human-robot interactive intelligence
- Mechatronic design of intelligent systems and devices
- Machine Learning and Responsible AI
- Assured autonomous and human-machine cooperative systems
- Fault-tolerant hardware and software algorithms design

LABORATORIES

Medical UltraSound Imaging and Intervention Collaboration

Emad Boctor

The MUSiiC research lab develops innovative ultrasound technologies for medical applications ranging from prostate and breast cancer treatment to liver ablation and brachytherapy, among others. In addition, the lab conducts research on advanced ultrasound techniques. These include ultrasound elastography imaging, 3D ultrasound reconstruction methods, parallel and GPU implementations, CT-US registration, tracked ultrasound, and segmentation, to name but a few. Our group is based on a collaboration among researchers from the Johns Hopkins School of Medicine, the Johns Hopkins Whiting School of Engineering, and partners from other academic institutions and industry.

ACCOMPLISHMENTS

The first co-robotic ultrasound imaging platform with hands-on cooperative force control

The first co-robotic ultrasound imaging platform with extended synthetic tracked aperture

The first co-robotic ultrasound tomography imaging system

The first robotic ultrasound system for tracking a catheter with an active ultrasound source

The first dual-armed robotic system for intraoperative ultrasound guided hepatic ablative therapy

The first Active Ultrasound Pattern Injection System (AUSPIS)

The first interventional photoacoustic surgical system

The first functional nerve imaging tool using electrophysiological recording with photoacoustic sensing

The first ultrasound thermometry imaging approach using direct time-of-flight recording

The first photoacoustic-based catheter tracking

The first photoacoustic-based approach for brachytherapy seed localization

The first non-invasive ultrasound neuromodulation instrument to assess neonatal brain function

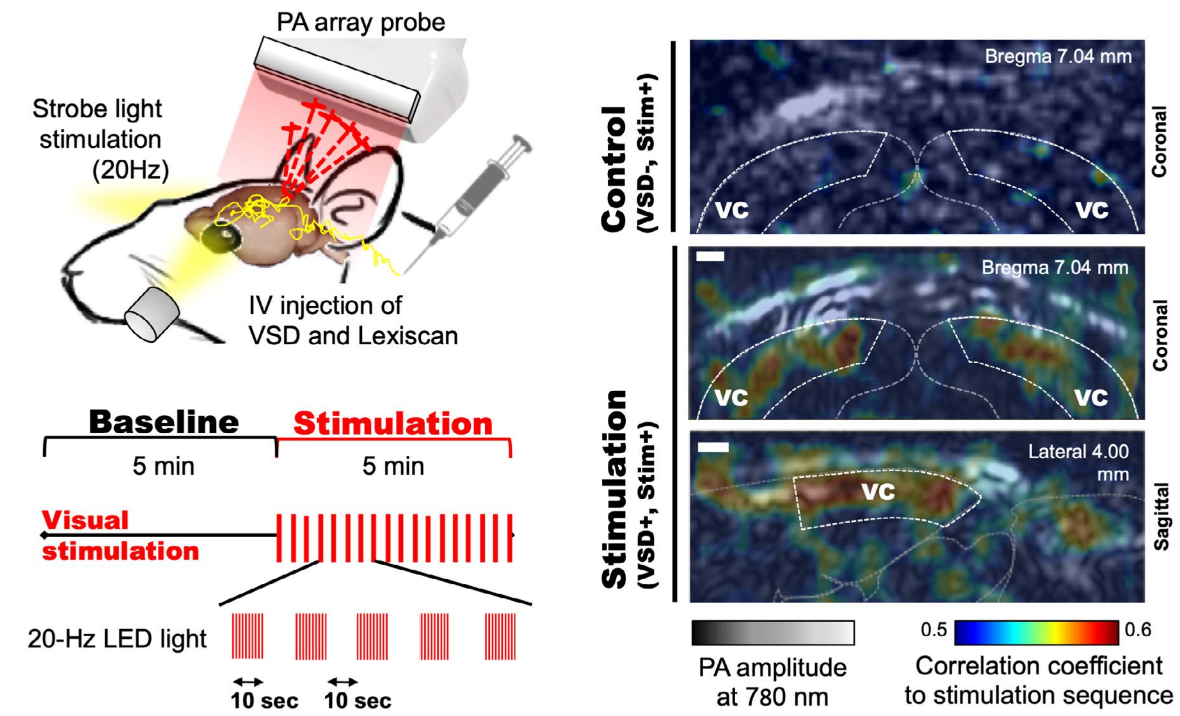
The first bioelectric identification of aggressive prostate cancer using ultrasound stimulation

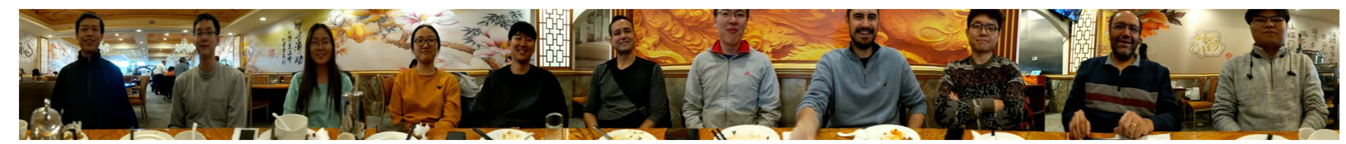
The first use of photoacoustic energy for controlled retinal stimulation

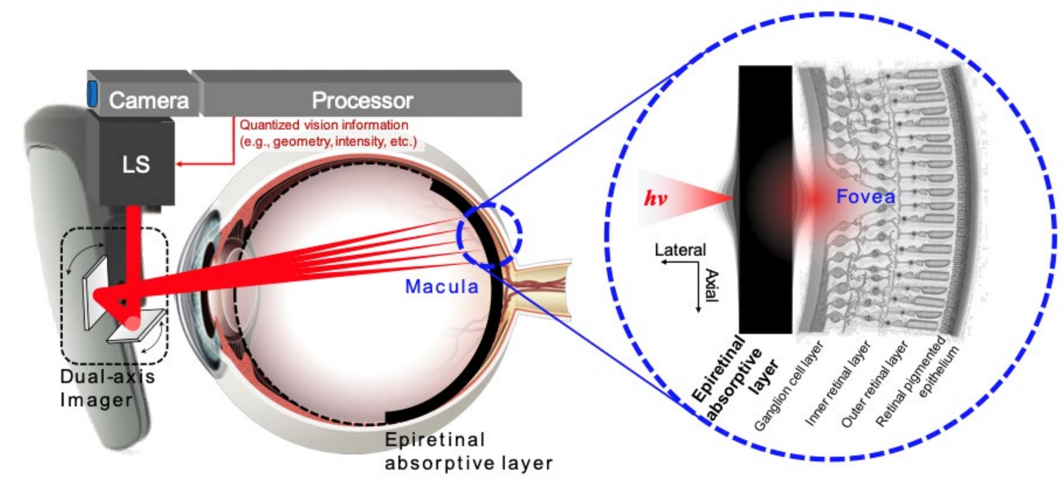
CURRENT PROJECTS

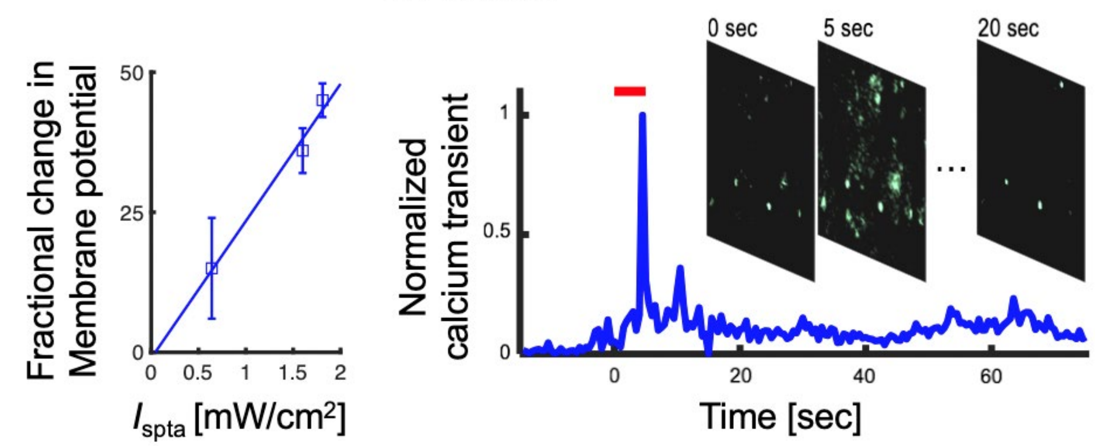
Co-Robotic Ultrasound Tomography Framework for In Vivo Prostate Imaging

Emad Boctor
Research Associate Professor
musiic.lcsr.jhu.edu
eboctor@jhu.edu









Advanced Medical Instrumentation and Robotics

Iulian Iordachita

AMIRo conducts research to aid and support robotic assisted medical technology encompassing medical diagnosis and therapy, and clinical research. The main goal is to create medical robots and devices that will help clinicians deliver earlier diagnosis and less-invasive treatments more quickly and at a lower cost.

Current research includes development of MRI-compatible robots and devices for prostate cancer therapy and musculoskeletal and spinal interventions, surgical robots and medical instrumentation for microsurgery and minimally invasive surgery, and small animals research platforms for preclinical cancer research.

The AMIRo lab works closely with other research groups inside and outside of Johns Hopkins University and Hospital, as well as local industries. Johns Hopkins-affiliated collaborators include: the CIIS, SMARTS, BIGSS, and ASCO at LCSR, POL at ECE and DROMRS at JHH. The outside collaborators include: SPL at BWH, AIM at WPI, Perk Lab at Queen's, SML at CMU, Acoustic MedSystems, and Xstrahl.

Our current efforts include developing:

MRI-compatible robots and devices for prostate cancer therapy and musculoskeletal and spinal interventions

Surgical robots and medical instrumentation for microsurgery and minimally invasive surgery

Small animals research platforms for preclinical cancer research

ACCOMPLISHMENTS

Alamdar, A., Patel, N., Urias, M.G., Ebrahimi, A., Gehlbach, P.L. and Iordachita, I., "Force and Velocity Based Puncture Detection in Robot Assisted Retinal Vein Cannulation: in-vivo Study," *IEEE Transactions on Biomedical Engineering*. vol. xx, no. x, pp.1-10, On-line 22 Sep. 2021, DOI: 10.1109/TBME.2021.3114638

Zhou, M., Wu, J., Ebrahimi, A., Patel, N., Liu, Y., Navab, N., Gehlbach, P., Knoll, A., Nasseri, M.A. and Iordachita, I.I., "Spotlight-based 3D Instrument Guidance for Autonomous Task in Robot-assisted Retinal Surgery," *IEEE Robotics and Automation Letters*, vol. 6, no. 4, pp. 7750-7757, Jul. 2021 doi:10.1109/LRA.2021.3100937.

Sefati, S., Hegeman, R., Iordachita, I., Taylor, R.H. and Armand, M., "A Dexterous Robotic System for Autonomous Debridement of Osteolytic Bone Lesions in Confined Spaces: Human Cadaver Studies," *IEEE Transactions on Robotics*. vol. xx, no. x, pp. 1-17, On-line Jul. 2021, doi: 10.1109/TRO.2021.3091283.

Patel, N., Yan, J., Li, G., Monfaredi, R., Priba, L., Donald-Simpson, H., Joy, J., Dennison, A., Melzer, A., Sharma, K., Iordachita, I.I., and Cleary, K., "Body-mounted Robotic System for MRI-guided Shoulder Arthrography: Cadaver and Clinical Workflow Studies MRI-guided Robot for Shoulder Arthrography," *Frontiers in Robotics and AI*, vol.8, 10 pages, art. # 667121, May 2021. https://doi.org/10.3389/frobt.2021.667121

Jinno, M. and Iordachita, I., "Improved Integrated Robotic Intraocular Snake: Analyses of the Kinematics and Drive Mechanism of the Dexterous Distal Unit." *Journal of Medical Robotics Research*. vol. 06, no.01n02, pp.1-13, p. 2140001, May 2021, https://doi.org/10.1142/S2424905X21400018.

Ebrahimi, A., Urias, M., Patel, N., Taylor, R.H., Gehlbach, P.L. and Iordachita, I., "Adaptive Control Improves Sclera Force Safety in Robot-Assisted Eye Surgery: A Clinical Study," *IEEE Transactions on Bio-Medical Engineering*. vol. xx, no. x, pp.1-10, On-line 09 Apr. 2021, DOI: 10.1109/TBME.2021.3071135

Rezaee, M., Iordachita, I. and Wong, J.W., "Ultrahigh dose-rate (FLASH) X-Ray irradiator for pre-clinical laboratory research," *Physics in Medicine & Biology*. vol. 66, no. 9, pp.1-10, p. 095006, Apr. 2021, https://doi.org/10.1088/1361-6560/abf2fa

Dai, J., He, Z., Fang, G., Wang, X., Li, Y., Cheung, C.L., Liang, L., Iordachita, I.I., Chang, H.C. and Kwok, K.W., "A Robotic Platform to Navigate MRI-guided Focused Ultrasound System," *IEEE Robotics and Automation Letters*. vol. 6, no. 3, pp.5137-5144, Jul. 2021, DOI: 10.1109/LRA.2021.3068953

Sommersperger, M., Weiss, J., Nasseri, M.A., Gehlbach, P., Iordachita, I. and Navab, N., "Real-time tool to layer distance estimation for robotic subretinal injection using intraoperative 4D OCT." *Biomedical Optics Express*, vol.12, no.2, pp.1085-1104. Feb. 12, 2021, https://doi.org/10.1364/BOE.415477

Li, G., Patel, N.A., Sharma, K., Monfaredi, R., Dumoulin, C., Fritz, J., Iordachita, I. and Cleary, K., "Body-Mounted Robotics for Interventional MRI Procedures," *IEEE Transactions on Medical Robotics and Bionics*, vol. 2, no. 4, pp.557-560, On-line 13 Oct. 2020, DOI: 10.1109/TMRB.2020.3030532

CURRENT PROJECTS

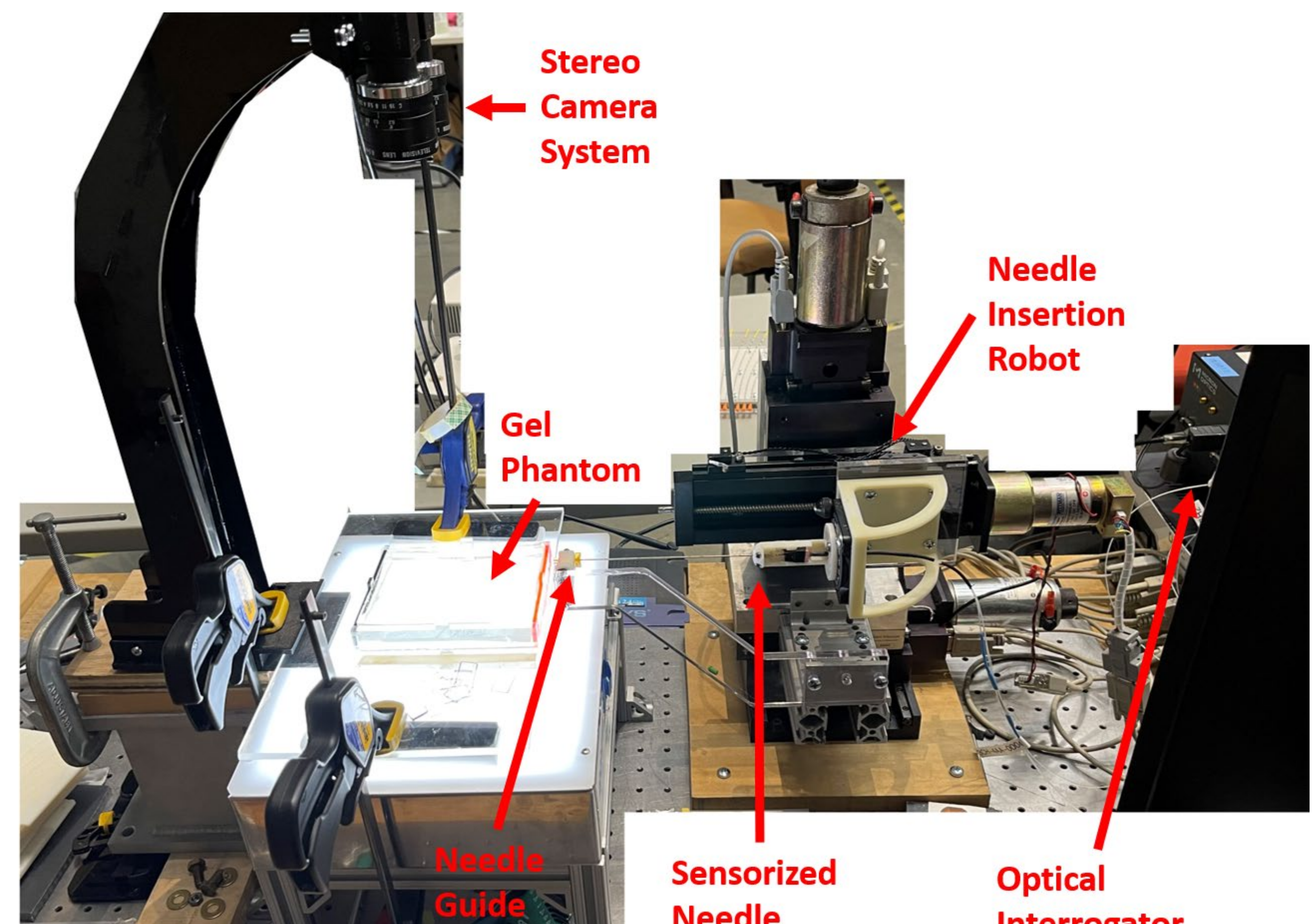
Enabling Technology for Image-Guided Robot-Assisted Sub-Retinal Injections

Adaptive Percutaneous Prostate Interventions using Sensorized Needle

MRI Compatible Robot for Improved Pain Injections in Adults and Children

Automated Mosquito Salivary Gland Removal

Iulian Iordachita
Research Professor
Department of Mechanical Engineering
amiro.lcsr.jhu.edu
iordachita@jhu.edu



Terradynamics

Chen Li

Aero- and hydrodynamics have helped us understand how animals fly and swim and to develop aerial and aquatic vehicles that move through air and water rapidly, agilely, and efficiently. By contrast, we know surprisingly little about how terrestrial animals move so well in nature, and even the best robots still struggle in complex terrains like building rubble, forest floor, mountain boulders, and cluttered indoor environments. Lab researchers are developing experimental tools and theoretical models to create terradynamics, a new field that describes these complex locomotor-terrain interactions and uses terradynamics to better understand animal locomotion and to advance robot locomotion in complex terrains.

ACCOMPLISHMENTS

Published 12 journal articles, with eight manuscripts under review/revision. Published 44 conference abstracts in 2020 and 2021.

Awards and Honors

Space@Hopkins Award, Johns Hopkins University, 2021

Trusted Reviewer Award, Institute of Physics, 2021

Mentee Awards

Finalist, LSRF Postdoctoral Fellowship (Ratan Othayoth), Life Sciences Research Foundation, 2022

First Place, REU Research Presentation (Jonathan Mi), Laboratory for Computational Sensing & Robotics, Johns Hopkins University, 2021

James F. Bell Award (Kaiwen Wang), for outstanding research and scholarly achievement, Department of Mechanical Engineering, Johns Hopkins University, 2021

Robert George Gerstmyer Award (Kaiwen Wang), for outstanding undergraduate achievement, Department of Mechanical Engineering, Johns Hopkins University, 2020

REFEREED JOURNAL PUBLICATIONS

Zheng B, Xuan Q, Li C (2022), "A minimalistic stochastic dynamics model of cluttered obstacle traversal," *IEEE Robotics and Automation Letters*, in press

Li C, Lewis K (2022), "The need for and feasibility of alternative robots to traverse sandy and rocky extraterrestrial terrain," *Advanced Intelligent Systems*, (Invited Article)

Othayoth R, Li C (2021), "Propelling and perturbing appendages together facilitate strenuous ground self-righting," *eLife*, 10:e60233

Othayoth R, Xuan Q, Wang Y, Li C (2021), "Locomotor transitions in the potential energy landscape-dominated regime," *Proceedings of the Royal Society B: Biological Sciences*, 288 (1949), 20202734

Han Y, Othayoth R, Wang Y, Hsu C-C, de la Tijera Obert R, Francois E, Li C (2021), "Shape-induced obstacle attraction and repulsion during dynamic locomotion," *International Journal of Robotics Research*, 40(6-7), 939-956

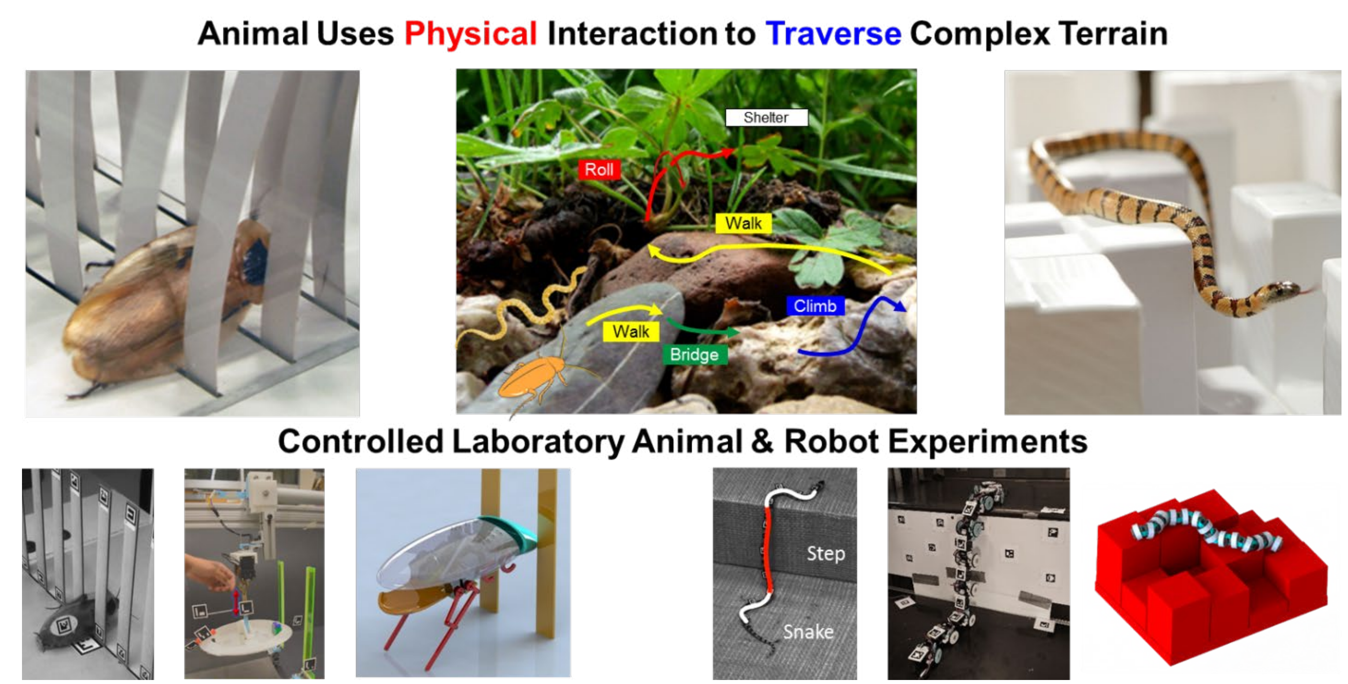
†Fu Q, †Mitchel TW, Kim JS, Chirikjian GS, *Li C (2021), "Continuous body 3-D reconstruction of limbless animals," *Journal of Experimental Biology*, 224 (6), (†Equal contribution)

CURRENT PROJECTS

The Terradynamics of Biological Movement in Complex Terrain

Neuromechanics of Legged Locomotion on Energy Landscapes of Complex Terrains

Simulation of Multi-Legged Robot Locomotor Transitions to Traverse Rocky Martian Terrain



Chen Li
Assistant Professor
Department of Mechanical Engineering
li.me.jhu.edu
chen.li@jhu.edu

Sensing, Manipulation, and Real-Time Systems

Peter Kazanzides

The Sensing, Manipulation, and Real-Time Systems (SMARTS) lab focuses on components and integrated systems for computer-assisted surgery and robotics in extreme environments. This includes the integration of real-time sensing and imaging to enable robotic assistance in more challenging settings, such as minimally invasive surgery, microsurgery and space (e.g., teleoperation with time delay of several seconds for satellite servicing). The lab also performs research in augmented/mixed reality for human/machine collaboration, including the use of head-mounted displays (HMDs) and novel input devices. Research in component technologies includes high-performance motor control, sensing, and sensor fusion. The lab emphasizes system integration activities, including system architectures and component-based software engineering, and is responsible for the development and support of the open source da Vinci Research Kit (dVRK).

We developed and disseminated the open-source da Vinci Research Kit to support worldwide research in medical robotics.

ACCOMPLISHMENTS

Kazanzides, P., Vagvolgyi, B., Pryor, W., Deguet, A., Leonard, S., Whitcomb, L., "Teleoperation and Visualization Interfaces for Remote Intervention in Space," *Frontiers in Robotics and AI*, 8, 2021.

D'Ettorre, C., Mariani, A., Stilli, A., y Baena, F.R., Valdastri, P., Deguet, A., Kazanzides, P., Taylor, R., Fischer, G., DiMaio, S., Menciassi, A., Stoyanov, D., "Accelerating Surgical Robotics Research: A Review of 10 Years With the da Vinci Research Kit," *IEEE Robotics and Automation Magazine*, 28 (4), pp. 56-78, 2021.

Vagvolgyi, B., Khrenov, M., Cope, J., Deguet, A., Kazanzides, P., Manzoor, S., Taylor, R., Krieger, A., "Telerobotic Operation of Intensive Care Unit Ventilators," *Frontiers in Robotics and AI*, 8, pp. 1-15, 2021, ISSN: 2296-9144.

Lin, H., Gao, Q., Chu, X., Dou, Q., Deguet, A., Kazanzides, P., Au, S., "Learning Deep Nets for Gravitational Dynamics with Unknown Disturbance through Physical Knowledge Distillation: Initial Feasibility Study" *IEEE Robotics and Automation Letters*, 6 (2), pp. 2658-2665, 2021.,

Munawar, A., Wu, J.Y., Taylor, R., Kazanzides, P., Fischer, G., "A Framework for Customizable Multi-User Teleoperated Control," *IEEE Robotics and Automation Letters*, 6 (2), pp. 3256-3263, 2021.

Wu, J.Y., Tamhane, Aniruddha, Kazanzides, Peter, Unberath, Mathias, "Cross-Modal Self-Supervised Representation Learning for Gesture and Skill Recognition in Robotic Surgery," Intl. *Journal of Computer Assisted Radiology and Surgery* (IJCARS), 16, pp. 779-787, 2021.

Yasin, R., Chalasani, P., Zevallos, N., Shahbazi, M., Li, Z., Deguet, A., Kazanzides, P., Choset, H., Taylor, R., Simaan, N. ,"Evaluation of Hybrid Control and Palpation Assistance for Situational Awareness in Telemanipulated Task Execution," *IEEE Trans. on Medical Robotics and Bionics*, 3 (1), pp. 31-43, 2021.

CURRENT PROJECTS

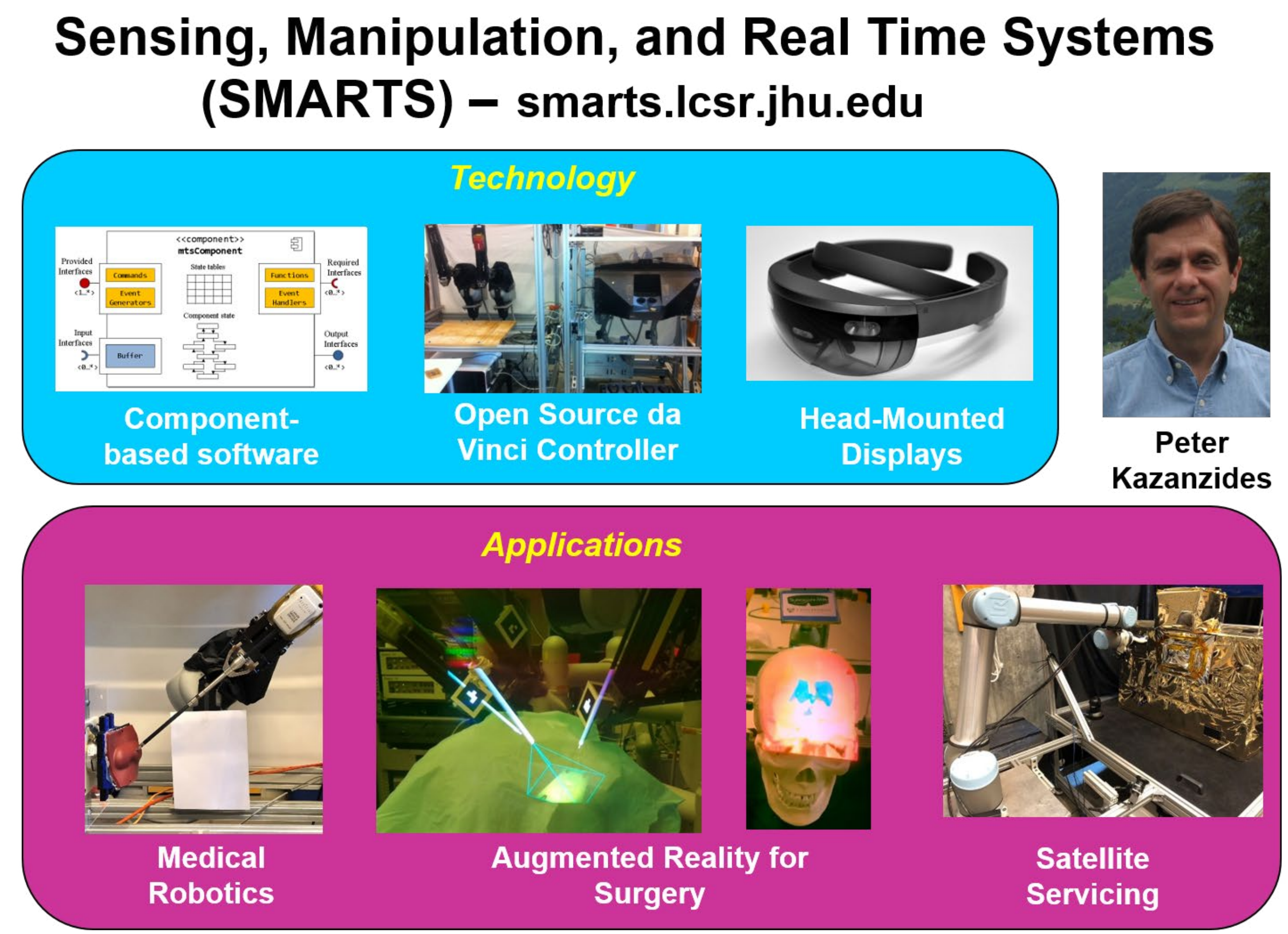
Telerobotic Satellite Servicing

Force Estimation for Surgical Robotics

Augmented Reality Assistance for Robotic Surgery

Virtual Reality Simulator for Temporal Bone Surgery

Peter Kazanzides
Research Professor
Department of Computer Science
smarts.lcsr.jhu.edu
pkaz@jhu.edu



Dynamical Systems and Control

Louis Whitcomb

The DSCL focuses on problems in the navigation, dynamics, and control of linear and nonlinear dynamical systems, observers, nonlinear systems analysis, modeling, and sensing relevant to robots that interact dynamically in extreme environments. DSCL researchers focus on problems motivated by several application areas that share a common underlying mathematical framework, including underwater robotics, space telerobotics, and medical robotics.

Lab Director Louis Whitcomb and his students have participated in the development of numerous underwater vehicles for oceanographic science missions, including the Nereus hybrid underwater vehicle that dove to the bottom of the Mariana Trench in 2009, and Nereid Under-Ice (NUI) hybrid underwater vehicle that was deployed under Arctic sea ice at 87°N 61°E in 2016. Recent deployments include a 10-day expedition aboard the RV Atlantic Explorer with the Sentry AUV to the Bowditch Seamount in 2018, and numerous deployments JHU Iver-3 AUV in the Chesapeake Bay 2015–Present. Our methodology is to address fundamental theoretical issues with concise mathematical analysis, and to experimentally validate our research results in actual working systems.

ACCOMPLISHMENTS

Recent Refereed Journal Publications

Andrew R. Spielvogel, Abhimanyu S. Shah, and Louis L. Whitcomb, "Online 3-Axis Magnetometer Hard-Iron and Soft-Iron Bias and Angular Velocity Sensor Bias Estimation Using Angular Velocity Sensors for Improved Dynamic Heading Accuracy," *Field Robotics*, 2021. Accepted, in press.

Peter Kazanzides, Balazs P. Vagvolgyi, Will Pryor, Anton Deguet, Simon Leonard, and Louis L. Whitcomb, "Teleoperation and Visualization Interfaces for Remote Intervention in Space," *Frontiers in Robotics and AI*. 2021(8):747917, December 2021. https://doi.org/10.3389/frobt.2021.747917

Christopher J. McFarland and Louis L. Whitcomb, "Stable Adaptive Identification of Fully-Coupled Second-Order 6-DOF Nonlinear Plant Models for Underwater Vehicles: Theory and Experimental Evaluation," *International Journal of Adaptive Control and Signal Processing*, 35(5):786-810, March, 2021. https://doi.org/10.1002/acs.3235

Laughlin D. L. Barker and Louis L. Whitcomb, "Performance Analysis of Ice-Relative Upward-Looking Doppler Navigation of Underwater Vehicles Beneath Moving Sea Ice, Journal of Marine Science and Engineering," *Special Issue on Control, Guidance, Coordination, and Localization of Autonomous Marine Vehicles*, 9(2):174-, February, 2021, https://doi.org/10.3390/jmse9020174.

Zachary J. Harris and Louis L. Whitcomb, "Cooperative Acoustic Navigation of Underwater Vehicles Without a DVL Utilizing a Dynamic Process Model: Theory and Field Evaluation," *Journal of Field Robotics*, 38(5):700-726, January 2021. https://doi.org/10.1002/rob.22008

Laughlin D. L. Barker, Michael V. Jakuba, Andrew D. Bowen, Christopher R. German, Ted Maksym, Larry Mayer, Antje Boetius, Pierre Dutrieux, and Louis. L. Whitcomb, "Scientific Challenges and Present Capabilities in Underwater Robotic Vehicle Design and Navigation for Oceanographic Exploration Under-Ice," *Remote Sensing*, vol. 12, no. 16, p. 2588, Aug. 2020, https://doi.org/10.3390/rs12162588

Andrew R. Spielvogel and Louis L. Whitcomb, "A Stable Adaptive Observer for Hard-Iron and Soft-Iron Bias Calibration and Compensation for Two-Axis Magnetometers: Theory and Experimental Evaluation," *IEEE Robotics and Automation Letters*, (5)2:1295-1302, April 2020, http:/dx.doi.org/10.1109/LRA.2020.2967308

Andrew R. Spielvogel and Louis L. Whitcomb, "Adaptive Bias and Attitude Observer on the Special Orthogonal Group for True-North Gyrocompass Systems: Theory and Preliminary Results", *International Journal of Robotics Research*. 39(2–3):321–338, 2020. http://doi.org/10.1177/0278364919881689 Invited Paper.

Recent Refereed Conference Publications

Annie M. Mao and Louis L. Whitcomb, "A Novel Quotient Space Approach to Stable Adaptive Model-Based Fault Detection and Isolation: Theory and Preliminary Simulation Evaluation," 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 7119-7126, October 2021. http://doi.org/10.1109/IROS51168.2021.9636026.

Tyler M. Paine and Louis L. Whitcomb, "Uniform Complete Observability of Mass and Inertial Parameters in Adaptive Identification of Rigid Body Plant Dynamics," 2021 IEEE International Conference on Robotics and Automation (*ICRA*), pp. 52-58, May 2021. https://doi.org/10.1109/*ICRA*48506.2021.9561892.

Will Pryor, Balazs P. Vagvolgyi, Anton Deguet, Simon Leonard, Louis L Whitcomb, and Peter Kazanzides, "Interactive Planning and Supervised Execution for High-Risk, High-Latency Teleoperation," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), October 2020.

Will Pryor, Balazs P. Vagvolgyi, William J. Gallagher, Anton Deguet, Simon Leonard, Louis L. Whitcomb, and Peter Kazanzides, "Experimental Evaluation of Teleoperation Interfaces for Cutting of Satellite Insulation," 2019 IEEE International Conference on Robotics and Automation (*ICRA*), Montreal, Canada, 4775-4781, 2019.

CURRENT PROJECTS

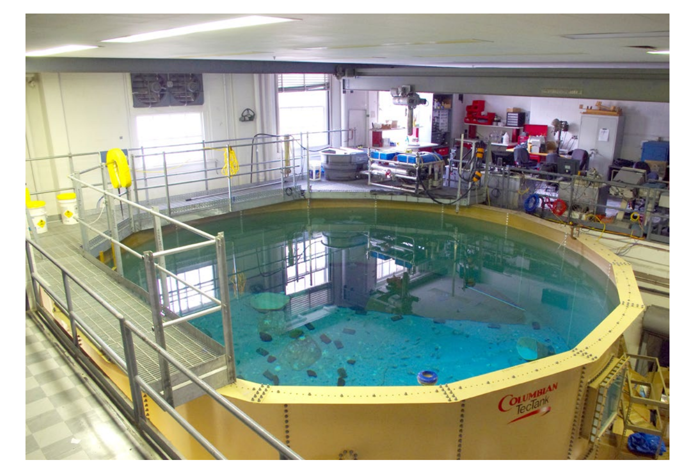
Development of Nereid Under-Ice (NUI): An Underwater Robot for Oceanographic Exploration Under Polar Ice

Development of a Low-Cost True-North Seeking Fiber Optic Gyrocompass for Precision Underwater Robot Navigation

Precision Navigation of Low-Cost Underwater Robotic Vehicles for Ocean Science

Telerobotic Satellite Servicing

Louis Whitcomb
Professor
Department of Mechanical Engineering
dscl.lcsr.jhu.edu
llw@jhu.edu



Autonomous Systems, Control and Optimization

Marin Kobilarov

The Autonomous Systems, Control and Optimization Laboratory (ASCO) aims to create robots with unprecedented agility and robustness that can fully exploit their dynamical and sensing abilities to operate in natural environments. Such systems will be aware of the complex interaction between mechanics, perception, and control, and will compute adaptively with performance guarantees in the presence of uncertainties.

The lab performs research in analytical and computational methods at the intersection of dynamical systems and control, optimization, and statistical learning, and in the design and integration of novel mechanisms and embedded systems. Current application areas are 1) autonomy in mobile (ground and aerial) robots and small spacecraft, and 2) computational tools for control and optimization of multi-body mechanical systems.

ACCOMPLISHMENTS

Demonstrated the successful development of theory, algorithms and software, and deployment on autonomous systems (self-driving cars, aerial drones, and underwater vehicles) operating in the real world.

M. Sheckells and M. Kobilarov, "Actor-Critic PAC Robust Policy Search," submitted to *ICRA* 2020 (pdf)

J. Kim, C. He, M. Urias, P. Gehlbach, G. D. Hager, I. Iordachita, and M. Kobilarov, "Autonomously Navigating a Surgical Tool Inside the Eye by Learning from Demonstration," submitted to *ICRA* RA-L 2020 (pdf)

G. Garimella, M. Sheckells, S. Kim, G. Baraban, and M. Kobilarov, "A Framework for Reliable Aerial Manipulation," (preprint) (pdf)

G. Garimella, M. Sheckells, and M. Kobilarov, "Nonlinear Model Predictive Control of an Aerial Manipulator using a Recurrent Neural Network Model," 2018 (preprint) (pdf)

CURRENT PROJECTS

Robotic Environmental Sampling

Autonomous Aerial Manipulation

Autonomously Navigating a Surgical Tool Inside the Eye by Learning from Demonstration

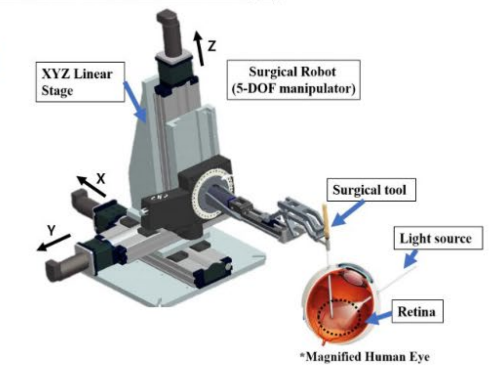
Enabling Technology for Image-Guided Robot-Assisted Sub-Retinal Injections

Marin Kobilarov
Assistant Professor
Department of Mechanical Engineering
asco.lcsr.jhu.edu
marin@jhu.edu

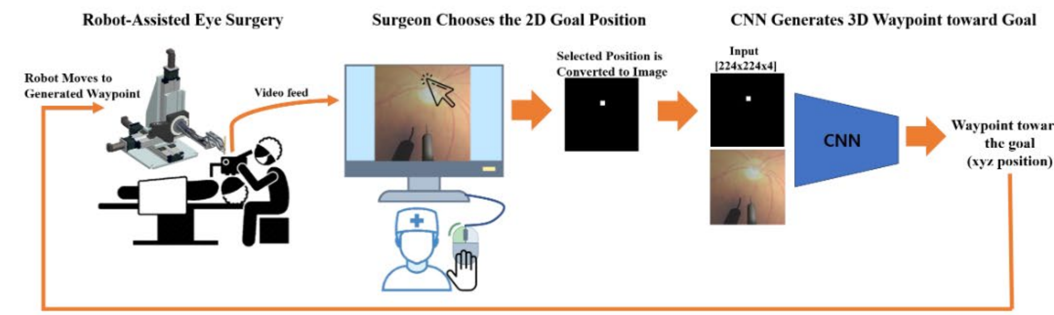
Autonomously Navigating a Surgical Tool Inside the Eye by Learning from Demonstration

Objective: Autonomously navigate a surgical tool to some desired location on the retinal surface using a surgical robot

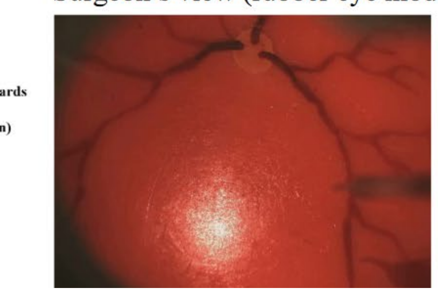
Method: Imitation Learning - demonstrate many expert trajectories and train a deep network to imitate the demonstrated trajectories



Application:



Surgeon's view (rubber eye model)



Intelligent Medical Robotic Systems & Equipment

Axel Krieger

Work in the IMERSE lab focuses on both fundamental and translational research in the development of novel tools, imaging, and robot control techniques for medical robotics. Specifically, the lab investigates methodologies that (i) increase smartness and autonomy and (ii) improve image guidance of medical robots to perform previously impossible tasks, improve efficiency, and ultimately enhance patient outcomes.

ACCOMPLISHMENTS

Best Student Paper Award at IEEE 21st International Conference on Bioinformatics and Bioengineering (BIBE) 2021

Latest research on Autonomous Laparoscopic Surgery published in Science Robotics: DOI: 10.1126/scirobotics.abj2908

"Telerobotics for Remote Control of Medical Equipment in Contagious Environments" won the Best Innovation Award at the inaugural Medical Robotics for Contagious Diseases Challenge 2020

Dr. Krieger's NSF Career award on "Advancing autonomy for soft tissue robotic surgery and interventions" was recommended for funding

RECENT REFEREED JOURNAL PUBLICATIONS

Saeidi H, Opfermann, JD, Kam M, Wei S, Leonard S, Hsieh MH, Kang JU, Krieger A. Autonomous Robotic Laparoscopic Surgery for Intestinal Anastomosis. *Science Robotics*. 7, no. 62 (2022). DOI: 10.1126/scirobotics.abj2908

Liu X, Aslan S, Kim B, Warburton L, Jackson D, Muhuri A, Subramanian A, Mass P, Cleveland V, Loke YH, Hibino N, Olivieri L, Krieger A. Computational Fontan Analysis: Preserving accuracy while expediting workflow. *World Journal for Pediatric and Congenital Heart Surgery*. Accepted, to appear.

Ghoreishi SF, Sochol R, Gandhi D, Krieger A, Fuge M. Physics-Informed Modeling and Control of Multi-Actuator Soft Catheter Robots. *Frontiers in Robotics and AI, Soft Robotics* (2021), p.386.

Mair LO, Chowdhury S, Liu X, Erin O, Udalov O, Raval S, Johnson B, Jafari S, Cappelleri DJ, Diaz-Mercado Y, Krieger A. Going Hands-Free: MagnetoSuture™ for Untethered Guided Needle Penetration of Human Tissue Ex Vivo. *Robotics* 10, no. 4 (2021): 129. DOI: https://doi.org/10.3390/robotics10040129

Mandell JG, Loke YH, Mass PN, Cleveland V, Delaney M, Opfermann JD, Aslan S, Krieger A, Hibino N, and Olivieri L. Altered hemodynamics by 4D flow cardiovascular magnetic resonance predict exercise intolerance in repaired coarctation of the aorta: an in vitro study. *Journal of Cardiovascular Magnetic Resonance*, 23(1), no. 1 (2021): 1-11.

Aroom K, Ge J, Al-Zogbi L, White M, Trustman A, Greenbaum A, Farley J, Krieger A. Positive Pressure Testing Booths Development and Deployment in Response To The COVID-19 Outbreak. *ASME Journal of Medical Devices*, MED-21-1004 (2021).

Vagvolgyi BP, Khrenov M, Cope J, Deguet A, Kazanzides P, Manzoor S, Taylor RH, Krieger A. Telerobotic Operation of Intensive Care Unit Ventilators. *Frontiers in Robotics and AI* (2021): 186. DOI: https://doi.org/10.3389/frobt.2021.612964

Liu X, Kim B, Loke YH, Mass P, Olivieri L, Hibino N, Fuge M, Krieger A. Semi-Automatic Planning and Three-dimensional Electrospinning of Patient-Specific Grafts for Fontan Surgery. *IEEE Transactions on Biomedical Engineering*, (2021) 69(1):186-198. PMID: 34156934. DOI: 10.1109/TBME.2021.3091113

Leonard S, Opfermann JD, Uebele N, Carroll L, Walter R, Bayne C, Ge J, Krieger A. Vaginal Cuff Closure with Dual-Arm Robot and Near-Infrared Fluorescent Sutures. *IEEE Transactions on Medical Robotics and Bionics* 3, no. 3 (2021): 762-772. DOI: 10.1109/TMRB.2021.3097415

Ghoreishi SF, Sochol RD, Gandhi D, Krieger A, Fuge M. Bayesian Optimization for Design of Multi-Actuator Soft Catheter Robots. *IEEE Transactions on Medical Robotics and Bionics* 3, no. 3 (2021): 725-737.

Ahuja A, Al-Zogbi L, Krieger A. Application of Noise-Reduction Techniques to Machine Learning Algorithms for Breast Cancer Tumor Identification. *Computers in Biology and Medicine* (2021), p.104576. DOI: https://doi.org/10.1016/j.compbiomed.2021.104576

Ghobadi K, Hager G, Krieger A, Levin S, Unberath M. Responding to a Pandemic: COVID-19 Projects in the Malone Center. *Surgical Innovation* (2021), p.15533506211018446.

Al-Zogbi L, Singh V, Teixeira B, Ahuja A, Bagherzadeh PS, Kapoor A, Saeidi H, Fleiter T, Krieger A. Autonomous Robotic Point-of-Care Ultrasound Imaging for Monitoring of COVID-19–Induced Pulmonary Diseases. *Frontiers in Robotics and AI* (2021), 8. DOI: 10.3389/frobt.2021.645756

Su H, Di Lallo A, Murphy RR, Taylor RH, Garibaldi BT, Krieger A. Physical human–robot interaction for clinical care in infectious environments. *Nature Machine Intelligence 3*, no. 3 (2021): 184-186. DOI: https://doi.org/10.1038/s42256-021-00324-z

Ge J, Opfermann JD, Saeidi H, Huenerberg KA, Badger CD, Cha J, Schnermann MJ, Joshi AS, Krieger A. A Novel Indocyanine Green-Based Fluorescent Marker for Guiding Trans-oral Robotic Surgery. *Journal of Innovative Optical Health Sciences* (2021): 2150013. DOI: https://doi.org/10.1142/S1793545821500139

Di Lallo A, Murphy R, Krieger A, Zhu J, Taylor RH, Su H.. Medical Robots for Infectious Diseases: Lessons and Challenges from the COVID-19 Pandemic. *IEEE Robotics & Automation Magazine* 28, no. 1 (2021): 18-27.

Al-Zogbi L, Bock B, Schaffer S, Fleiter T, Krieger A. A 3-D-Printed Patient-Specific Ultrasound Phantom for FAST Scan. *Ultrasound in Medicine & Biology* 47, no. 3 (2021): 820-832. PMID: 33328132. DOI: https://doi.org/10.1016/j.ultrasmedbio.2020.11.004

Mandell JG, Loke YH, Mass PN, Opfermann J, Cleveland V, Aslan S, Hibino N, Krieger A, Olivieri LJ. Aorta size mismatch predicts decreased exercise capacity in patients with successfully repaired coarctation of the aorta. *The Journal of Thoracic and Cardiovascular Surgery* 162, no. 1 (2021): 183-192. PMID: 33131888.

ONGOING PROJECTS

Autonomous Robotic Soft Tissue Surgery

Image Guided Interventions and Planning

Autonomous Robotic Ultrasound

Magnetically Actuated Microrobots

Cardiac Planning and Patient Specific Implant Design

Axel Krieger
Assistant Professor
Department of Mechanical Engineering
imerse.lcsr.jhu.edu
axel@jhu.edu

Computer Integrated Interventional Systems

Russell Taylor

The Computer-Integrated Interventional Systems (CiiS) Lab focuses on all aspects of medical robotics and computer-integrated interventional medicine, as well as related subject areas in medical image analysis, robotics, and human-machine cooperation. The lab's overall strategy is to create a three-way partnership between humans, technology, and information to fundamentally improve surgery and other medical procedures by making them safer, less invasive, and more effective.

The CiiS lab collaborates closely with other labs within LCSR and the Malone Center for Engineering in Healthcare, with surgeons and others in the Johns Hopkins Engineering School and School of Medicine, and with research groups and institutions around the world.

Some recent research projects (many undertaken with other LCSR labs) include robot-assisted microsurgery (steady hand-eye robot, ENT robot), surgical control and planning, snake robot, deformable human anatomical models, smart surgical instruments, treatment plan optimization in radiation oncology, image overlay, a laparoscopic-assisted robot system, robot-assisted ultrasound and MRI-compatible robotics, and a system for automatic dissection of mosquitoes for malaria vaccine production.

ACCOMPLISHMENTS

The REMS head-and-neck microsurgery robot developed within CiiS by Kevin Olds is being commercialized by a startup company, Galen Robotics, which is also sponsoring research within LCSR.

Starting with its existence within the CISST ERC, the CiiS lab has produced more than 480 peer reviewed journal and conference publications, and more than 50 U.S. and international patents. These have led to many "best paper" awards. Within the past two years, the lab has produced more than 20 refereed conference papers and 33 journal papers. There were also four issued patents, with many others in various stages of prosecution. A few selected recent publications are below.

R. B. Grupp, R. A. Hegeman, R. J. Murphy, C. P. Alexander, Y. Otake, B. A. McArthur, M. Armand, and R. H. Taylor, "Pose Estimation of Periacetabular Osteotomy Fragments with Intraoperative X-Ray Navigation," *IEEE Trans Biomed Eng.*, vol. 67- 2, pp. 441-452, Feb., 2020. Epub 8 March 2019 10.1109/TBME.2019.2915165

Z. Li, M. Shahbazi, N. Patel, E. O. Sullivan, H. Zhang, K. Vyas, P. Chalasani, A. Deguet, P. L. Gehlbach, I. Iordachita, G.-Z. Yang, and R. H. Taylor, "Hybrid Robot-assisted Frameworks for Endomicroscopy Scanning in Retinal Surgeries," *IEEE Trans Medical Robotics and Bionics*, vol. 2- 2, pp. 176-187, May, 2020. 4/17/2020 10.1109/TMRB.2020.2988312

Z. Li, M. Shahbazi, N. Patel, E. O. Sullivan, H. Zhang, K. Vyas, P. Chalasani, A. Deguet, P. L. Gehlbach, I. Iordachita, G.-Z. Yang, and R. H. Taylor, "Hybrid Robot-assisted Frameworks for Endomicroscopy Scanning in Retinal Surgeries," *IEEE Trans Medical Robotics and Bionics*, vol. 2- 2, pp. 176-187, May, 2020. 4/17/2020 10.1109/TMRB.2020.2988312

C. D'Ettorre, A. Mariani, A. Stilli, F. R. y. Baena, P. Valdastri, A. Deguet, P. Kazanzides, R. H. Taylor, G. S. Fischer, S. P. DiMaio, A. Menciassi, and D. Stoyanov, "Accelerating Surgical Robotics Research: A Review of 10 Years With the da Vinci Research Kit,"*IEEE Robotic & Automation Magazine*, vol. 28- 4, pp. 56-78, Sept. 8, 2021. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9531355 10.1109/MRA.2021.3101646

B. P. Vagvolgyi, M. Khrenov, J. Cope, A. Deguet, P. Kazanzides, S. Manzoor, R. H. Taylor, and A. Krieger, "Telerobotic Operation of Intensive Care Unit Ventilators," *Frontiers in Robotics and AI*, vol. 8- 612964, pp. 1-15, 24 June, 2021. https://www.frontiersin.org/article/10.3389/frobt.2021.612964 10.3389/frobt.2021.612964

G. Hager, V. Kumar, R. Murphy, D. Rus, and R. Taylor, "The Role of Robotics in Infectious Disease Crises," *Report of an CCC/NAE-sponsored workshop* held July 9-10, 2020, https://arxiv.org/abs/2010.09909.

CURRENT PROJECTS

Assured Autonomous Control of ICU Ventilators (with Tony Dahbura)

X-ray Image-based Navigation for Periacetabular Osteotomy with Intraoperative Biomechanical Feedback

3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning

Robot-assisted Confocal Endoscopic Imaging for Retinal Surgery

Automated Mosquito Salivary Gland Removal

Steady-Hand Robot for Head-and-Neck Surgery

Deformable Registration using Statistical Shape Models

Enhanced Navigation for Endoscopic Sinus Surgery through Video Analysis

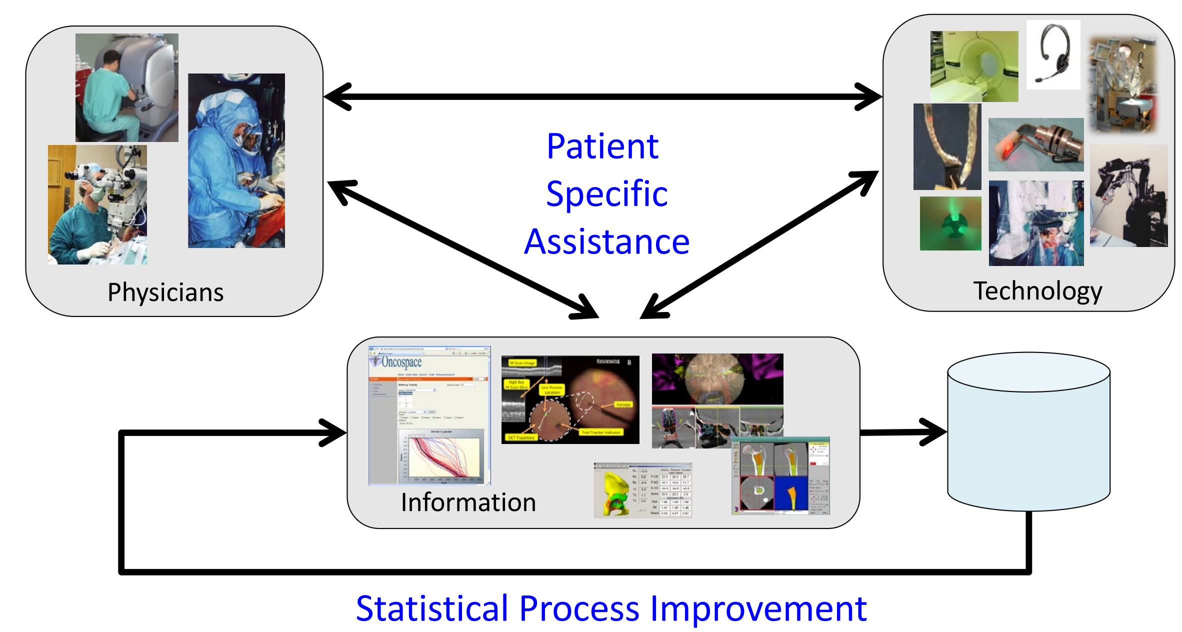
Image-based Modeling and Analysis of Anatomic Structures in the Human Temporal Bone

Real time modeling and registration of 3D surgical field from surgical microscope data

Virtual Reality Simulator for Temporal Bone Surgery

Russell H. Taylor
John C. Malone Professor
Professor, Department of Computer Science
Director, Laboratory for Computational Sensing and Robotics
rht@jhu.edu

Human-machine partnership to fundamentally improve interventional medicine



Computational Interaction and Robotics

Greg Hager

The Computational Interaction and Robotics Laboratory (CIRL) is devoted to the study of problems that involve dynamic, spatial interaction at the intersection of imaging, robotics, and human-computer interaction. The laboratory has a number of ongoing projects in this area. The Language of Motion project seeks to develop new methods to recognize and evaluate human activities and skilled human manipulation, with a particular emphasis on surgery. Applications include automated skill evaluation, training, and human-robot collaborative task execution. Other work is aimed at machine learning to create systems that perform complex manipulation tasks.

CIRL also works in the area of medical imaging. Interactive computer-aided diagnostic systems based on images are also an area of interest. The CIRL lab has made advances in a number of areas, including automated systems for surgical workflow analysis and surgical coaching, collaborative systems for manufacturing, perception and learning-based manipulation, and video-CT registration for surgical navigation.

ACCOMPLISHMENTS

Abdelaal AE, Liu J, Hong N, Hager GD, Salcudean S., “Parallelism in Autonomous Robotic Surgery,” *IEEE Robotics and Automation Letters*. 2021.

Holden MS, O’Brien M, Malpani A, Naz H, Tseng YW, Ishii L, Vedula SS, Ishii M, Hager G, “Reconstructing the Nasal Septum from Instrument Motion During Septoplasty Surgery,” *Journal of Medical Imaging* 2021.

Hager GD, Maier-Hein L, Vedula SS, “Surgical Data Science,” *Handbook of Medical Image Computing and Computer Assisted Intervention*. 2020.

Malpani A, Vedula SS, Lin HC, Hager GD, Taylor RH, “Effect of Real-Time Virtual Reality-Based Teaching Cues on Learning Needle Passing for Robot-Assisted Minimally Invasive Surgery: a Randomized Controlled Trial,” *IJCARS* 2020

Alnafisee N, Zafar S, Park K, Vedula SS, Sikder S, “Artificial Intelligence in Cataract Surgery Training,” *Artificial Intelligence in Ophthalmology* 2021

CURRENT PROJECTS

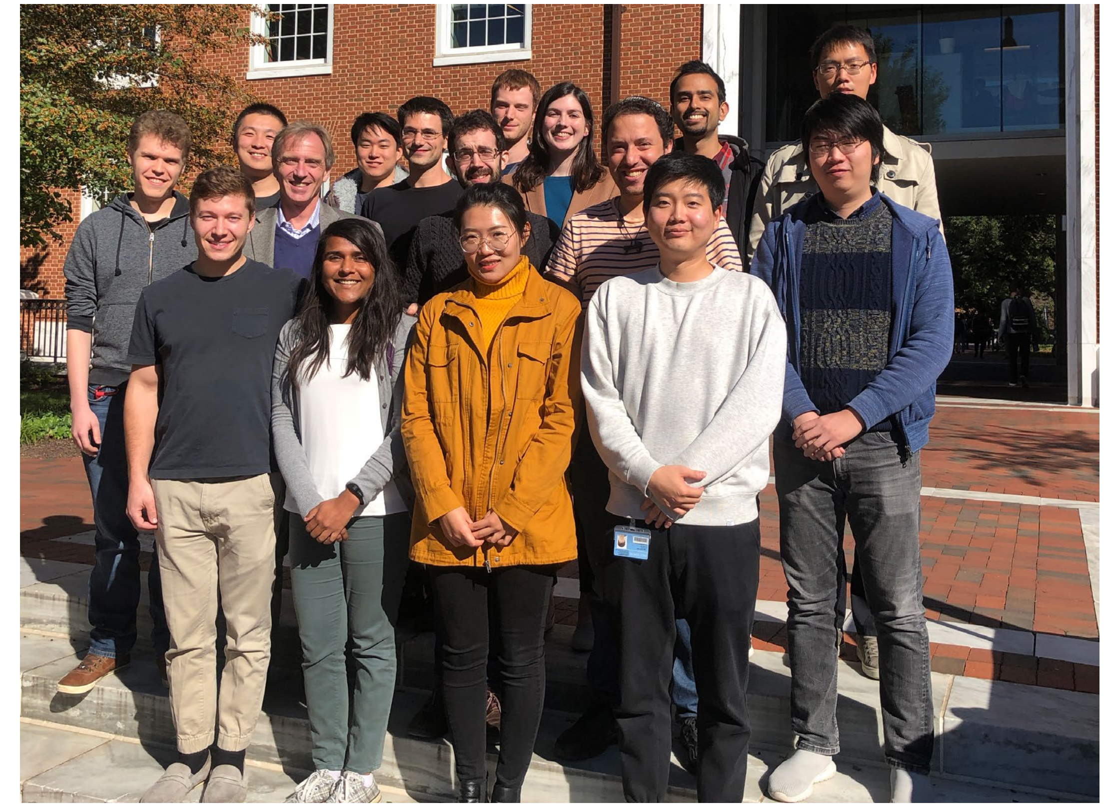
The Language of Surgery Project

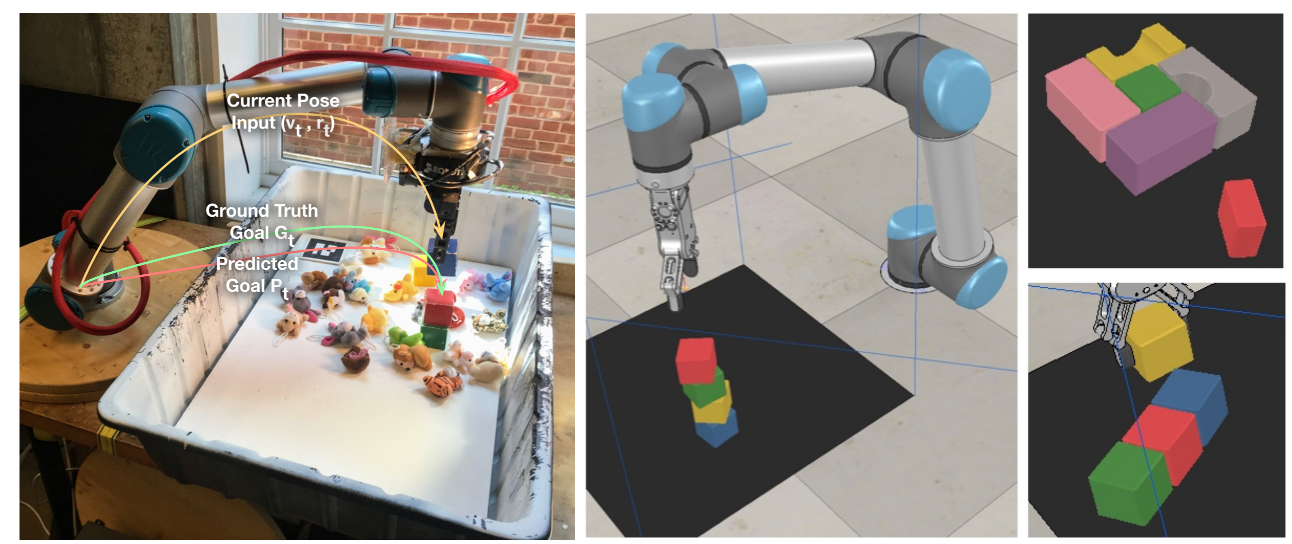
Machines with Imagination: Learning from Description through Synthesis and Analysis

Enhanced Navigation for Endoscopic Sinus Surgery through Video Analysis

3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning

Greg Hager
Mandell Bellmore Professor of Computer Science
cirl.lcsr.jhu.edu
hager@jhu.edu





Locomotion In Mechanical and Biological Systems

Noah J. Cowan

Why is it that a chess engine easily defeats human grandmasters, but a child can move the pieces with greater agility than the best robots? The LIMBS lab approaches this broad question by applying dynamical systems and control theory to discover principles of how the brain and body work together to achieve agile movement. We study problems in neuromechanics, locomotion, control theory, system identification, and robotics. Central to the LIMBS mission is working collaboratively with neuroscientists.

ACCOMPLISHMENTS

In the past few years, we have published our work in multiple flagship journals including *Nature*, *Scientific Reports*, *Current Biology*, and *IEEE Transactions on Automatic Control*, among others, including a new review of the application of control theory to neuroscience in *Annual Reviews of Control, Robotics, and Autonomous Systems*.

In collaboration with researchers at Hopkins and other institutions, the LIMBS laboratory has garnered more than $5 million in extramural funding over the last few years. Funding agencies include the National Institutes of Health, National Science Foundation, and Department of Defense.

B. P. Vagvolgyi, R. P. Jayakumar, M. S. Madhav, J. J. Knierim, N. J. Cowan, "Wide-Angle, Monocular Head Tracking using Passive Markers," *J Neurosci Meth*, p. 109453, 2022.

M. S. Madhav, R. P. Jayakumar, S. G. Lashkari, F. Savelli, H. T. Blair, J. J. Knierim, N. J. Cowan, "The Dome: a virtual reality apparatus for freely locomoting rodents," *J Neurosci Meth*, p. 109336, 2022.

C. S. Yang, N. J. Cowan, and A. M. Haith, "De Novo Learning Versus Adaptation of Continuous Control in a Manual Tracking Task," *eLife*, vol. 10, p. e62578, 2021.

M. S. Madhav and N. J. Cowan, "The Synergy Between Neuroscience and Control Theory: the Nervous System as Inspiration for Hard Control Challenges," *Annu Rev Control Robot Auton Syst*, vol. 3, 2020.

R. W. Nickl, M. M. Ankarali, and N. Cowan, "Complementary Spatial and Timing Control in Rhythmic Arm Movements," *J Neurophysiol*, vol. 121, iss. 4, p. 1543–1560, 2019.

I. Uyanik, S. A. Stamper, N. J. Cowan, and E. S. Fortune, "Sensory Cues Modulate Smooth Pursuit and Active Sensing Movements," *Front Behav Neurosci*, vol. 13, iss. 59, 2019.

R. P. Jayakumar, M. S. Madhav, F. Savelli, H. T. Blair, N. Cowan, and J. J. Knierim, "Recalibration of Path Integration in Hippocampal Place Cells," *Nature*, vol. 566, iss. 745, p. 533-537, 2019.

CURRENT PROJECTS

A User's Guide to System Identification for Sensorimotor Control

Programming Thermobiochemomechanical (TBCM) Multiplex Robot Gels

Human Sensory-Motor Control

Noah J. Cowan
Professor
Department of Mechanical of Engineering
limbs.lcsr.jhu.edu
ncowan@jhu.edu

Haptics and Medical Robotics

Jeremy D. Brown

The Haptics and Medical Robotics (HAMR) Laboratory seeks to extend knowledge surrounding the human perception of touch, especially as it relates to applications of human/robot interaction and collaboration. We are particularly interested in medical robotics applications such as minimally invasive surgical robots, upper-limb prosthetic devices, and rehabilitation robots. To solve many of the problems in these areas, we apply techniques from human perception, human motor control, neuromechanics, and control theory.

ACCOMPLISHMENTS

We were recently awarded an Intuitive Technology Research Grant (in collaboration with Axel Krieger) to investigate shared control approaches for robotic minimally invasive surgery.

S. Machaca, Z. Karachiwalla, N. D. Riaziat, and J. D. Brown, “Towards a ROS-based modular multi-modality haptic feedback system for robotic minimally invasive surgery training assessments,” in *IEEE International Symposium on Medical Robotics (Accepted)*, 2022.

M. Singhala and J. D. Brown, “Investigating upper limb perceptual asymmetries for unconstrained active exploration of stiffness cues,” in *IEEE Haptics Symposium (Accepted)*, 2022.

M. Singhala and J. D. Brown, “A novel testbed for investigating the impact of teleoperator dynamics on perceived environment dynamics,” in 2021 *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2021, pp. 8358–8364.

A. J. Miller, N. D. Riaziat, and J. D. Brown, “An Open-Source Ungrounded Hapkit for Educational Applications,” in *IEEE World Haptics Conference*, 2021, pp. 1155–1155.

A. J. Miller, G. Carolina Bettelani, S. Fani, M. Bianchi, and J. D. Brown, “On the Utility of Affective Feedback in Prosthesis Embodiment,” in *IEEE World Haptics Conference*, 2021, pp. 874–874.

C. G. Rose, A. D. Deshpande, J. Carducci, and J. D. Brown, “The road forward for upper-extremity rehabilitation robotics,” *Current Opinion in Biomedical Engineering*, vol. 19, p. 100291, Sep. 2021.

N. Thomas, F. Fazlollahi, J. D. Brown, and K. J. Kuchenbecker, “Sensorimotor-inspired Tactile Feedback and Control Improve Consistency of Prosthesis Manipulation in the Absence of Direct Vision,” in 2021 *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2021, pp. 6174–6181.

N. Thomas, G. Ung, H. Ayaz, and J. D. Brown, “Neurophysiological Evaluation of Haptic Feedback for Myoelectric Prostheses,” *IEEE Transactions on Human-Machine Systems*, vol. 51, no. 3, pp. 253–264, Jun. 2021.

S. Machaca, G. Ung, and J. D. Brown, “Towards an Understanding of the Utility of Dual-Modality Haptic Feedback in Teleoperated Medical Devices,” *IEEE Transactions on Medical Robotics and Bionics*, vol. 2, no. 4, pp. 574–577, Nov. 2020.

CURRENT PROJECTS

Anthropomorphically Driven Upper-Extremity Prosthesis

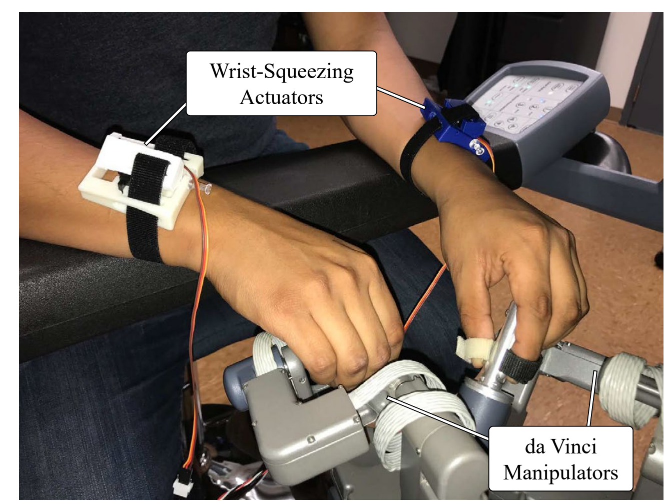
Robot-Assisted Minimally Invasive Surgical Training

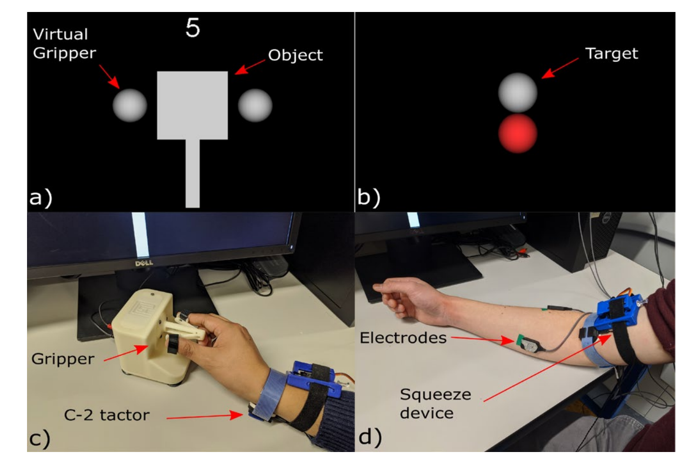
Neuroergonomic Evaluation on Haptic Feedback in Upper-Extremity Prostheses

Sensorimotor-Inspired Control for Upper-Extremity Prostheses

Haptic Perception and Task Performance During Non-Transparent Teleoperation

Jeremy D. Brown
Assistant Professor
Department of Mechanical Engineering
hamr.lcsr.jhu.edu
jdelainebrown@jhu.edu





Biomechanical- and Image-Guided Surgical Systems

Mehran Armand

The Biomechanical-and Image-Guided Surgical Systems (BIGSS) laboratory focuses on developing innovative computer-aided surgical guidance systems involving novel robots, advanced imaging, and real-time biomechanical assessments to improve surgical outcomes.

BIGSS researchers develop and test robotic workstations to assist in surgeries treating bone defects by designing and applying continuum manipulators, imaging, and visualization using augmented reality. The BIGSS lab also focuses on applying machine learning and intraoperative biomechanical analysis for craniofacial and orthopaedic surgery. The lab also develops and tests image-guided navigation systems for the treatment of hip dysplasia and single-stage cranioplasty

RECENT PAPERS

S. Sefati, R. Hegeman, I. Iordachita, R. H. Taylor and M. Armand, "A Dexterous Robotic System for Autonomous Debridement of Osteolytic Bone Lesions in Confined Spaces: Human Cadaver Studies," in *IEEE Transactions on Robotics*, doi: 10.1109/TRO.2021.3091283.

J. Fotouhi, A. Mehrfard, T. Song, A. Johnson, G. Osgood, M. Unberath, M. Armand, N. Navab et al.., "Development and Pre-Clinical Analysis of Spatiotemporal-Aware Augmented Reality in Orthopedic Interventions," *IEEE Transactions on Medical Imaging*, vol. 40, pp. 765–778, 2021

S. Sefati, C. Gao, I. Iordachita, R. H. Taylor, and M. Armand, "Data-Driven Shape Sensing of a Surgical Continuum Manipulator Using an Uncalibrated Fiber Bragg Grating Sensor," *IEEE Sensors Journal*, vol. 21, pp. 3066–3076, 2021

A. Farvardin, M. Bakhtiarinejad, R. J. Murphy, E. Basafa, H. Khanuja, J. K. Oni, M. Armand "A Biomechanically-Guided Planning and Execution Paradigm for Osteoporotic Hip Augmentation: Experimental Evaluation of the Biomechanics and Temperature-rise," *Clinical Biomechanics*, p. 105392, 2021/05/29/ 2021

J. H. Ma, S. Sefati, R. H. Taylor, and M. Armand, "An Active Steering Hand-Held Robotic System for Minimally Invasive Orthopaedic Surgery Using a Continuum Manipulator," *IEEE Robotics and Automation Letters*, vol. 6, pp. 1622–1629, 2021

S. Liu, W. L. Huang, C. Gordon, M. Armand, "Automated Implant Resizing for Single-Stage Cranioplasty," in *IEEE Robotics and Automation Letters*, vol. 6, no. 4, pp. 6624-6631, Oct. 2021, doi: 10.1109/LRA.2021.3095286.

CURRENT PROJECTS

Continuum Robots, Tools, and Algorithms for Tissue Manipulation

Perceptual Visualization for Surgical Guidance in Orthopaedics Using Augmented Reality

Total Body Imaging for Skin Cancer Detection

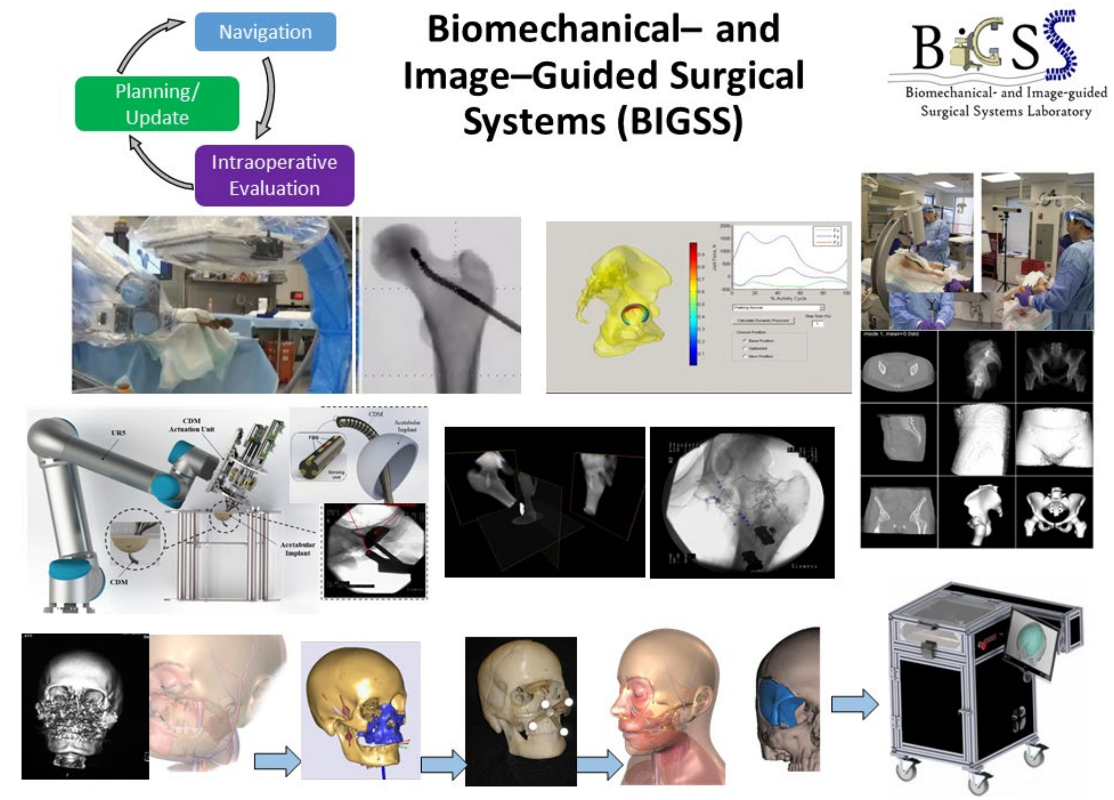
Automated Implant Modification for Neuroplastic Surgery

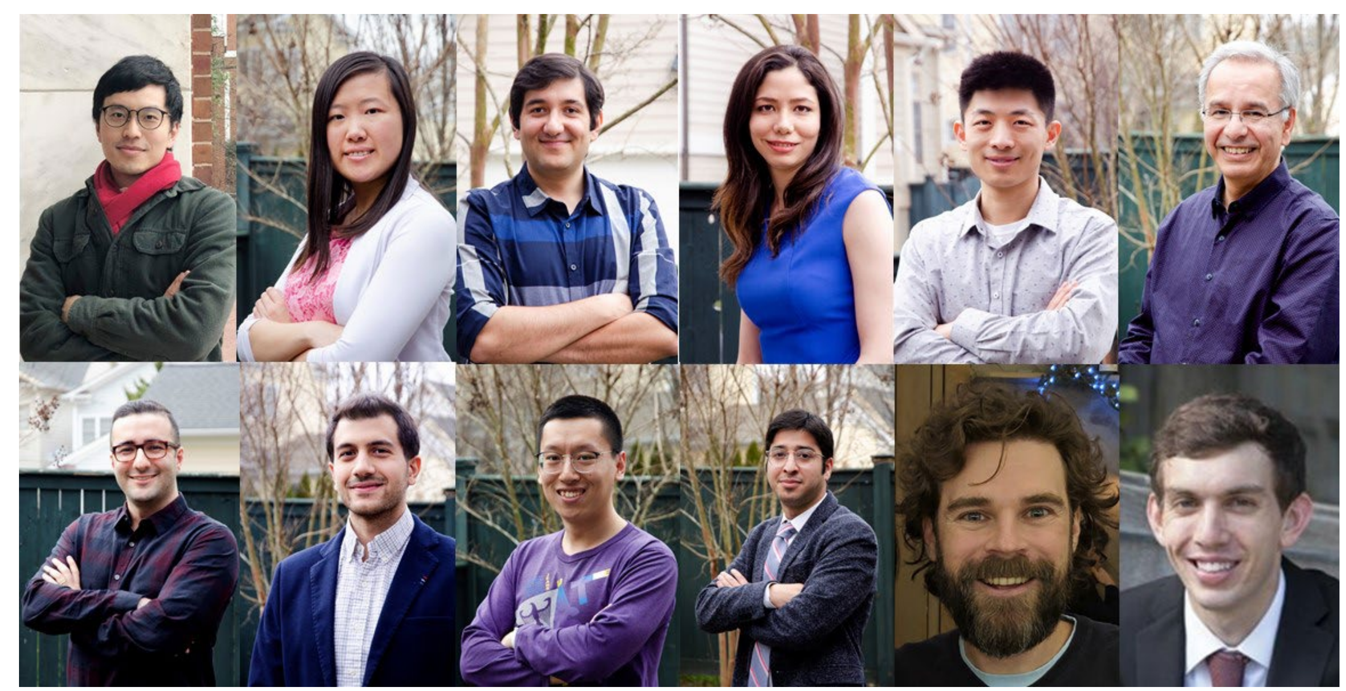
Robot-Assisted Femoroplasty

Robot-Assisted Transcranial Magnetic Stimulation

X-ray Image-based Navigation for Periacetabular Osteotomy with Intraoperative Biomechanical Feedback

Mehran Armand
Principal Staff Member, Johns Hopkins University Applied Physics Laboratory
Professor, Orthopaedic Surgery, Mechanical Engineering and Computer Science (cross appointment)
bigss.lcsr.jhu.edu
marmand2@jhu.edu





Advanced Robotics and Computationally Augmented Environments

Mathias Unberath

The ARCADE Lab develops collaborative intelligent systems that support clinical workflows to increase access to and expand the possibilities of highest-quality health care. Through synergistic advancement of imaging, computer vision, machine learning, and interaction design, this lab pioneers human-centered solutions that are embodied in emerging technology such as mixed reality and robotics. Its researchers collaborate closely with care providers to understand clinical workflow, identify opportunities and constraints, and facilitate translation. The lab is based on Homewood campus and is affiliated with the Laboratory for Computational Sensing and Robotics and the Malone Center for Engineering in Healthcare.

CURRENT PROJECTS

Task-aware and Autonomous C-arm Imaging

3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning

Transparent Machine Learning for Healthcare

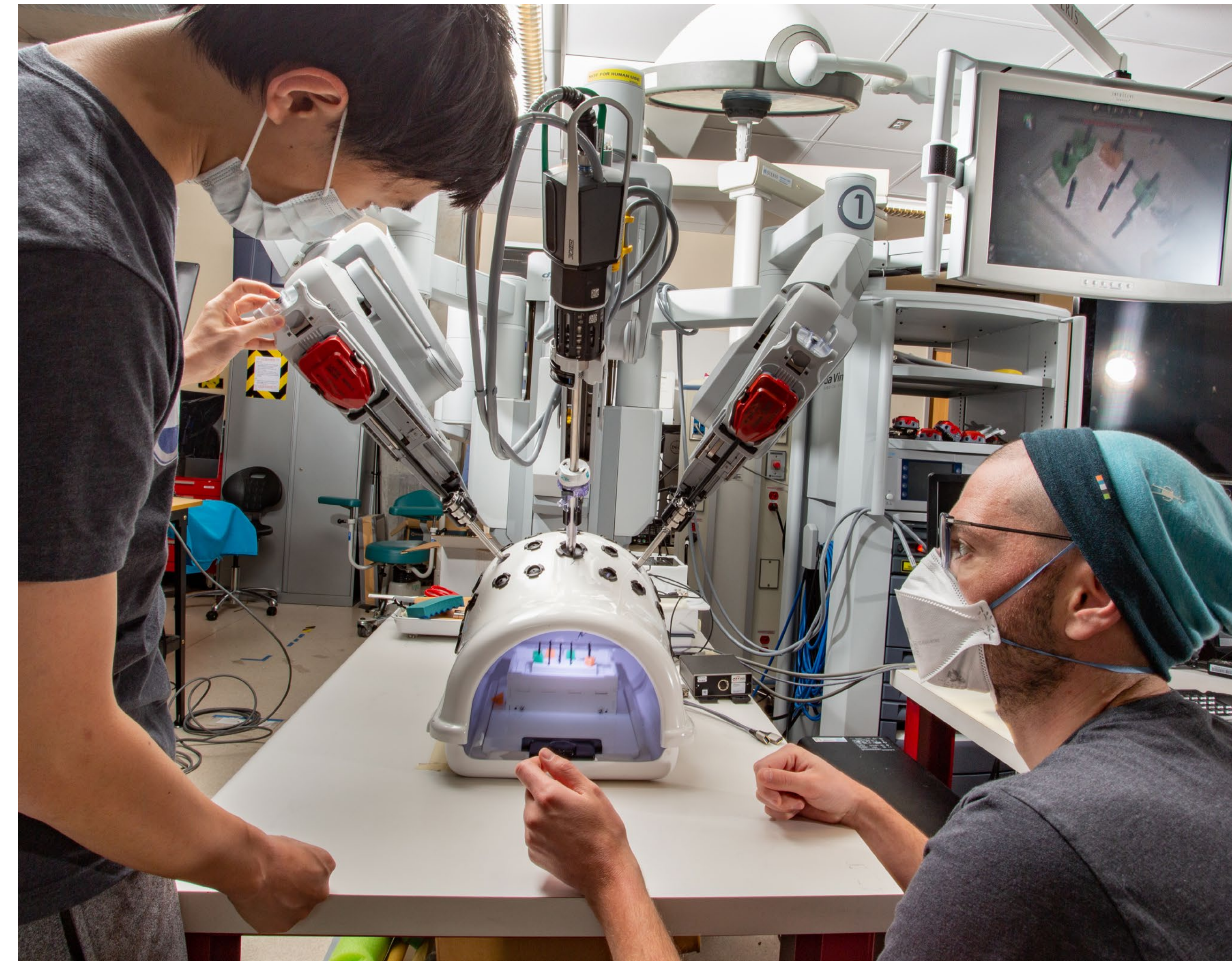
SyntheX: Scaling Up Learning-based X-ray Image Analysis Through In Silico Experiments

Mixed Reality for Surgical Guidance

Real time modeling and registration of 3D surgical field from surgical microscope data

Virtual Reality Simulator for Temporal Bone Surgery

Mathias Unberath
Assistant Professor
Department of Computer Science
arcade.cs.jhu.edu
mathias@jhu.edu



Computer Aided Medical Procedures

Nassir Navab

The CAMP laboratory develops next generation solutions for computer-assisted interventions. The complexity of surgical environments requires us to study, model, and monitor surgical workflow, enabling the development of novel patient and process specific imaging and visualization methods. Due to the requirements of flexibility and reliability, CAMP researchers work on novel robotized multi-modal imaging solutions. In order to satisfy challenging usability requirements, they focus on data fusion and its interactive representation within augmented reality environments. The lab creates a bridge across the Atlantic Ocean by hosting researchers working at both of Dr. Navab's groups at JHU in Baltimore and at TUM in Germany.

ACCOMPLISHMENTS

Fotouhi J., Song T., Mehrfard A., Taylor G., Wang Q., Xian F., Martin-Gomez A., Fuerst B., Armand M., Unberath M., Navab N., "Reflective-AR Display: An Interaction Methodology for Virtual-Real Alignment in Medical Robotics," *IEEE Robotics and Automation Letters* (RA-L) and International Conference on Robotics and Automation (*ICRA*) 2020.

Fotouhi J., Unberath M., Song T., Gu W., Johnson A., Osgood G., Armand M., Navab N., "Interactive Flying Frustums (IFFs): Spatially Aware Surgical Data Visualization," *International Journal of Computer Assisted Radiology and Surgery*. 2019 Jun 1;14(6):913-22.

Fotouhi J., Unberath M., Song T., Hajek J., Lee S.C., Bier B., Maier A., Osgood G., Armand M., Navab N., "Co-Localized Augmented Human and X-ray Observers in Collaborative Surgical Ecosystem," *International Journal of Computer Assisted Radiology and Surgery*. 2019 Sep 1;14(9):1553-63.

Koutenaei B.A., Fotouhi J., Alambeigi F., Wilson E., Guler O., Oetgen M., Cleary K., Navab N., "Radiation-Free methods for Navigated Screw Placement in Slipped Capital Femoral Epiphysis Surgery," *International Journal of Computer Assisted Radiology and Surgery*. 2019 Dec 1;14(12):2199-210.

Unberath M., Zaech J.N., Gao C., Bier B., Goldmann F., Lee S.C., Fotouhi J., Taylor R., Armand M., Navab N., "Enabling Machine Learning in X-ray-Based Procedures via Realistic Simulation of Image Formation," *International Journal of Computer Assisted Radiology and Surgery*. 2019 Sep 1;14(9):1517-28."

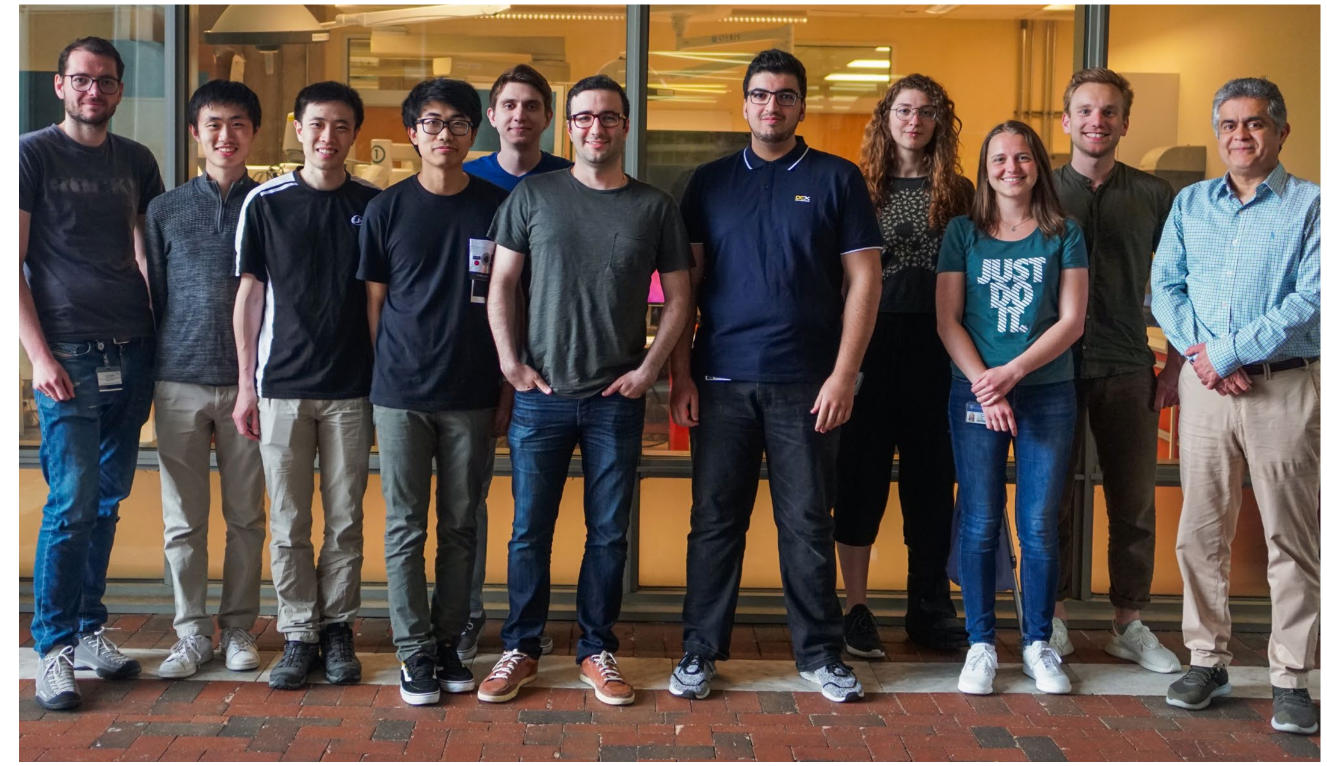
CURRENT PROJECTS

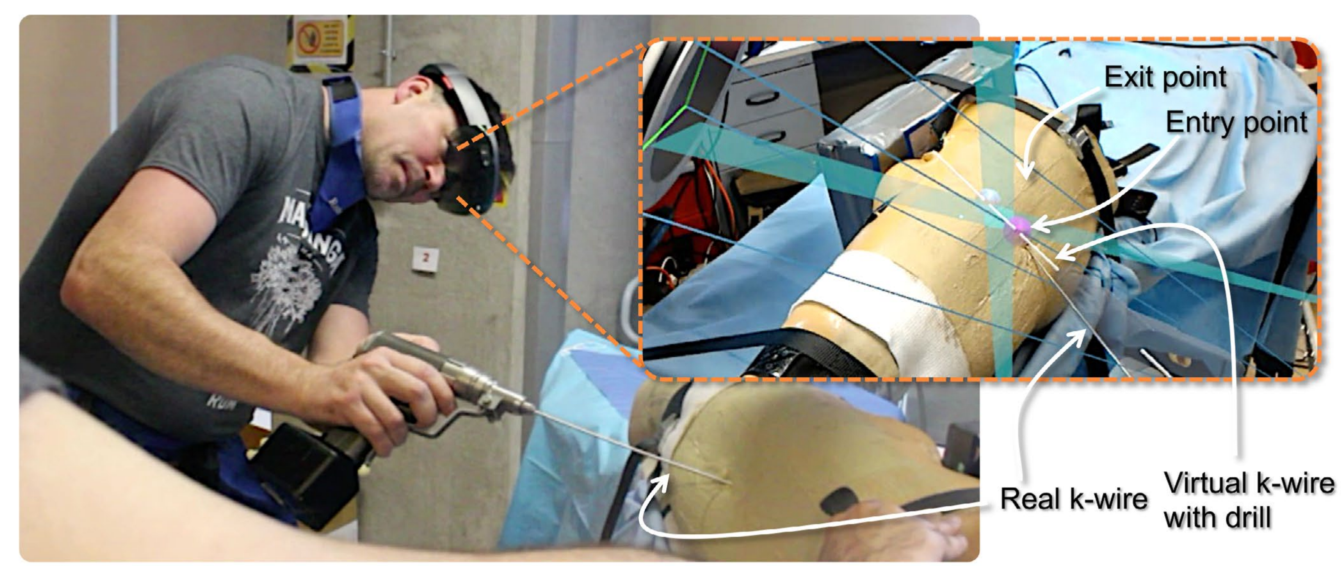
Interactive Flying Frustums

Augmented Mirrors

iOCT-Guided Robot-Assisted Sub Retinal Injection

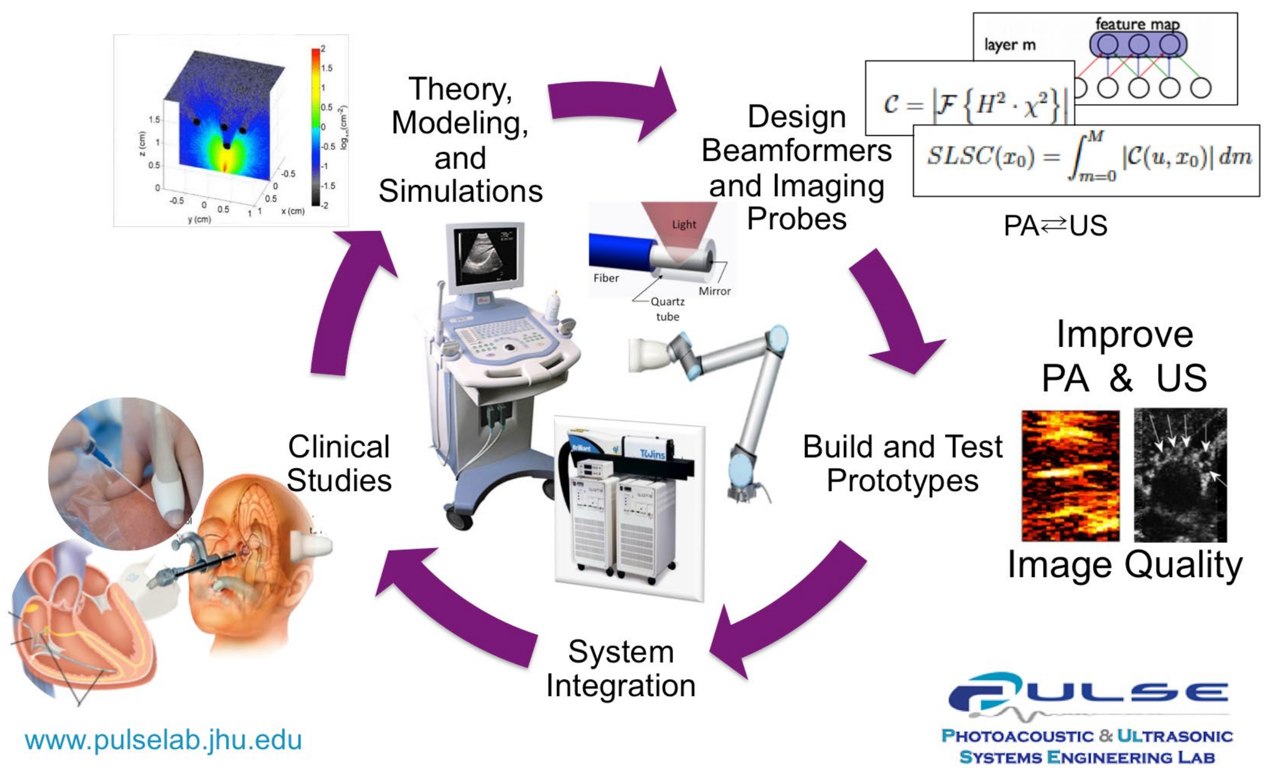
Nassir Navab
Adjunct Professor
Laboratory for Computational Sensing and Robotics
camp.lcsr.jhu.edu
nnavab1@jhu.edu





Photoacoustic & Ultrasonic Systems Engineering

Muyinatu Bell



The PULSE Lab integrates light, sound, and robots to develop innovative biomedical imaging systems that simultaneously address unmet clinical needs and improve patient care. The PULSE Lab's emphasis is diagnostic and surgical ultrasound and photoacoustic technologies, with applications in neurosurgery, cancer detection and treatment, and women's health. PULSE Lab technologies are designed to benefit patients through research-related clinical translation opportunities.

ACCOMPLISHMENTS

Prof. Bell Appointed the John C. Malone Assistant Professor

Alycen Wiacek Named 2022 Siebel Scholar

Reese Dunne Wins 2021 Goldwater Scholarship

Photoacoustic-Guided Surgery Review is a Top 10 Download in *Biomedical Optics Express*

Prof. Bell Wins SPIE Early Career Achievement Award 2021

Gubbi, Bell, "Deep Learning-Based Photoacoustic Visual Servoing: Using Outputs from Raw Sensor Data as Inputs to a Robot Controller," *IEEE International Conference on Robotics and Automation* (*ICRA*), Xi'an, China, May 30–June 5, 2021

A. Wiacek, K.C. Wang, H. Wu, M.A.L. Bell, "Photoacoustic-Guided Laparoscopic and Open Hysterectomy Procedures Demonstrated with Human Cadavers," *IEEE Transactions on Medical Imaging*, 40(12):3279–3292, 2021

D. Hyun, A. Wiacek, S. Goudarzi, S. Rothlübbers, A. Asif, K. Eickel, Y.C. Eldar, J. Huang, M. Mischi, H. Rivaz, D. Sinden, R.J.G. van Sloun, H. Strohm, M.A.L. Bell, "Deep Learning for Ultrasound Image Formation: CUBDL Evaluation Framework & Open Datasets," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 68(12):3466-3483, 2021

E. González, C. Graham, M.A.L. Bell, "Acoustic Frequency-Based Approach for Identification of Photoacoustic Surgical Biomarkers," *Frontiers in Photonics*, 2, 2021

X. Huang, M.A.L. Bell, K. Ding, "Deep Learning for Ultrasound Beamforming in Flexible Array Transducer," *IEEE Transactions on Medical Imaging*, 40(11): 3178-3189, 2021

E. González, A. Jain A, M.A.L. Bell, "Combined Ultrasound and Photoacoustic Image Guidance of Spinal Pedicle Cannulation Demonstrated with Intact Ex-vivo Specimens," *IEEE Transactions on Biomedical Engineering*, 68(8):2479-2489, 2021

Tian L, Hunt B, Bell MAL, Yi J, Smith JT, Ochoa M, Intes X, Durr NJ, "Deep Learning in Biomedical Optics," *Lasers in Surgery and Medicine*, 53: 748-775, 2021

Wiacek A, Bell MAL, "Photoacoustic-Guided Surgery from Head to Toe," *Biomedical Optics Express*, 12(4), 2079-2117, 2021 [Invited Review]

Huang J, Wiacek A,Kempski KM, Palmer T, Izzi J, Beck S, Bell MAL, "Empirical Assessment of Laser Safety for Photoacoustic-Guided Liver Surgeries," *Biomedical Optics Express*, 12, 1205-1216, 2021

Stevens KR, Masters KS, Imoukhuede PI, Haynes KA, Setton LA, Cosgriff-Hernandez E, Bell MAL, Rangamani P, Sakiyama-Elbert SE, Finley SD, Willits RK, Koppes AN, Chesler NC, Christman KL, Allen JB, Wong JY, El-Samad H, Desai TA, Eniola-Adefeso O, "Fund Black scientists," *Cell*, 184(3):561-565, 2021

OTHER INFO

Our highly interdisciplinary research agenda integrates optics, acoustics, robotics, signal processing, and medical device design, to significantly improve the standard of patient care. We develop theories, models, and simulations to investigate advanced beamforming techniques for improving ultrasonic and photoacoustic image quality. In parallel, we design and build novel light delivery systems for photoacoustic imaging and incorporate medical robots to improve operator maneuverability and enable standardized procedures for more personalized medicine. Our technologies are then interfaced with patients treated at the Johns Hopkins Hospital to facilitate clinical translation of the devices, methods, and tools developed in our lab. These techniques and technologies have applications in neurosurgical navigation, women's health, coronary artery disease, early cancer detection, and improved cancer treatment.

CURRENT PROJECTS

Deep Learning Approach to Photoacoustic Visual Servoing

Photoacoustic-Guided Hysterectomy

Deep Learning COVID-19 Features in Lung Ultrasound Images

Muyinatu Bell
John C. Malone Assistant Professor
Department of Electrical and Computer Engineering
pulselab.jhu.edu
mledijubell@jhu.edu

Intuitive Computing

Chien-Ming Huang

The Intuitive Computing Laboratory seeks to innovate interactive robot systems to provide personalized physical, social, and behavioral support to people with various characteristics and needs. The interdisciplinary IC lab designs, builds, and studies intuitive interaction capabilities of robotic systems to improve their utilities and user experience. Lab researchers draw on principles and techniques from human-computer interaction, robotics, and machine learning in their research and are interested in using their systems to address problems in health care, education, and collaborative manufacturing.

Human-Robot Teaming

Robots that are capable of working alongside humans hold great promise in augmenting people's capabilities and productivity. To enable seamless human-robot teamwork, we aim to (a) understand how people work together as a team in achieving common goals, (2) develop interactive robot systems that can work cooperatively with people as informed by our understanding of human teamwork, and (3) deploy and evaluate how cooperative robots may increase task performance and enhance user experience. We have focused on (i) deciphering human behavioral cues (e.g., eye gaze) for recognizing task intent (RSS'15, HRI'16), (ii) synthesizing intuitive robot behaviors to facilitate collaborative activities (HRI'14), and (iii) developing interfaces and methods for people to re-skill robots to perform custom tasks (IUI'19).

Socially Assistive Robotics

Socially assistive robots (SAR) provide assistance through social, as opposed to physical, interactions and have potential to provide cognitive, behavioral, and therapeutic support for people with diverse characteristics and needs. Our research has explored (1) how SARs can positively impact children's learning by providing timely cognitive (HRI'17) and meta-cognitive (HRI'18) support and (2) how SARs can aid in behavioral intervention for children with Autism Spectrum Disorders (ASD) (*Science Robotics*).

ACCOMPLISHMENTS

Ajaykumar, G. and Huang, C.-M (2020), "User Needs and Design Opportunities in EndUser Robot Programming," *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction Late-Breaking Report* (HRI'20 LBR).

Wang, Y., Ajaykumar, G., and Huang, C.-M. (2020), "See What I See: Enabling User-Centric Robotic Assistance Using First-Person Demonstrations," *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction* (HRI'20).

CURRENT PROJECTS

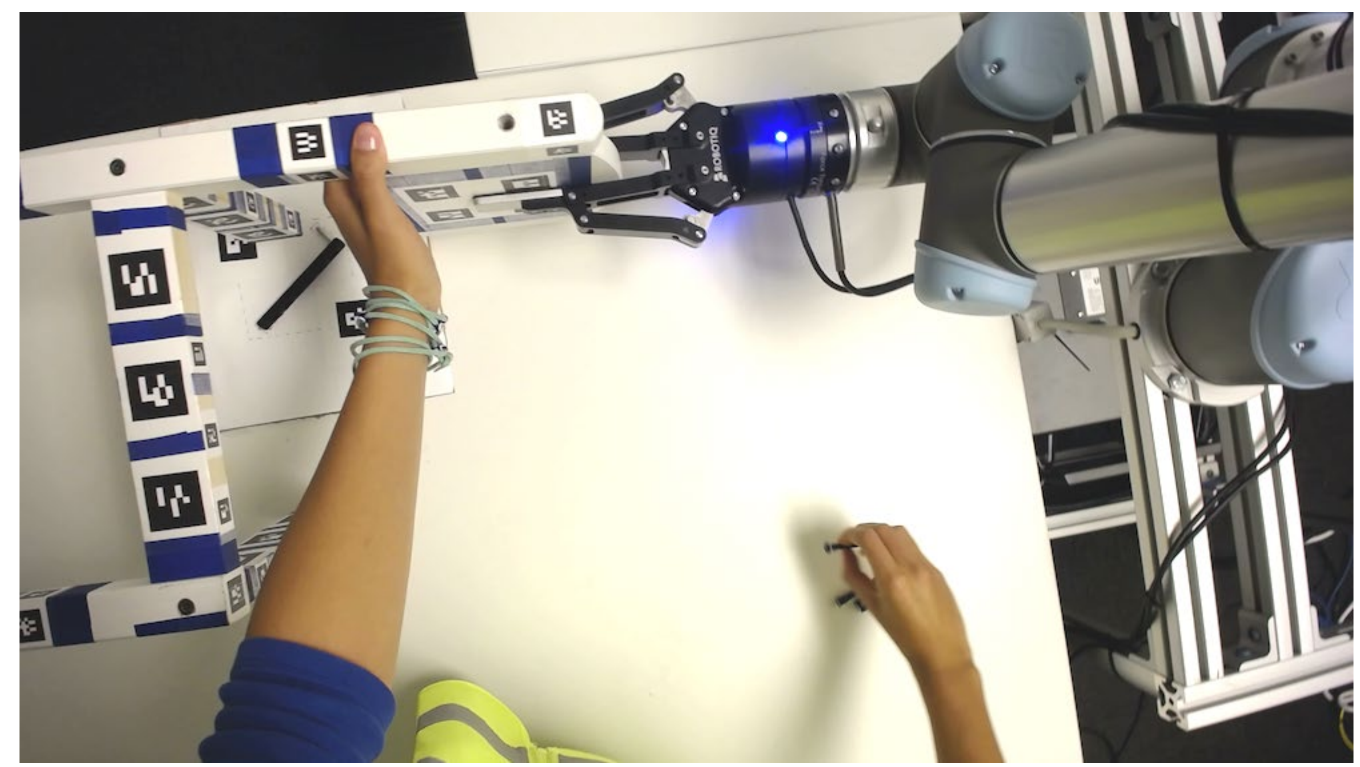
Human-Robot Co-Navigation

Human-Machine Teaming for Medical Decision Making

Accessible Robot Programming

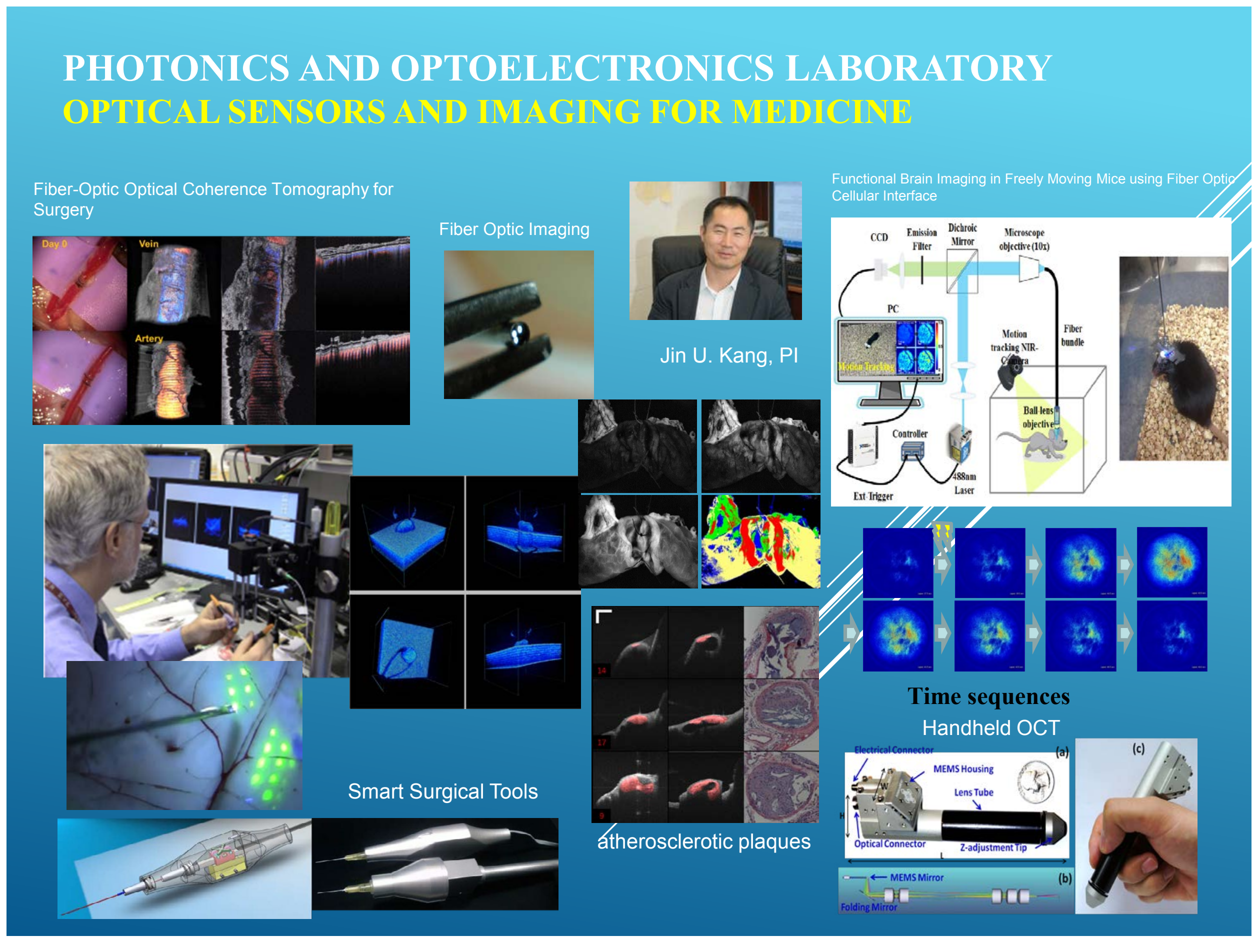
Socially Assistive Robots for Behavioral Interventions

Chien-Ming Huang
Assistant Professor
Department of Computer Science
intuitivecomputing.jhu.edu
chienming.huang@jhu.edu



Photonics and Optoelectronics

Jin U. Kang



The Photonics and Optoelectronics (PO) Laboratory conducts experimental and theoretical investigations in the area of photonics and optoelectronics with an emphasis on developing novel fiber optic imaging and sensor systems, novel fiber laser systems, and ultrafast fiber optic and optoelectronic devices. These developments have applications in the areas of medicine, communications, and the space sciences.

The PO lab is currently developing optical coherence tomography (OCT) techniques for medical imaging and sensing; these systems have enabled the development of microsurgical and robotic tools that allow safer, more precise surgical outcomes. The lab was the first to develop and demonstrate real-time 4D OCT systems that allow real-time 3D video monitoring of surgical sites during operations.

The lab works closely with the NASA, FDA, ARL, NIST, NRL as well as local industries and other research groups in and outside the Johns Hopkins University.

ACCOMPLISHMENTS AND PUBLICATIONS

Dr. Kang recently launched a JHU Fast Forward startup company, LIV (Live Imaging Vision) Med Tech Inc., to commercialize OCT image-guided robotic tools.

2022

Saeidi, H., Opfermann, J. D., Kam, M., Wei, S., Leonard, S., Hsieh, M. H., ... & Krieger, A. (2022). Autonomous robotic laparoscopic surgery for intestinal anastomosis. Science Robotics, 7(62), eabj2908.

2021

Pak, R., Kang, J., Boctor, E., & Kang, J. U. (2021). Optimization of near-infrared fluorescence voltage-sensitive dye imaging for neuronal activity monitoring in the rodent brain. *Frontiers in Neuroscience*, 1436.

Wei, S., & Kang, J. U. (2021). Stabilizing the phase of swept-source optical coherence tomography by a wrapped Gaussian mixture model. *Optics Letters*, *46*(12), 2932-2935.

Lee, S., & Kang, J. U. (2021). CNN-based CP-OCT sensor integrated with a subretinal injector for retinal boundary tracking and injection guidance. *Journal of Biomedical Optics*, *26*(6), 068001.

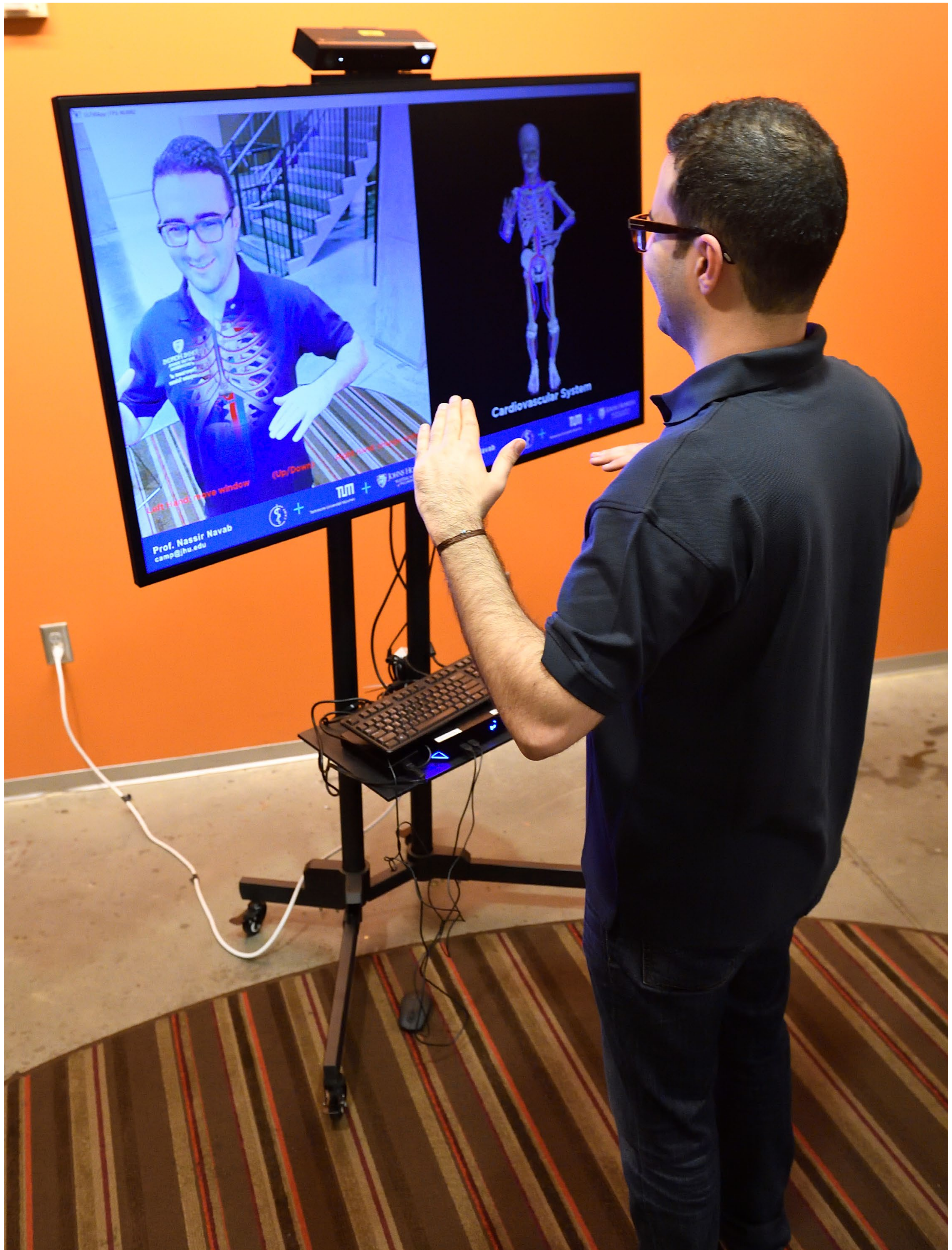
2020

Wei, S., & Kang, J. U. (2020). Optical flow optical coherence tomography for determining accurate velocity fields. *Optics Express*, *28*(17), 25502-25527.

Guo, S., Sarfaraz, N. R., Gensheimer, W. G., Krieger, A., & Kang, J. U. (2020). Demonstration of Optical Coherence Tomography Guided Big Bubble Technique for Deep Anterior Lamellar Keratoplasty (DALK). *Sensors*, *20*(2), 428.

Lee S., Wei S., Guo S., Kim J., Kim B., Kim G., Kang J.U.(2020). Selective retina therapy monitoring by speckle variance optical coherence tomography for dosimetry control. *Journal of Biomedical Optics*, *25*(2), 026001.

Jin U. Kang
Professor
Department of Electrical and Computer Engineering
engineering.jhu.edu/biophotonics
jkang@jhu.edu



AREAS OF IMPACT

COLOR KEY FOR RESEARCH AREAS

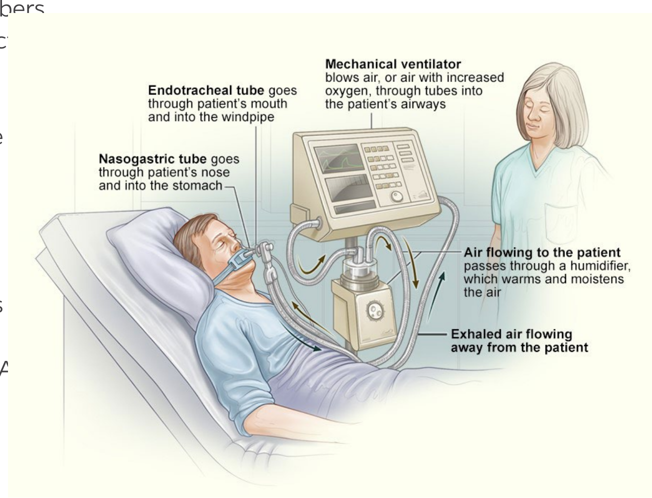
- BIOROBOTICS
- HUMAN MACHINE COLLABORATIVE SYSTEMS
- MEDICAL ROBOTS AND COMPUTER INTEGRATED INTERVENTIONAL SYSTEMS
- MODELING, DYNAMICS, NAVIGATION, AND CONTROL
- PERCEPTION AND COGNITIVE SYSTEMS
- ROBOTICS IN EXTREME ENVIRONMENTS

Assured Autonomous Control of ICU Ventilators

PIs: Anton Dahbura and Russell Taylor

Medical Robots and Computer Integrated Interventional Systems

Accomplishment: The group, consisting of faculty members in LCSR, IAA, MCEH, and the SoM, have defined a projec that uses digital twins, reinforcement learning, and trust monitors to architect an autonomous mechanical ventilator control system with an extremely high degree trustworthiness for use in ICUs.



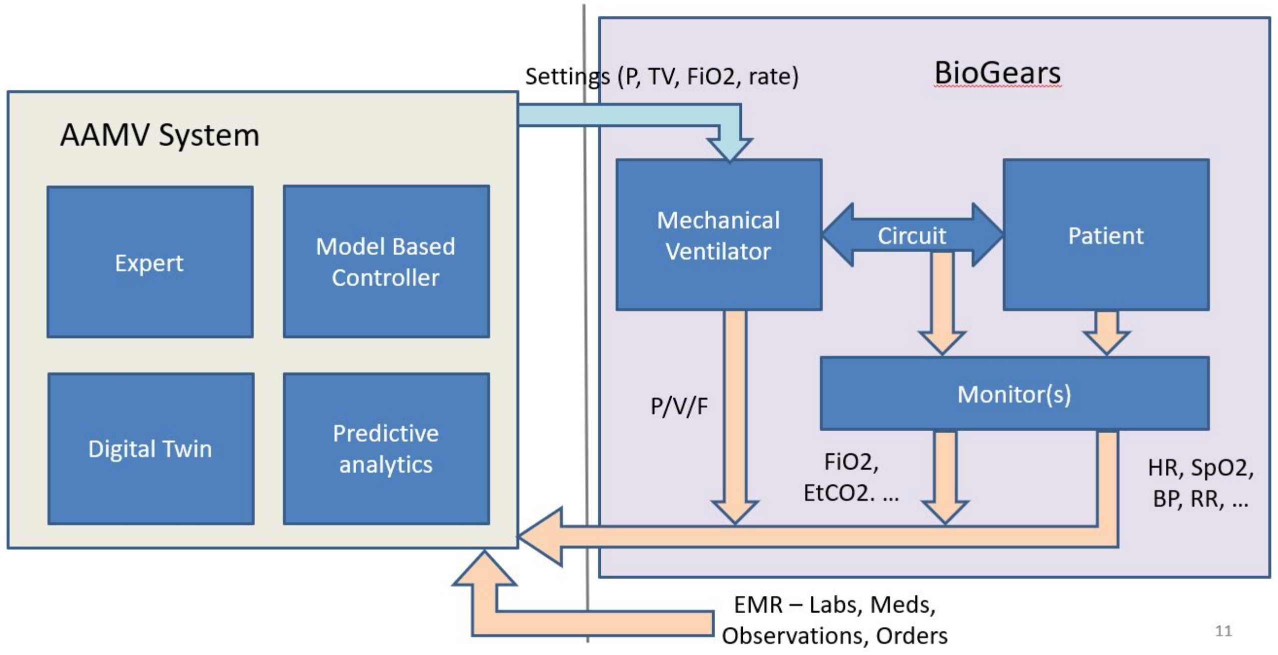
Status: Initial phases

Funding: JHU internal funding

Key Personnel: Russ Taylor, CS, LCSR and MCEH; James Fackler, SoM and MCEH; Jules Bergmann, SoM; Kimia Ghobadi, AMS, CaSE and MCEH; Anton Dahbura, CS, IAA LCSR and MCEH; Khalid Halba, CS; Antwan Clark, AMS

Patents and Disclosures: In process

For More Information: AntonDahbura@jhu.edu



Autonomous Robotic Soft Tissue Surgery

PI: Axel Krieger

Medical Robots and Computer Integrated Interventional Systems

Status: Increased autonomy has transformed fields such as manufacturing and aviation by drastically increasing efficiency and reducing failure rates. While pre-operative planning and automation have also improved the outcomes of surgical procedures with rigid anatomy, practical considerations have hindered progress in soft-tissue surgery mainly because of unpredictable shape changes, tissue deformations, and motions limiting the use of pre-operative planning. Our research aims to overcome these challenges through robotic tools, improved surgical sensing, and robot control strategies.

Robotic Tools—We are developing specialized robotic tools that eliminate the need for complex motions and reduce tissue deformations and tissue changes by incorporating the maneuverability and complex actuations in the tool tip.

Improved Surgical Sensing—We are investigating novel surgical imaging techniques to enable high-fidelity quantitative perception and tracking of soft tissue targets that are in constant motion and deformation due to patient breathing, peristalsis, and tool interactions.

Robot Control Strategies—We are developing novel robot control methods that increase the autonomy of surgical robots and effectively enhance the surgeon's capabilities.

Key Personnel: Xiaolong Liu, Onder Erin, Michael Kam, Jiawei Ge, Seda Aslan, Lydia Zoghbi, Justin Opfermann, Trevor Schwehr, Qiyuan Wu, Axel Krieger

For More Information: imerse.lcsr.jhu.edu

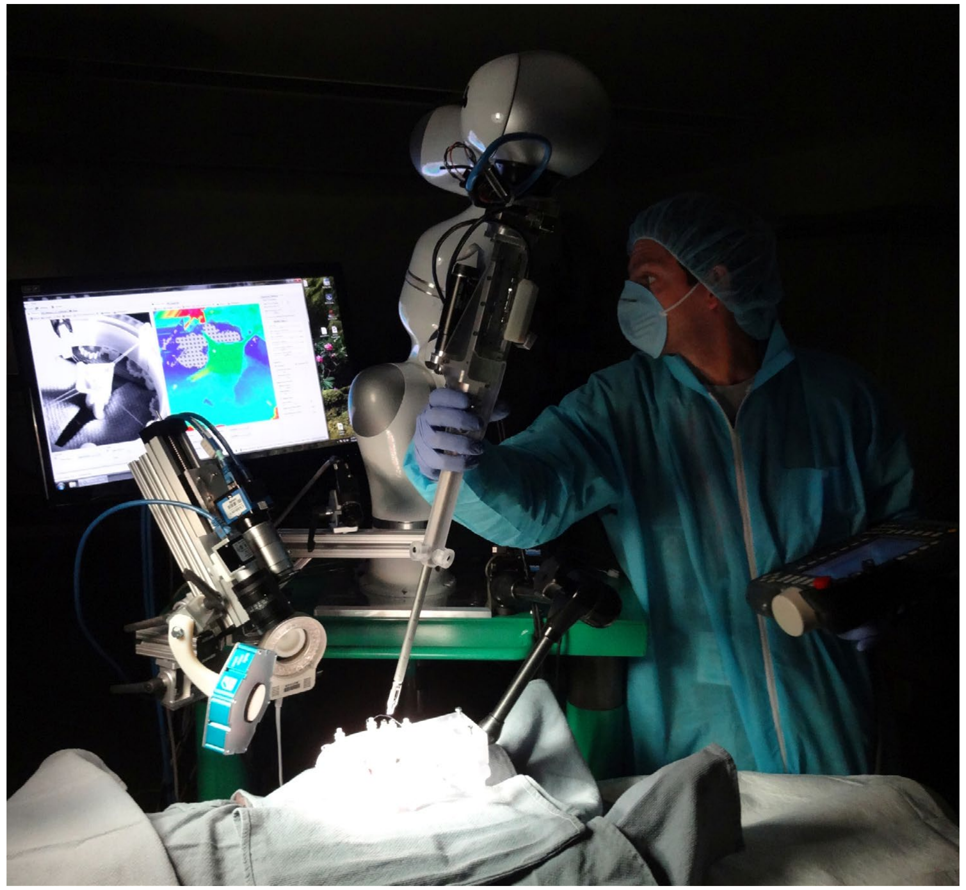


Image Guided Interventions and Planning

PI: Axel Krieger

Medical Robots and Computer Integrated Interventional Systems

Status: Diagnostic imaging has dramatically improved over the years to the point at which small tumors and defects now are often detectable before they affect a patient's health. However, in many cases imaging during intervention and surgery is limited to basic color cameras, resulting in missed tumors and sub-optimal surgical results. Our research focuses on improving image guidance and image display during planning, intervention, and surgery. This often requires specialized robots to work alongside the imaging technique and novel displays.

Magnetic Resonance Imaging (MRI) Guided Prostate Interventions—MRI has higher sensitivity in detecting prostate cancer compared to ultrasound, the current standard for image guided prostate biopsy. Prostate biopsy inside an MRI magnet, however, is difficult to perform due to material and space restrictions. We were the first to develop and deploy in the clinic an integrated robotic system for trans-rectal robotic prostate biopsy under MRI guidance.

3D Printing and Displays—Congenital heart defects (CHD) are the most common congenital defects, often require open-heart surgery, and are among the leading causes of death in newborns. Despite the rich 3D information provided by cardiac imaging, the display of this information is still largely constrained to viewing multiple contiguous 2D slices of the 3D scan, which is sub-optimal. We are developing novel methods to visualize CHD using 3D printing and 3D displays for education, procedural planning, and patient specific implant designs.

Key Personnel: Xiaolong Liu, Onder Erin, Michael Kam, Jiawei Ge, Seda Aslan, Lydia Zoghbi, Justin Opfermann, Trevor Schwehr, Qiyuan Wu, Axel Krieger

For More Information: imerse.lcsr.jhu.edu

Autonomous Robotic Ultrasound

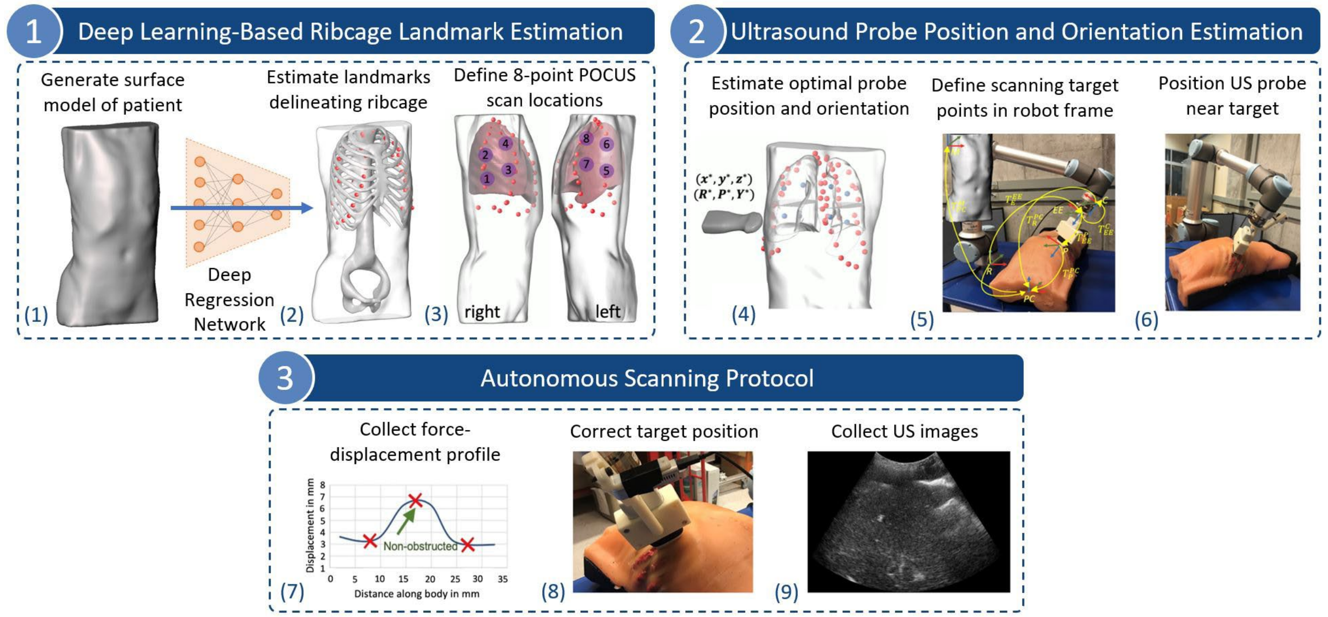
PI: Axel Krieger

Medical Robots and Computer Integrated Interventional Systems

Status: Unintentional injury or trauma is among the leading causes of death in the United States with up to 29% of pre-hospital trauma deaths attributed to uncontrolled hemorrhages. Our research focuses on developing a fully autonomous robotic system for performing ultrasound scans and analysis en route to the hospital for earlier trauma diagnosis and faster initialization of lifesaving care. We develop image-based novel techniques enabling improved ultrasound imaging of chest organs, as well as design robotic systems for therapeutic intervention, such as reboa insertion.

Key Personnel: Xiaolong Liu, Onder Erin, Michael Kam, Jiawei Ge, Seda Aslan, Lydia Zoghbi, Justin Opfermann, Trevor Schwehr, Qiyuan Wu, Axel Krieger

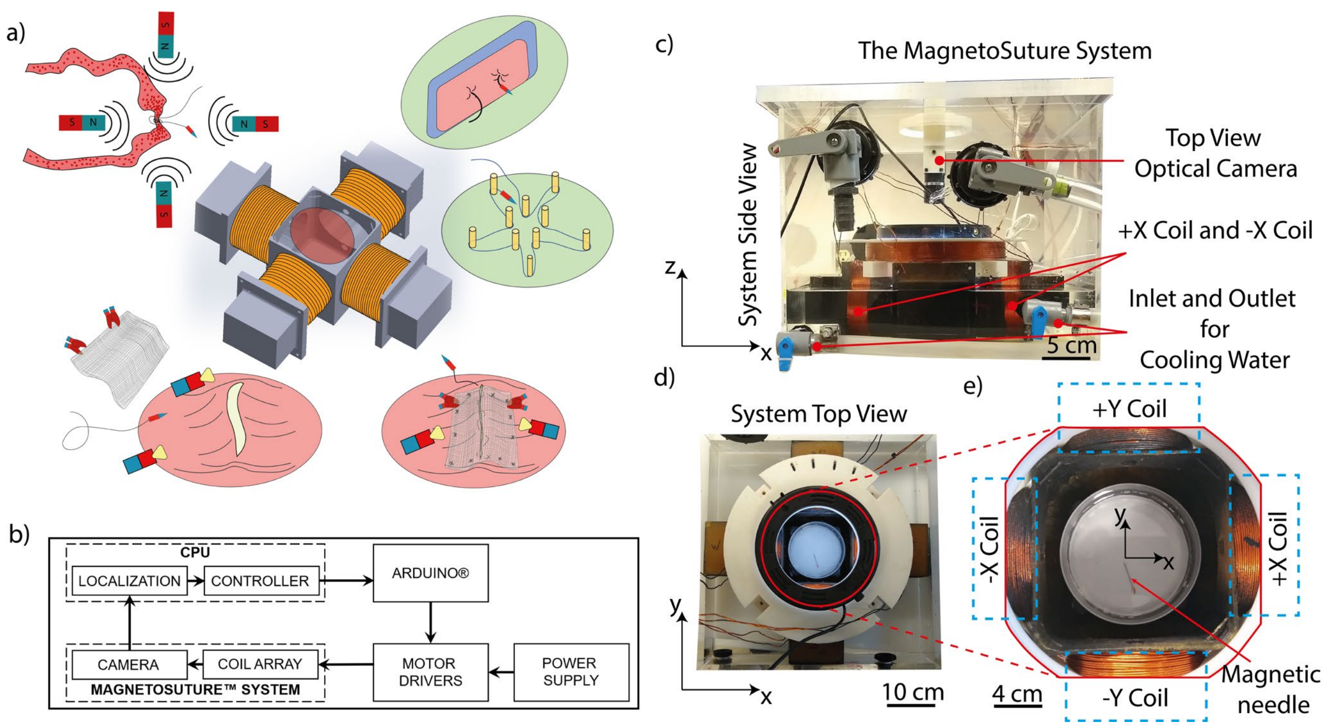
For More Information: imerse.lcsr.jhu.edu



Magnetically Actuated Microrobots

PI: Axel Krieger

Medical Robots and Computer Integrated Interventional Systems



Status: Magnetic fields are capable of exerting forces and torques onto remote magnetic surgical tools located inside a patient's body, allowing to obviate the physical connections with the standard robotic arm structures. This unique feature of magnetic robots provides a promising pathway to miniaturize surgical tools for the next generation of surgical systems, all while minimizing tissue trauma and enhancing patient comfort. As a target medical application, we focus on magnetic suturing, where a magnetic needle is guided to penetrate various tissue layers to complete a suturing task. Our ongoing research focuses on enhancing the penetration capability and system-level intelligence by merging digital and physical intelligence.

Key Personnel: Xiaolong Liu, Onder Erin, Michael Kam, Jiawei Ge, Seda Aslan, Lydia Zoghbi, Justin Opfermann, Trevor Schwehr, Qiyuan Wu, Axel Krieger

For More Information: imerse.lcsr.jhu.edu

Cardiac Planning and Patient Specific Implant Design

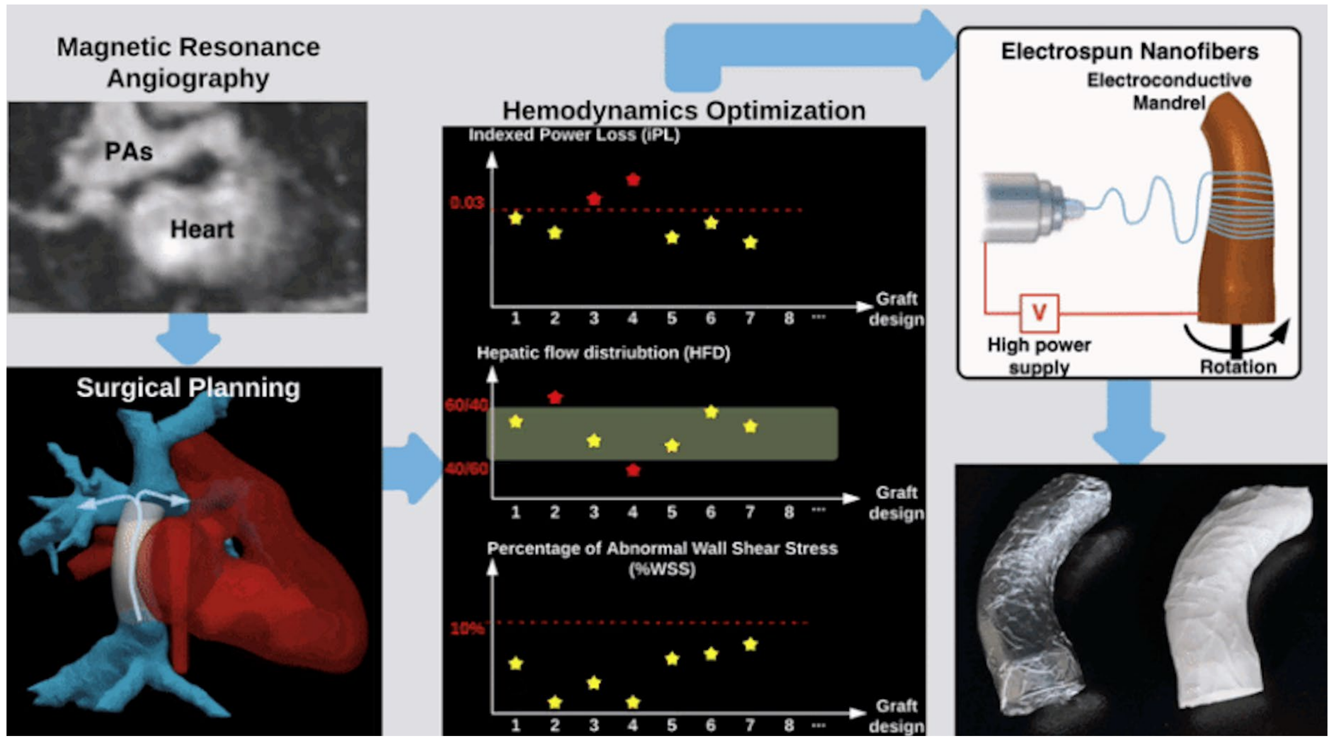
PI: Axel Krieger

Medical Robots and Computer Integrated Interventional Systems

Status: We use surgical planning tools to design and manufacture patient-specific tissue-engineered vascular grafts for pediatric patients who suffer from congenital heart defects. Computational fluid dynamics simulations are used to obtain the hemodynamics in the native anatomy and to design grafts that will optimize the hemodynamics by repairing the defect in the native geometry. Our surgical planning software Corfix allows doctors to visualize the anatomy in 3D, diagnose the defected region, and create optimized patient specific grafts. The simulation results of the designed grafts are also visualized in Corfix to assess the hemodynamic performance before the surgery.

Key Personnel: Xiaolong Liu, Onder Erin, Michael Kam, Jiawei Ge, Seda Aslan, Lydia Zoghbi, Justin Opfermann, Trevor Schwehr, Qiyuan Wu, Axel Krieger

For More Information: imerse.lcsr.jhu.edu



The Terradynamics of Biological Movement in Complex Terrain

PI: Chen Li

- Bio-Robotics
- Modeling, Dynamics, Navigation, and Control
- Robotics in Extreme Environments

Published 15 journal papers; submitted three journal papers and four conference papers

Discovered general principles of legged locomotor transitions in complex 3D terrain across model systems of beam, gap, bump, and vertical pillar traversal

Developed strategies for robots to modulate their locomotor mode transitions and improve large obstacle traversal and self-righting performance.

Developed a legged robot (OmniRoach) capable of traversing multiple types of large obstacles and self-righting

Developed a minimalistic, stochastic dynamics model and its simulation to understand dynamics of cluttered obstacle traversal

Developed continuous 3D reconstruction methods for studying motion of limbless animals

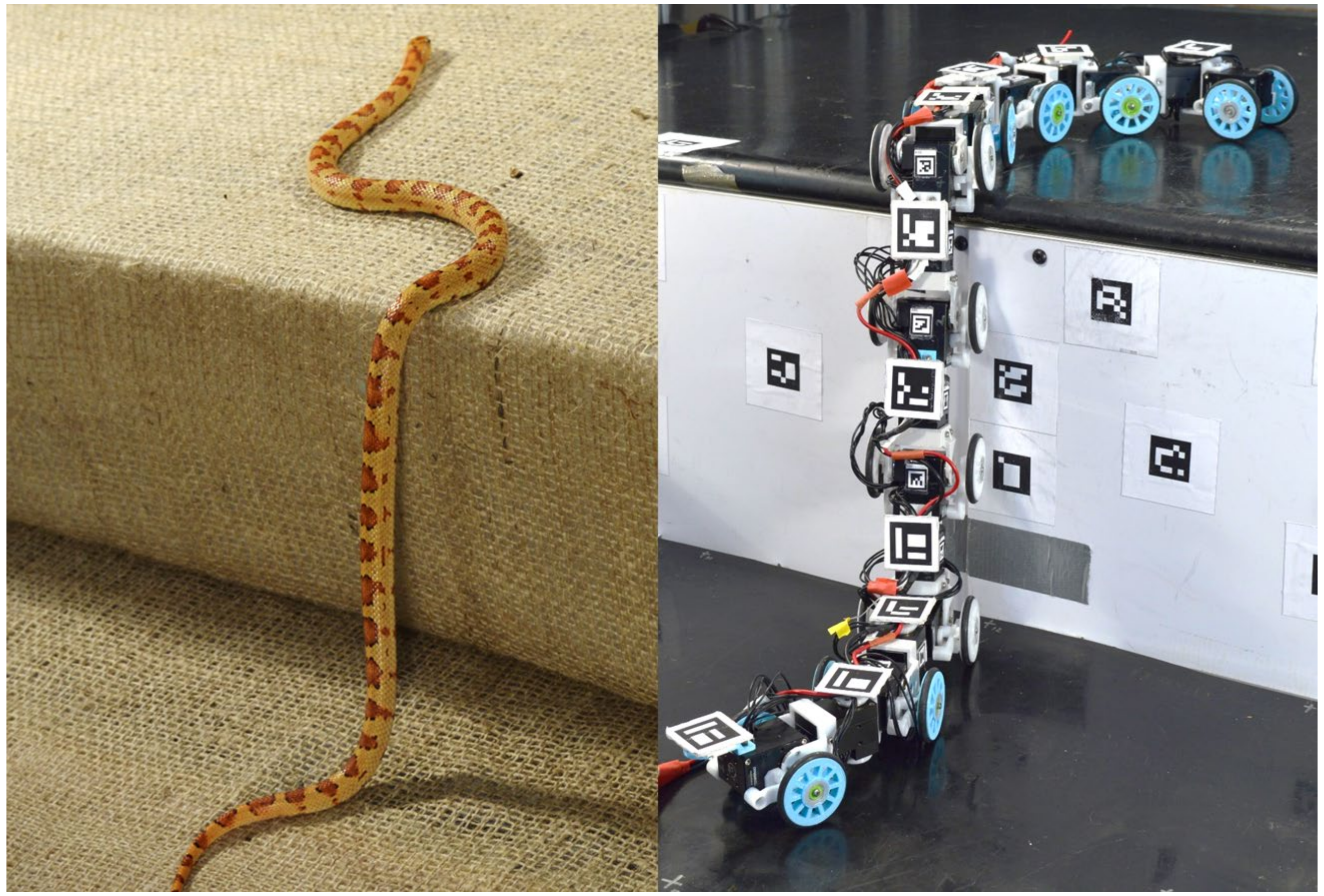
Revealed the benefits of body compliance for snakes traversing large vertical obstacles using a robotic model

Discovered that snakes use lateral and vertical bending to traverse uneven terrain

Status: Ongoing

Funding: Burroughs Welcome Fund Career Award at the Scientific Interface

Key Personnel: Qiyuan Fu, Divya Ramesh, Chen Li



Neuromechanics of Legged Locomotion on Energy Landscapes of Complex Terrains

PI: Chen Li

- Bio-Robotics
- Modeling, Dynamics, Navigation, and Control
- Robotics in Extreme Environments

Published six journal papers; submitted three journal papers and four conference papers

Discovered that cockroaches actively adjust body and appendages to facilitate traversal of large obstacles

Created a novel terrain treadmill to study animal locomotion through large obstacles at large spatiotemporal scales

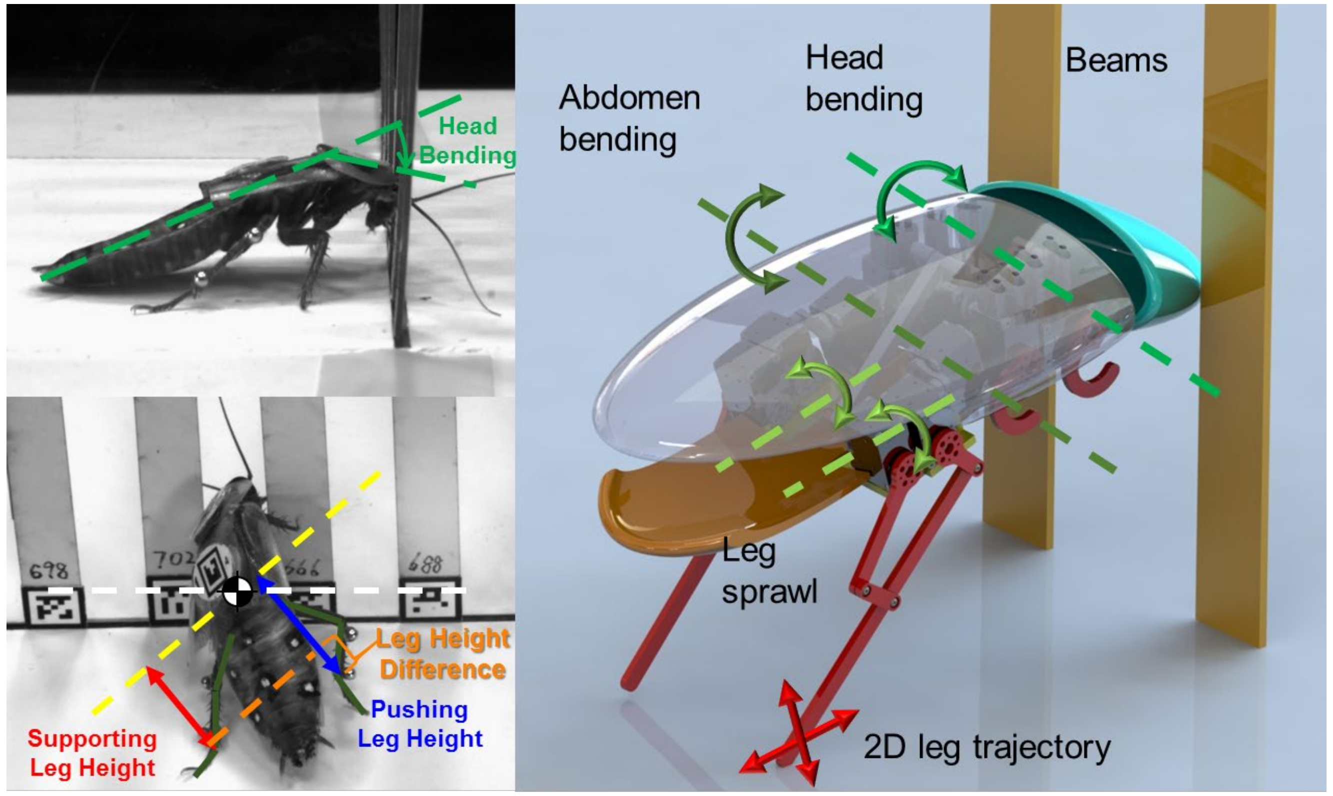
Developed robotic physical models capable of 3D body bending, contact force sensing, and feedback control to study how legged insects and limbless snakes traverse obstacles in complex 3D terrain

Demonstrated that legged and limbless robots using environmental force sensing can traverse cluttered obstacles with interaction

Status: Ongoing

Funding: Arnold and Mabel Beckman Foundation

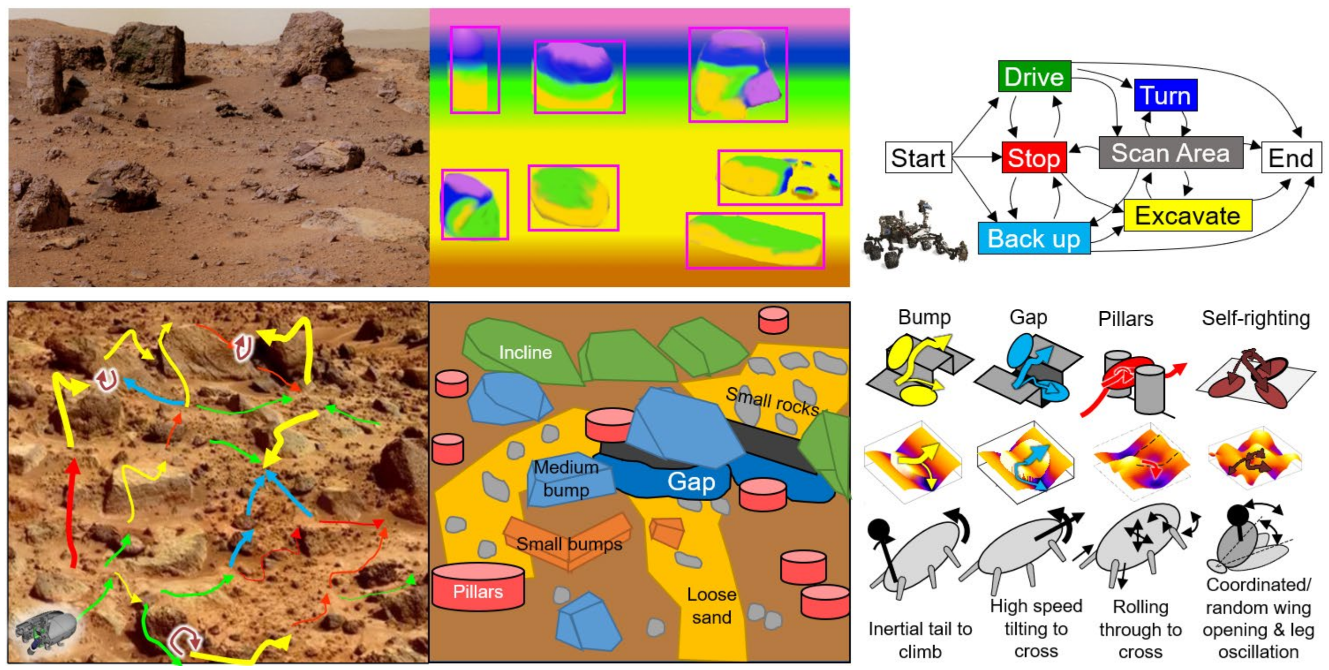
Key Personnel: Yaqing Wang, Ratan Othayoth, Divya Ramesh, Qiyuan Fu, Qihan Xuan, Chen Li



Simulation of Multi-Legged Robot Locomotor Transitions to Traverse Rocky Martian Terrain

PI: Chen Li

- Bio-Robotics
- Modeling, Dynamics, Navigation, and Control
- Robotics in Extreme Environments



Published a journal paper

Developed simulation-based experiments to study obstacles traversal and locomotor transitions performance in rocky, extraterrestrial environments.

Simulated strategies for a multi-modal legged robot to achieve desired locomotor transitions via physical interaction with environment

Status: Ongoing

Funding: Space@Hopkins

Key Personnel: Qihan Xuan, Eugene Lin, Chen Li, Kevin Lewis

Human-Robot Co-Navigation

PI: Chien-Ming Huang

- Human-Machine Collaborative Systems

Key Personnel: Kapil Katyall-Jeng Wang

Funding: JHU IAA seed fund

Accomplishments and Status: As we build and transition into the autonomous future, it is critical to place people at the center of our disruptive innovations. Therefore, this research aims to design, develop, and evaluate human-centered assured autonomy; we focus this project particularly on socially aware robot navigation in human environments. While abundant research has explored techniques for enabling mobile robots to navigate in human environments, most efforts have been on avoiding collisions with dynamic (e.g., people) and static (e.g., environmental constraints) obstacles and have treated pedestrians as individual entities neglecting social grouping and their interactions. However, to maximize utility and ensure a wide acceptance and trust of intelligent mobile robots in assisting human work, we need to probe beyond simple obstacle avoidance and consider the more complicated aspects of social norms and interpersonal interactions in naturalistic human environments. This research particularly addresses the aspects of technology and ecosystem in assured autonomy.

Through three research thrusts, the team will investigate (1) dynamic social groups in human environments; (2) socially aware robot navigation; and (3) the longer-term effects of deploying mobile robots in naturalistic human environments. The successful integration of autonomous mobile robots into human spaces has the opportunity to revolutionize the future of human work. Our collaborative efforts in human-centered assured autonomy will help guide this revolution and contribute to the creation of a productive human-robot ecosystem. This project expects to generate tangible products, including (a) scholarly publications; (b) an open-source software testbed for simulating human social groups and navigation; (c) a physical testbed for studying social navigation; (d) a field deployment of human-robot co-navigation; and (e) guidelines for designing autonomous mobile robots and smart environments for near-term effective human-robot interaction.

Human-Machine Teaming for Medical Decision Making

PI: Chien-Ming Huang

Human-Machine Collaborative Systems

Key Personnel: Suchi Saria

Funding: NSF

Accomplishments and Status: Algorithmic advances in artificial intelligence are transforming human work in diverse areas including transportation, finance, national security, and medicine. Machine intelligence presents opportunities to increase human work productivity and the quality of jobs through augmenting human capabilities. Effective teaming between humans and intelligent machines similar to effective human-human teamwork has the potential to yield significant near-term gains. This project explores the challenges of human-machine teaming in medical decision making. Health care is one of the most difficult challenges that the United States is facing. The U.S. spends $3 trillion dollars in health care each year, while medical error is the third leading cause of death. Human-machine cognitive teaming creates a new model of patient care in which providers team with intelligent cognitive assistants to enhance quality of care under time pressure, taxing workloads, and uncertainties in medical conditions. This project explores the potential for effective human-machine teaming to mitigate such challenging problems in health care.

Specifically, this project seeks to understand (1) whether human-machine teaming can benefit medical decision making and decision making in other related high stakes domains; (2) the guiding principles for designing effective human-machine teams; (3) barriers that currently exist for building such teams; (4) novel solutions needed to address barriers in order to develop highly performant teams; and (5) the economic and societal impacts of the planned approach for human-machine teaming. Understanding effective human-machine teaming, including the broader implications in the workspace and in human workflows, will contribute to positive transformation of human work. In particular, it is anticipated that the outcomes of this project will result in improvements in hospital utilization and reduction of medical errors. The project integrates multiple disciplinary perspectives, including computer science, medical expertise, health policy, and decision making. The impacts of the research will extend to multiple hospitals in the Baltimore region. Furthermore, the project will engage local high school students in summer research experiences, and the outcomes of the research will be integrated into undergraduate curricula.

Find out more: nsf.gov/awardsearch/showAward?AWD_ID=1840088&HistoricalAwards=false

Accessible Robot Programming

PI: Chien-Ming Huang

Human-Machine Collaborative Systems

Perception and Cognitive Systems

Funding: JHU internal funding

Accomplishments and Status: The goal of accessible robot programming is to empower everyday people who may not have technical training or backgrounds to be able to author robotic assistance to meet their needs and contextual constraints.

Collaborative robots are envisioned to assist people in an increasing range of domains, from manufacturing to home care; however, due to the variable nature of these fields, such robots will inevitably face unfamiliar situations and unforeseen task requirements, and must be able to interact with users who possess diverse skill sets, backgrounds, and needs. Presently, robust, autonomous solutions for appropriately handling these vast possibilities and uncertainties are unattainable. End-user robot programming offers an alternative approach that lets end users provide task specifications and author robot skills to meet their own specific contextual constraints and custom task needs. Contextual information—such as task objects, environmental landmarks, and user preferences—is essential in realizing desirable, flexible, and reliable robot programs. However, most robot programming systems at present do not afford intuitive ways of specifying contextual information. This project explores new approaches to providing a robot system with contextual information about the user, task, and environment, and how these methods can help improve task performance and user experience.

Socially Assistive Robots for Behavioral Interventions

PI: Chien-Ming Huang

Human-Machine Collaborative Systems

Perception and Cognitive Systems

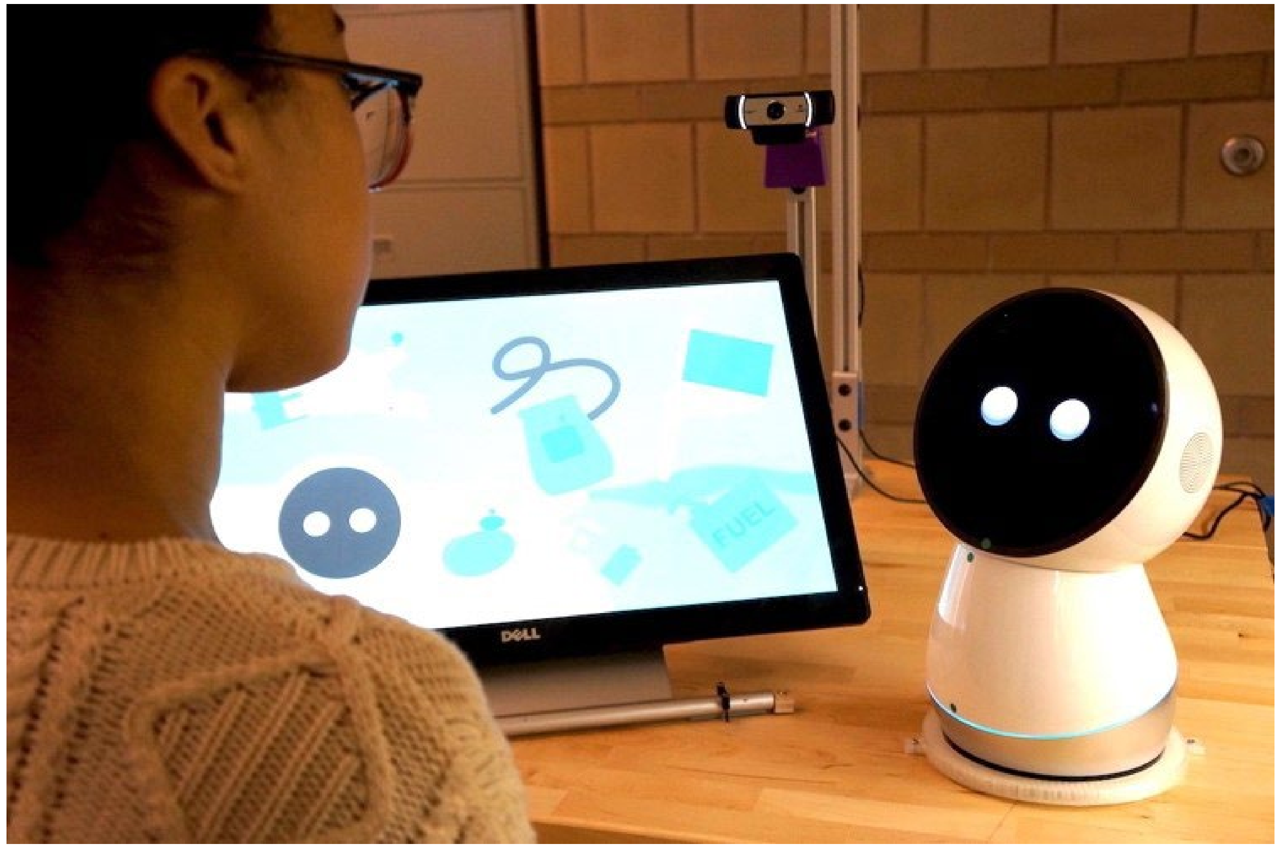
Socially Assistive Robots (SAR) provide assistance through social, as opposed to physical, interactions. These robots have potential to provide cognitive, behavioral, and therapeutic support for people with diverse characteristics and needs. Our research has explored (1) how SARs can positively impact children's learning by providing timely cognitive (HRI'17) and meta-cognitive (HRI'18) support and (2) how SARs can aid in behavioral intervention for children with Autism Spectrum Disorders (ASD) (*Science Robotics*).

Selected Publications: Scassellati, B., Boccanfuso, L.*, Huang, C.-M.*, Mademtzi, M.*, Qin, M.*, Salomons, N.*, Ventola, P., and Shic, F. (2018). "Improving Social Skills in Children with ASD Using a Long-Term, In-Home Social Robot." *Science Robotics*. *equal contribution, science.org/doi/pdf/10.1126/scirobotics.aat7544.

Ramachandran, A., Huang, C.-M., Gartland, E. and Scassellati, B. (2018). "Thinking Aloud with a Tutoring Robot to Enhance Learning." In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction* (HRI'18), dl.acm.org/doi/10.1145/3171221.3171250.

Ramachandran, A., Huang, C.-M. and Scassellati, B. (2017). Give Me a Break! Personalized Timing Strategies to Promote Learning in Robot-Child Tutoring. In Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction (HRI'17), dl.acm.org/doi/10.1145/2909824.3020209.

Sponsor: This line of research is currently funded by the Malone Center for Engineering in Healthcare.

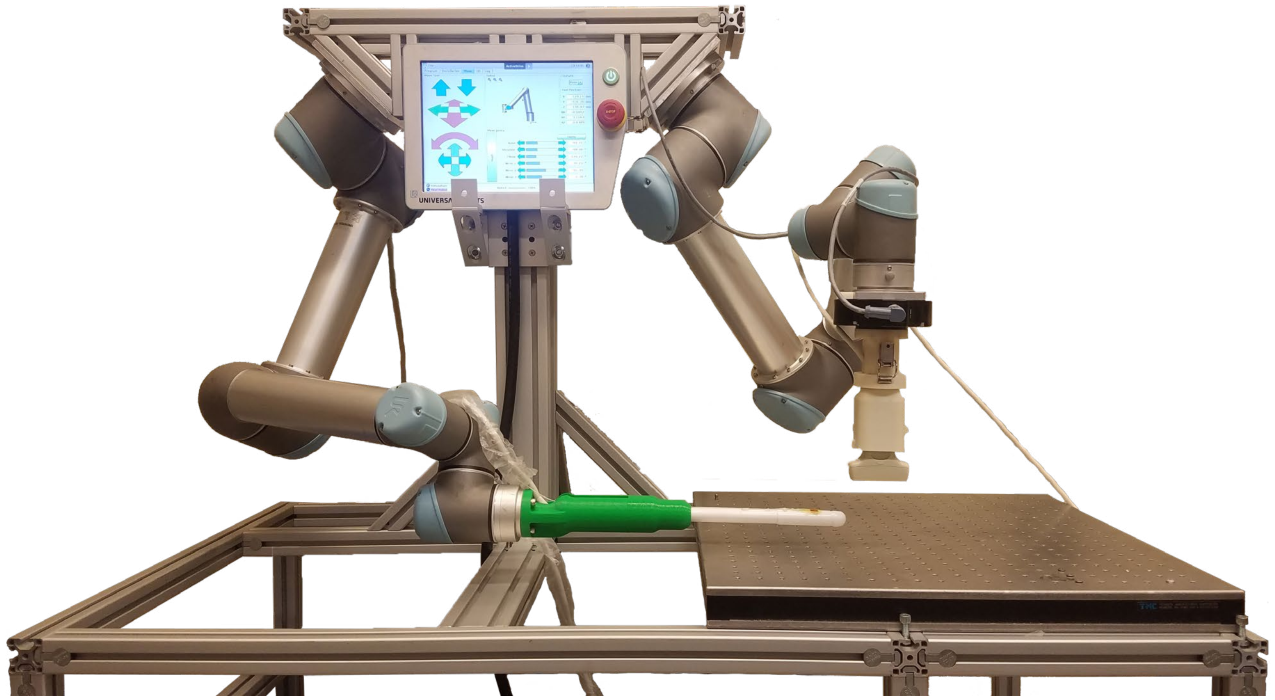


Co-Robotic Ultrasound Tomography Framework for In Vivo Prostate Imaging

PI: Emad Boctor

Human-Machine Collaborative Systems

Medical Robots and Computer Integrated Interventional Systems



Accomplishment: Our goal is to develop a co-robotic framework for controlled ultrasound slice acquisition of the in vivo prostate. Slices are to be acquired via transmission ultrasound between robotically held, collinear Tx and Rx probes flanking the anatomy to be imaged: one located abdominally and one located transrectally for prostate imaging. These slices will then serve as input to a limited-angle tomography reconstruction algorithm previously developed by our lab to generate a quantitative measurement of the prostate's acoustic properties.

Status: The robot control framework that keeps the abdominal probe held against the skin and aligned with the hand-maneuvered transrectal (TRUS) probe has been developed. Over the coming weeks, our team will use the robotic system to acquire ultrasound slices of a pelvic phantom that has varying speed of sound within the prostate and perform tomographic reconstruction to measure the system's overall effectiveness in tissue characterization.

Key Personnel: Kevin Gilboy, Yixuan Wu, Russell Taylor, Emad Boctor

The Language of Surgery Project

PI: Gregory Hager

Human-Machine Collaborative Systems

Medical Robots and Computer Integrated Inverventional Systems

Status: The Language of Surgery Project is focused upon methods to represent and model complex surgical performance data to support applications that improve surgical care and education. Since its inception in 2006, the Language of Surgery Project has fostered several interdisciplinary collaborations across the university, including with various divisions in the School of Medicine and departments in the Whiting School of Engineering.

Funding: Current and past sources supporting research in this project include:

NSF (CPS 0931805, CDI 0941362, IIS 0534359; PI: Gregory Hager);

NIH (1R01DE025265 and 5R21DE022656; PI: Masaru Ishii);

Intuitive Surgical, Inc. (PIs: Gregory Hager, Austin Reiter);

Wilmer Eye Institute Pooled Professors Fund (PI: Shameema Sikder);

Johns Hopkins Science of Learning Institute (Co-PIs: Gregory Hager and Anand Malpani); and

NIH (1R01EY033065, (PI: Shameema Sikder and Swaroop Vedula)

Key Personnel: *Whiting School of Engineering*: Gregory Hager; Swaroop Vedula

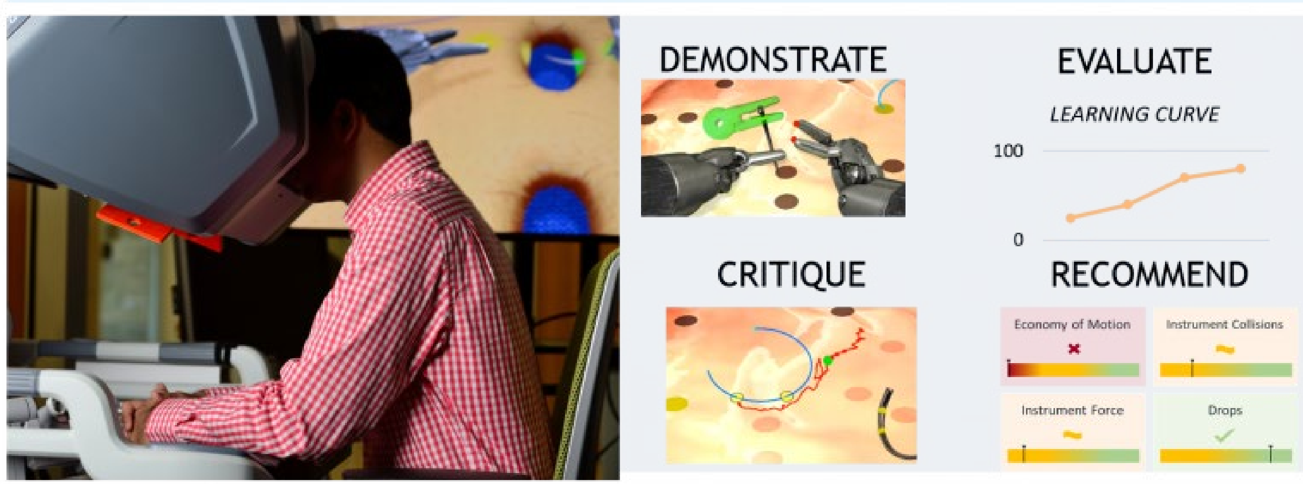
School of Medicine: Masaru Ishii; Shameema Sikder; Gina Adrales; Grace Chen

Past Collaborators: Anand Malpani; Narges Ahmidi; Sanjeev Khudanpur; Rene Vidal; David Yuh; Steve Hsiao

The core research objectives for the Language of Surgery Project enable the following applications: automated recognition of surgical context including activity; objective assessment of surgical skill in the operating room and in simulation; automated targeted feedback for individualized learning; and human machine collaboration including automated coaching in surgical robotics. The eventual outcome these applications aims to improve safety and effectiveness of surgical care, and efficiency of surgical training.

For More Information: cirl.lcsr.jhu.edu/research/language-of-surgery-update

Automated Coaching in Surgical Robotics



Dr. Malpani demonstrates a needle passing task in the da Vinci Surgical Simulator®. He works as part of the Language of Surgery team to make surgical education more effective, efficient and safe..

Machines with Imagination: Learning from Description through Synthesis and Analysis

PI: Gregory Hager

Perception and Cognitive Systems

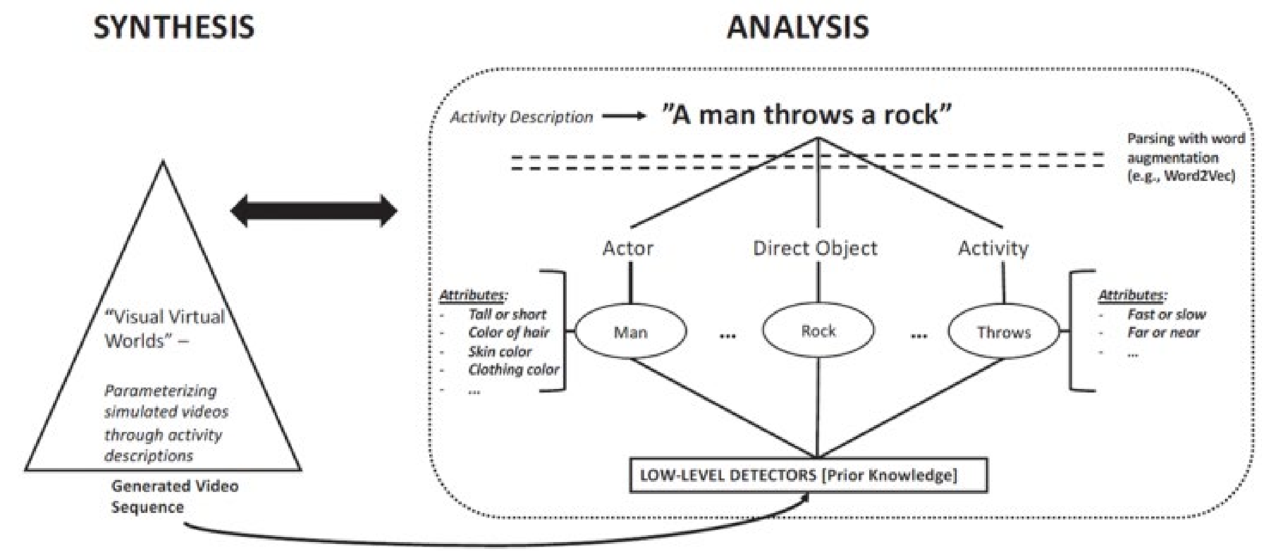


Figure 1: The proposed Analysis-by-Synthesis pipeline. Synthetic virtual world generates or "imagines" instances of activities given a semantic description. This is used to train discriminative models.

Accomplishment: The DIVA (Deep Intermodal Video Analytics) project has fostered active collaborations with other institutions in the DIVA IARPA program, as well as the wider research community, yielding a visual data synthesis system capable of generating highly structured visual data at scale as well as a strong publication record in computer vision and machine learning.

Status: Funding: Supported by the Intelligence Advanced Research Projects Activity (IARPA) via Department of Interior/Interior Business Center (DOI/IBC) contract number D17PC00342; (PIs: Gregory Hager and Alan L. Yuille)

Key Personnel: *From Computational Interaction and Robotics Laboratory*: Gregory Hager (Principal Investigator); Tae Soo Kim (PhD Student); Michael Peven (PhD Student); Jin Bai (PhD Student)

From Computational Cognition, Vision and Learning: Alan L. Yuille (Principal Investigator); Weichao Qiu (PhD Student); Yi Zhang (PhD Student); Zihao Xiao (PhD Student)

Past Collaborators: Austin Reiter; Haider Ali; Chi Li; Balazs Vagvolgyi; Chenxu Luo

The "DIVA" (Deep Intermodal Video Analytics) project is focused on developing an analysis-by-synthesis framework which takes advantage of state-of-the-art advancements both in graphical rendering engines and machine learning to create an intelligent system that can learn to recognize complex activities from descriptions. The core research objectives of the DIVA project span multiple disciplines in the field of computer vision and machine learning, including fine-grained activity recognition applied towards smarter video surveillance, 3D object pose estimation under severe visual conditions, and development of techniques for machine learning with data synthesis systems.

For More Information: cirl.lcsr.jhu.edu/deep-intermodal-video-analytics-diva-project

Enabling Technology for Image-Guided Robot-Assisted Sub-Retinal Injections

PI: Iulian Iordachita

Human-Machine Collaborative Systems

Medical Robots and Computer Integrated Inverventional Systems

The central goal of this project is to design, develop, and evaluate a clinically compatible surgical platform for assisting ophthalmologists in providing therapy to the subretinal domain. Efficient, safe, reproducible delivery methods would enable stem cell, nanoparticle, and gene therapies for prevalent and incompletely treated ocular diseases, including but not limited to age-related macular degeneration (AMD). To achieve our goal we will: (1) design, construct, and evaluate a clinical-grade robotic assistant to enable precise tool manipulation for enhanced targeted delivery and properly orienting cells and genetic cargo in subretinal domains, thereby increasing their chances of survival in the target area; (2) develop methods utilizing real-time intraoperative 3D OCT images to detect and track previously invisible subretinal microstructural anatomy and to design optimized trajectories for safe and controlled subretinal injections to the target considering virtual fixtures to avoid dangerous motions; and (3) develop assistive control schemes and workflow that fuse tool-tissue interactions and OCT-based visual information. Statistically significant results in vivo, in clinically realistic conditions, will demonstrate the feasibility of our approach.

Status: Finalize the robotic system development (hardware and software) and run evaluation experiments.

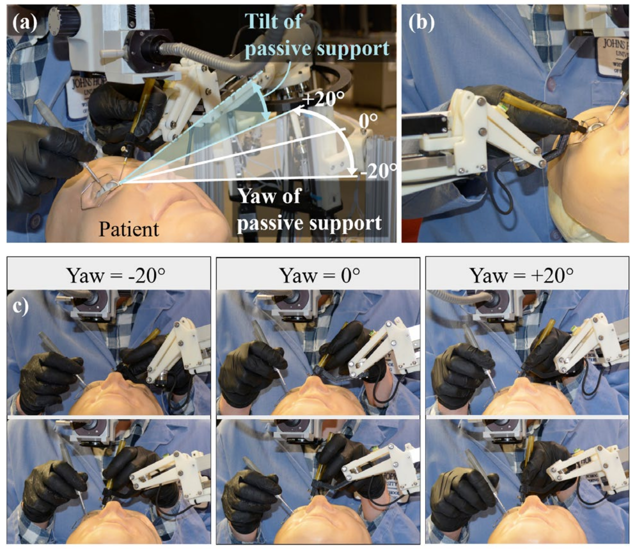
Develop real-time algorithms based on microscope-integrated intraoperative optical coherence tomography (iOCT) to provide enhanced visualization during surgery, segment retinal layers and surgical instruments, and estimate the distance between the tooltip of the surgical instruments and important retinal layers for subretinal injection.

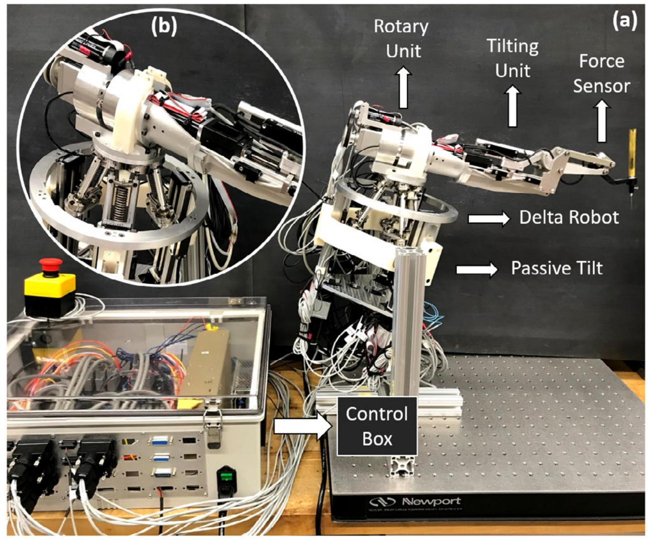
Develop robot hybrid control algorithms and workflow for fusing OCT-based position-input virtual fixture with tool-tissue interactions to assist the surgeon with sensorimotor guidance toward safe robot-assisted subretinal stem cell injections.

Funding: NIH and JHU internal funds

Key Personnel: Iordachita I., Navab, N., Gehlbach P., Taylor R., Dagnelie, G., Patel N., Alamdar, A., Ebrahimi A., Kim, J.W., Mach, K., Martin-Gomez, A., Bosch, C., Wu, J., Sommersperger, M., Roth, R.W.

For More Information: amiro.lcsr.jhu.edu/research





Adaptive Percutaneous Prostate Interventions Using Sensorized Needle

PI: Iulian Iordachita

Medical Robots and Computer Integrated Inverventional Systems

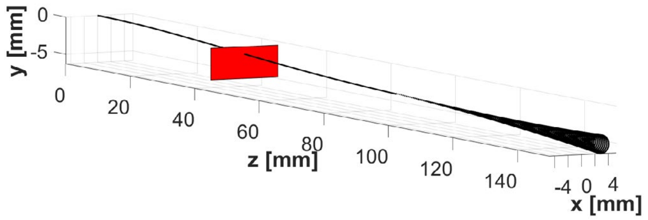


Figure 1: Bounds of the needle insertion workspace in double-layer tissue predicted up to a 150 mm insertion depth from a 90 mm reference insertion shape.

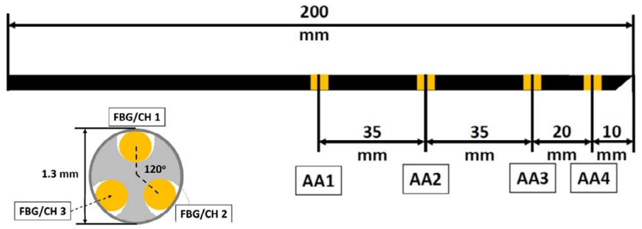


Figure 2: Four active area sensorized needle: (a) design of the needle (b) successfully constructed needle.

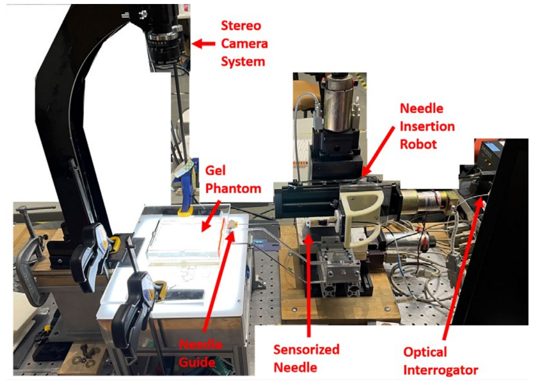


Figure 3: Needle insertion experimental setup under stereo visualization.

The central goal of this project is to overcome the issues of false-negative biopsies and suboptimal ablations caused by inaccurate needle placements in the context of prostate cancer management—a major healthcare problem in the U.S. To achieve our goal we will: (1) develop and validate an optimized sensorized needle with embedded FBG strain sensors with the objective to detect real-time deviation of the needle from the planned path within 1 mm; (2) develop and validate an adaptive needle guide with the sensorized needle to assist physicians in compensating for the needle deviation by continuously adjusting the needle guide and the bevel tip orientation during insertion to achieve a targeting accuracy of ‹ 1.6 mm in a tissue-mimicking phantom; and (3) validate adaptive needle placement using the sensorized needle in vivo under MR guidance to test the hypothesis that the adaptive needle guide with the sensorized needle improves the needle placement accuracy and meets our accuracy requirement of ‹ 1.6 mm in vivo.

Status: Develop and evaluate a new computational model for accurate needle shape-sensing and shape prediction during varying multi-layer insertions.

Prototype, calibrate, and evaluate an FBG-based sensorized needle.

Develop and evaluate a semi-automatic needle calibration platform for sensorized needles.

Funding: NIH, BWH, and JHU internal funds

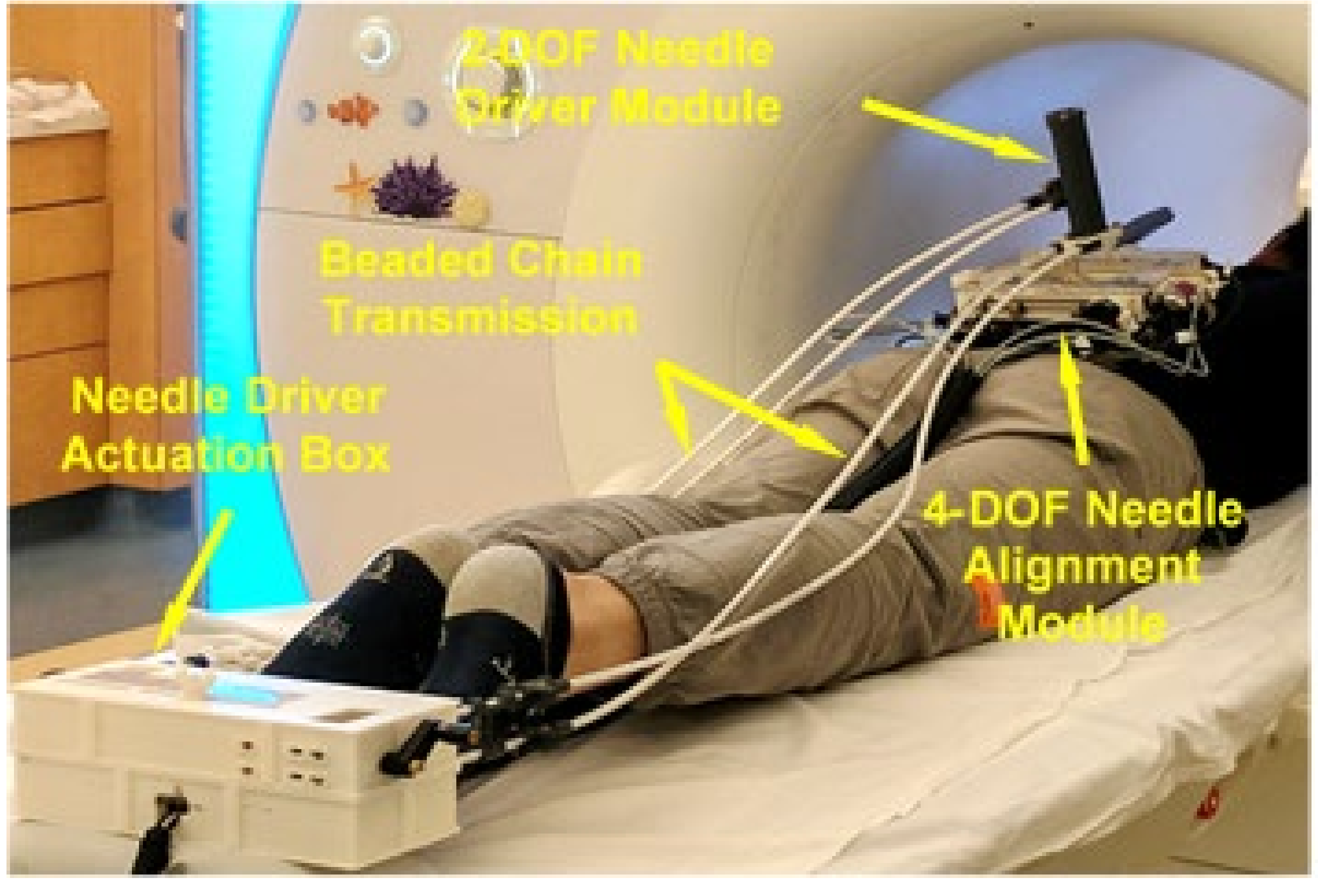
Key Personnel: (BWH) Tokuda, J., Hata, N., Lopes Da Frota Moreira, P., (JHU) Iordachita I., Kim, J.S., Lezcano, D.

For More Information: amiro.lcsr.jhu.edu/research

MRI Compatible Robot for Improved Pain Injections in Adults and Children

PI: Iulian Iordachita

Medical Robots and Computer Integrated Inverventional Systems



The goal of this Bioengineering Research Grant is to develop and evaluate a patient-mounted MRI-compatible robot that allows for highly accurate needle placement while completely eliminating radiation exposure. The robot will serve as an enabling platform technology that can be applied to any needle-based MRI-guided interventions that require a high level of precision. In this project, we will develop and evaluate a body-mounted MRI-compatible robot for perineural injections used to treat pain in adult and pediatric patients. The robot will be strapped over the area of interest and will precisely orient a needle guide for injection inside the MRI scanner bore. The robot will include active needle driving to enable real-time imaging of the path and needle tip as the needle is advanced via remote control.

Status: A 4-DOF needle positioning and orientation robot and a 2-DOF needle driver was developed and tested.

A 3D slicer-based user interface to control the robot is under development.

Two cadaver experiments to evaluate the system in OR done so far.

Funding: NIH, Children's National Health System, Sheikh Zayed Institute for Pediatric Surgical Innovation, and JHU internal funds

Key Personnel: (CNMC) Monfaredi R., Sharma K., Cleary K., (JHU) Iordachita I., Fritz J. Patel N. Li G., Wu D. Yan J. Wang Y.

For More Information: amiro.lcsr.jhu.edu/research

Anthropomorphically Driven Upper-Extremity Prosthesis

PI: Jeremy D. Brown

Bio-Robotics

Human-Machine Collaborative Systems

Accomplishment: We developed an anthropomorphically driven upper-extremity prosthesis that uses antagonist tendon actuation for bidirectional control of hand opening and closing. The device also features an integrated haptic feedback system that provides wearers with real-time information regarding the tension in the tendon actuators.

Two distinct control schemes were proposed and compared in a user study with able-bodied participants performing the Box and Blocks test. The first control scheme was designed to provide a more intuitive, human-like actuation and relaxation of the hand, while the simpler controller was designed to reduce fatigue from sustaining EMG signals. Participants performed significantly better with lower fatigue levels while using the controller designed to be intuitive as opposed to the simpler controller. In addition, task performance with both controllers was better than reported performance with standard myoelectric prostheses.

Status: Details of the device and preliminary evaluation were published in the 2020 IEEE International Symposium on Medical Robotics (doi: 10.1109/ISMR48331.2020.9312933). We are now modifying the device to improve the haptic feedback system

Funding: Hopkins internal

Key Personnel: Ethan Miller, Lorena Velásquez

Robot-Assisted Minimally Invasive Surgical Training

PI: Jeremy D. Brown

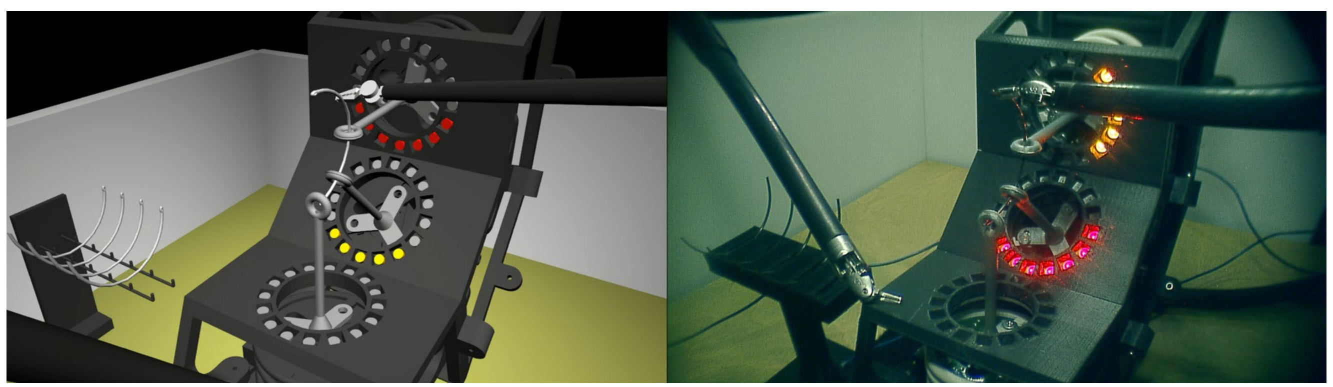
- Human-Machine Collaborative Systems
- Medical Robots and Computer Integrated Inverventional Systems

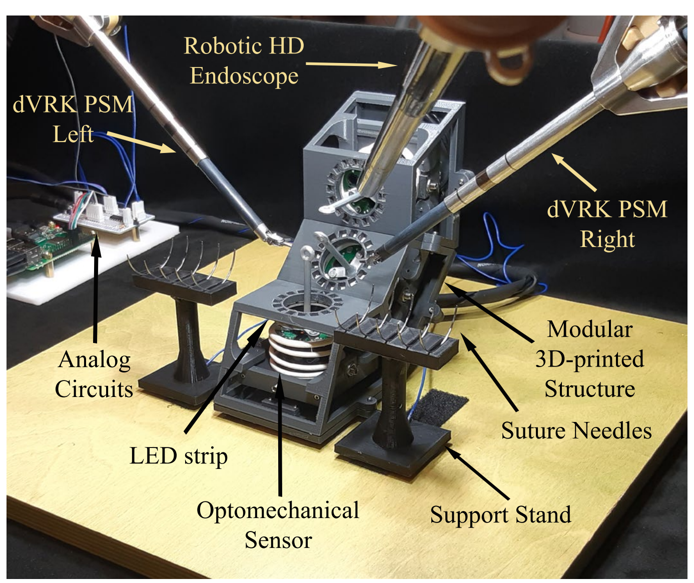
Accomplishment: We conducted a user study comparing virtual reality and inanimate approaches to robot-assisted minimally invasive surgery training. Using a custom-developed needle-driving training task with inanimate and virtual analogs, we investigated the extent to which N=18 participants improved their skill on a given platform post-training, and transferred that skill to the opposite platform. Results indicate that the two approaches are not equivalent, with more salient skill transfer after inanimate training than virtual training.

Status: The findings have been published in the *IEEE Transactions on Medical Robotics and Bionics* (doi:10.1109/TMRB.2020.2990692)

Funding: Hopkins internal

Key Personnel: Guido Caccianiga, Gabriela Cantarero

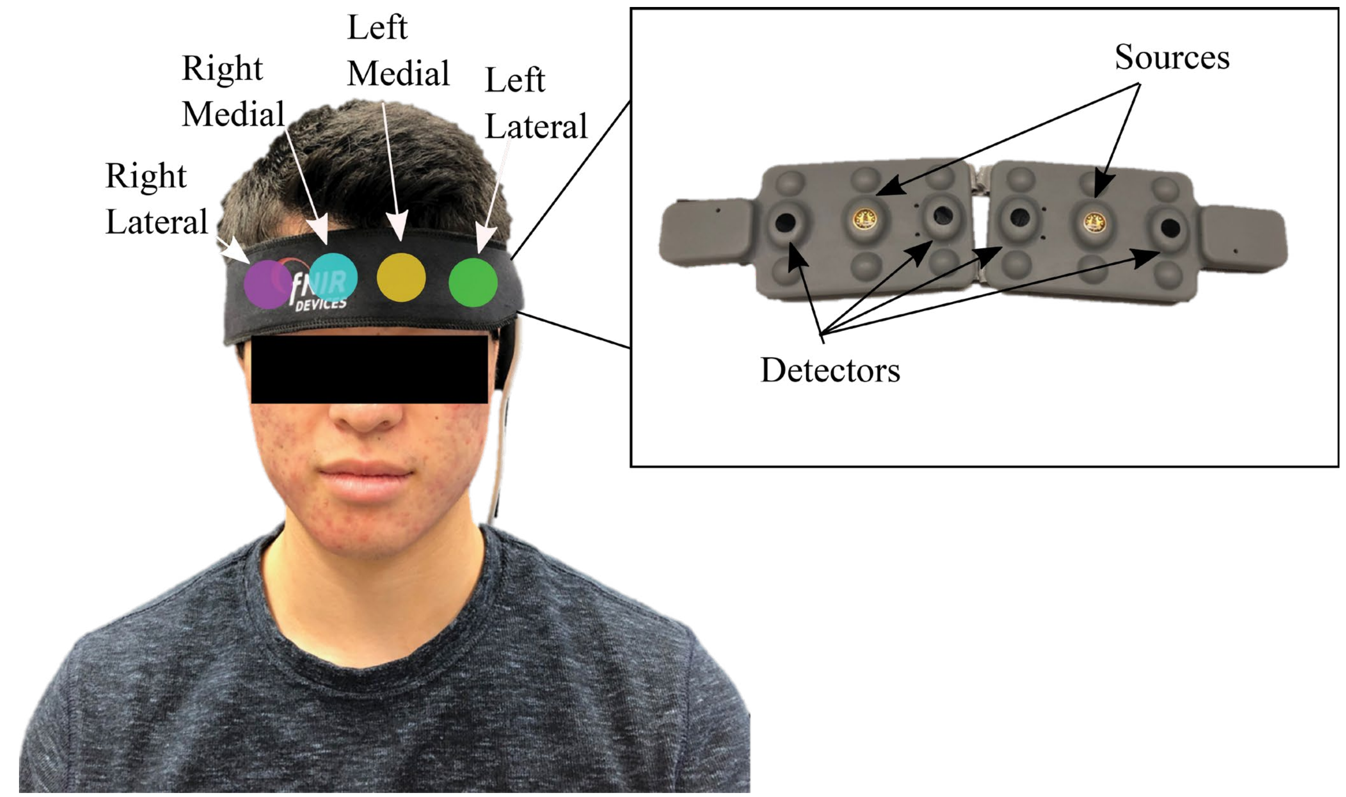




Neuroergonomic Evaluation on Haptic Feedback in Upper-Extremity Prostheses

PI: Jeremy D. Brown

- Bio-Robotics
- Human-Machine Collaborative Systems



Accomplishment: We conducted a user study to evaluate the impact of haptic feedback of grip force in an upper-extremity prosthesis from both a task performance and cognitive load perspective (using function near-infrared spectroscopy). Utilizing fNIRS in a two-alternative forced-choice stiffness discrimination task, we asked participants to differentiate objects using their natural hand, a (traditional) myoelectric prosthesis without sensory feedback, and a myoelectric prosthesis with haptic (vibrotactile) feedback of grip force. Results showed that discrimination accuracy and mental effort are optimal with the natural hand, followed by the prosthesis featuring haptic feedback, and then the traditional prosthesis, particularly for objects whose stiffness was difficult to differentiate.

Status: The findings were recently published in the *IEEE Transactions on Human Machine Systems* (doi: 10.1109/THMS.2021.3066856).

Funding: Hopkins internal

Key Personnel: Neha Thomas, Hasan Ayaz

Sensorimotor-Inspired Control for Upper-Extremity Prostheses

PI: Jeremy D. Brown

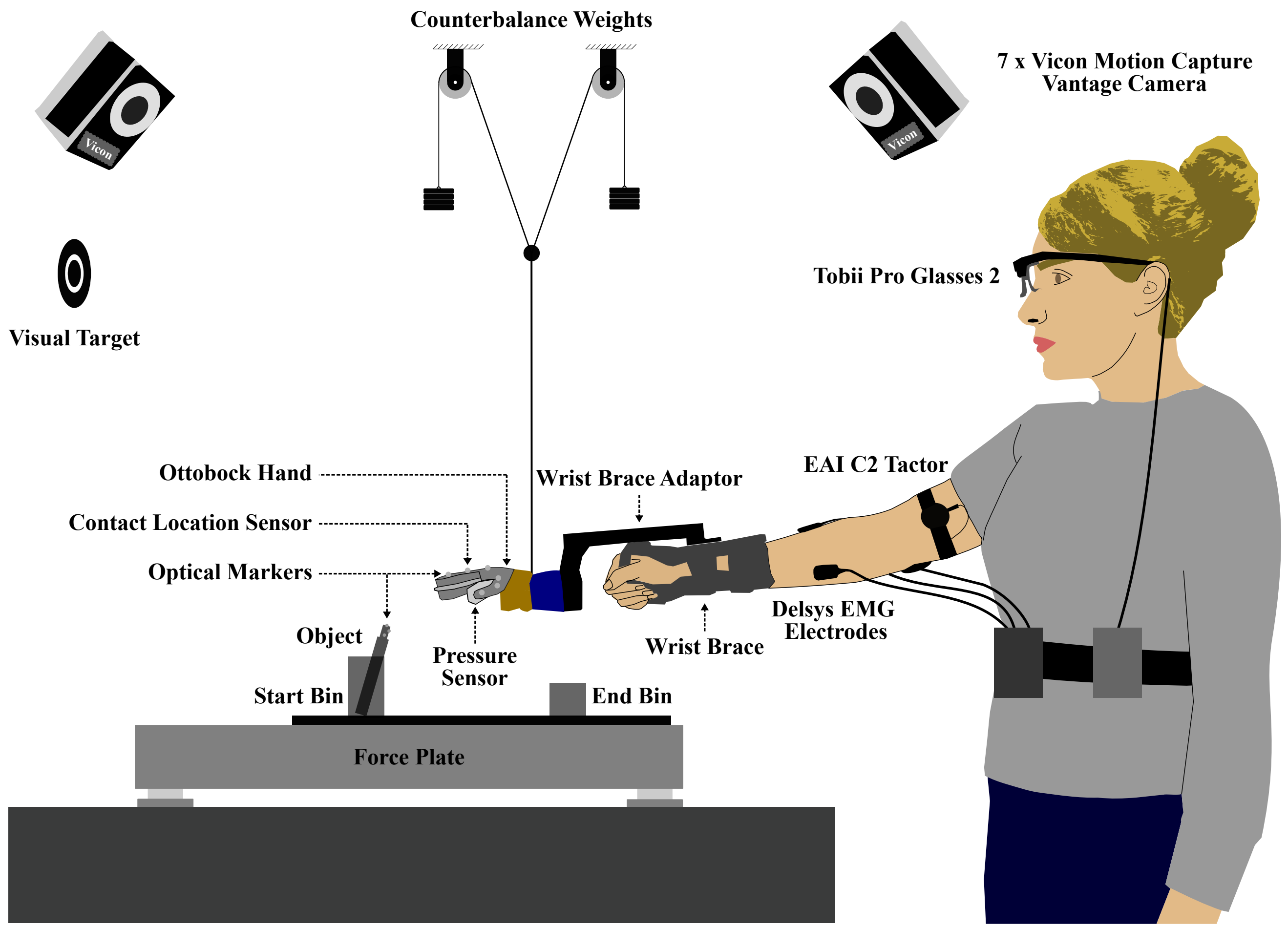
Bio-Robotics
Human-Machine Collaborative Systems

Accomplishment: To implement this system, we constructed two fabric-based tactile sensors that measure contact location along the palmar and dorsal sides of the prosthetic fingers and grasp pressure at the tip of the prosthetic thumb. We compared this novel system to a standard myoelectric prosthesis in a challenging reach-to-pick-and-place task conducted without direct vision; 17 non-amputee adults took part in this single-session between-subjects study. Participants in the sensorimotor control group achieved more consistent high performance compared to participants in the standard group.

Status: Our initial study evaluating this system was recently published in the 2021 *IEEE International Conference on Intelligent Robots and Systems* (IROS) (doi: 10.1109/IROS51168.2021.9635885)

Funding: Hopkins internal, Fulbright Fellowship

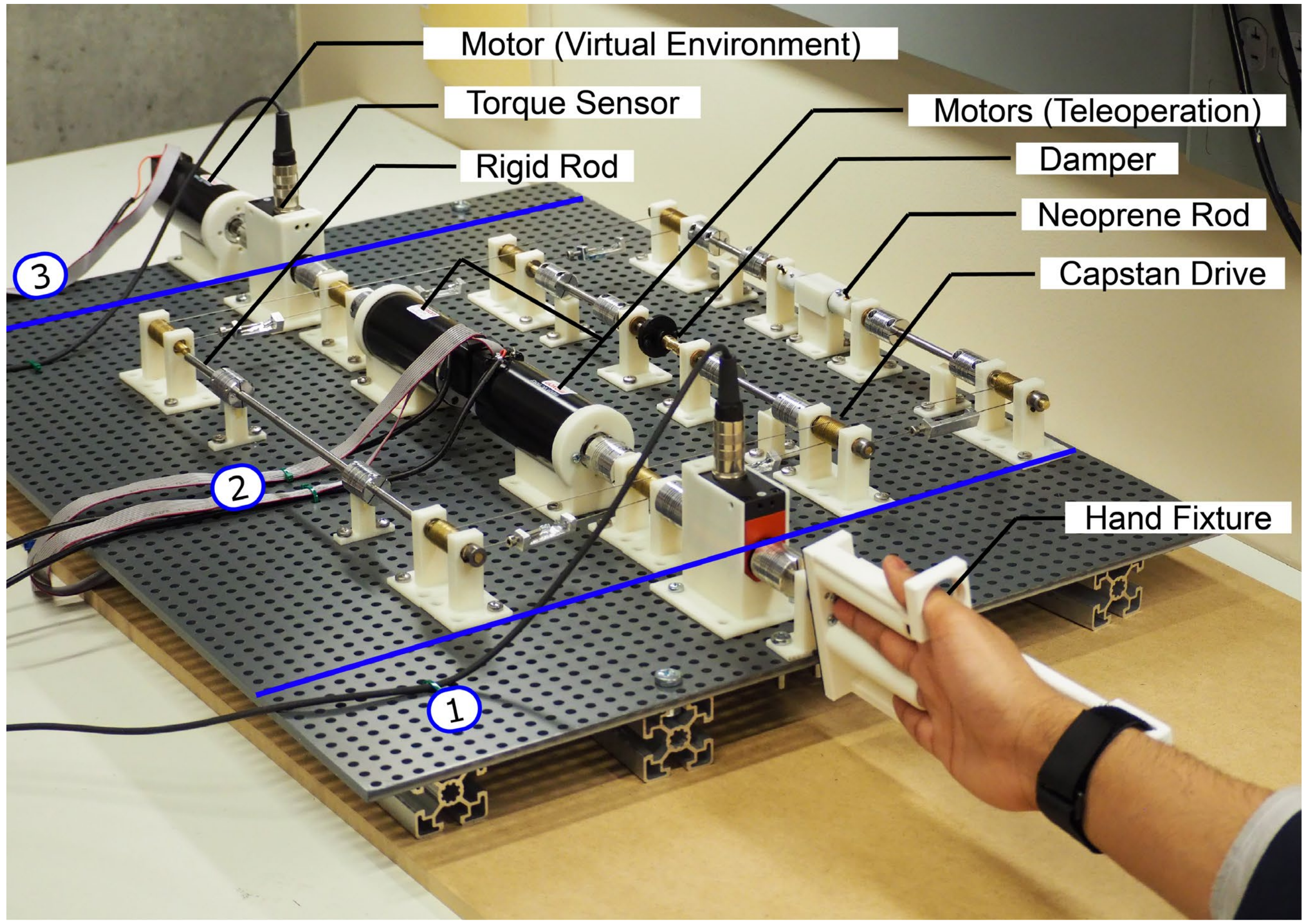
Key Personnel: Neha Thomas, Katherine J. Kuchenbecker



Haptic Perception and Task Performance During Non-Transparent Teleoperation

PI: Jeremy D. Brown

Human-Machine Collaborative Systems



Accomplishment: We have a developed a teleoperation testbed that allows for systematic investigations of human and robot dynamics on perceptual fidelity and task performance. This testbed utilizes a unique teleoperation design architecture that features modular dynamic transmissions between the leader and follower of the teleoperator to vary the energy exchange between body and environment.

Status: Details of the device and system evaluation were published in the 2021 *IEEE International Conference on Intelligent Robots and Systems* (doi: 10.1109/IROS51168.2021.9636829)

Funding: NSF CISE Small

Key Personnel: Mohit Singhala

Development of Nereid Under-Ice (NUI): An Underwater Robot for Oceanographic Exploration Under Polar Ice

PI: Louis L. Whitcomb

- Human-Machine Collaborative Systems,
- Modeling, Dynamics, Navigation, and Control
- Robotics in Extreme Environments

Key Personnel: Michael V. Jakuba, Christopher R. German, Andrew D. Bowen, Louis L. Whitcomb

Collaborators: Antje Boetius, Christian Katlein, Stefanie Arndt, Mar Fernandez Mendez, Benjamin Lange, Marcel Nicolaus, Frank Wenzhofer, Larry Mayer, Kevin Hand, Andrew Branch, Steve Chien, Christopher McFarland

Funding: NSF Office of Polar Programs, James Family Foundation, George Fredrick Jewett Foundation East, Woods Hole Oceanographic Institution, NASA Astrobiology Program, NOAA OER, Chief Scientist Dr. Antje Boetius, Alfred Wegener Institute for Polar and Marine Research, and the officers, crew, and scientific research teams of PS 86 Expedition (2014) and P S101 Expedition (2016).

Accomplishments and Status: The Nereid Under-Ice (NUI) vehicle is a lightly tethered hybrid AUV/ROV (HROV) developed by Woods Hole Oceanographic Institution and collaborator Louis Whitcomb at the Johns Hopkins University. Designed to be operated under fixed or moving ice, NUI is capable of standoff distances up to 20 km from the deployment vessel and is equipped with a navigation suite including LBL and OWTT acoustic packages, a FOG IMU, and a Doppler velocity log. McFarland et al. describe the ice-relative navigation algorithm as implemented during July 2014 operations at 83°N 6°W from icebreaker F/S Polarstern.

Katlein et al. presents under-ice light transmission data from some of NUI's first science operations.

NUI is operational and has completed major Arctic expeditions to 83°N 6°W in 2018, and to 87°N 61°E in 2016.

Publications: Michael V. Jakuba, Christopher R. German, Andrew D. Bowen, Louis L. Whitcomb, Kevin Hand, Andrew Branch, Steve Chien, and Christopher McFarland, "Teleoperation and Robotics Under Ice: Implications for Extra-Planetary Exploration," 2018 IEEE Aerospace Conference.

C. Katlein, S. Arndt, M. Nicolaus, D. K. Perovich, M. V. Jakuba, S. Suman, S. Elliot, Louis L. Whitcomb, C. J. McFarland, R. Gerdes, A. Boetius, and C. R. German, "Infuence of Ice Thickness and Surface Properties on Light Transmission through Arctic Sea Ice," *J. Geophys. Res. Oceans*, 120:1-13, Sept. 2015. doi:10.1002/2015JC010914.

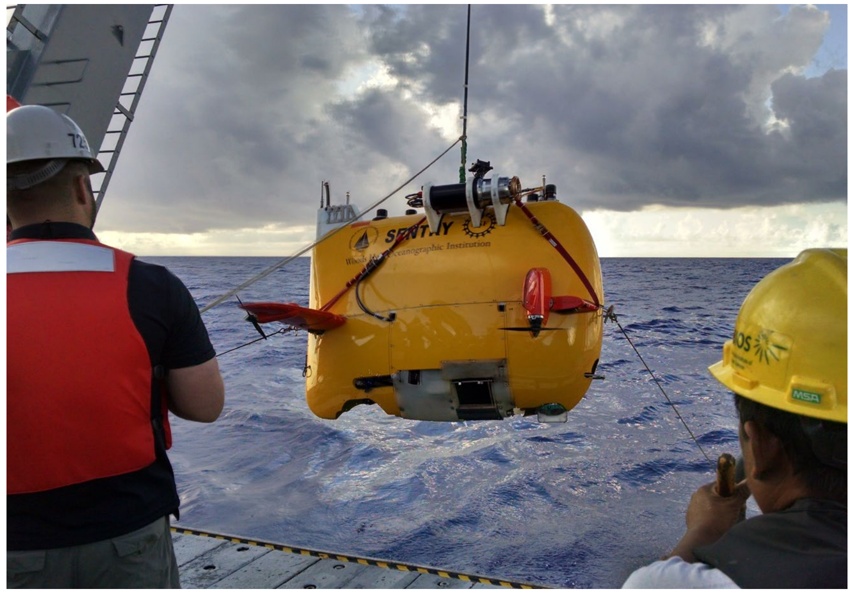
C. J. McFarland, M. V. Jakuba, S. Suman, J. C. Kinsey and L. L. Whitcomb, "Toward Ice-Relative Navigation of Underwater Robotic Vehicles Under Moving Sea Ice: Experimental Evaluation in the Arctic Sea," 2015 IEEE International Conference on Robotics and Automation (*ICRA*), Seattle, WA, 2015, pp. 1527-1534. doi: 10.1109/*ICRA*.2015.7139392 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7139392&isnumber=7138973

For More Information: whoi.edu/what-we-do/explore/underwater-vehicles/nereid-under-ice

Development of a Low-Cost True-North Seeking Fiber Optic Gyrocompass for Precision Underwater Robot Navigation

PI: Louis L. Whitcomb

- Modeling, Dynamics, Navigation, and Control
- Perception and Cognitive Systems
- Robotics in Extreme Environments



Key Personnel: Louis Whitcomb, Andrew Spielvogel, Rachel Hegeman

Funding: NSF

Accomplishments and Status: This project seeks to develop a high-accuracy comparatively low-cost, compact, and low-power true-North seeking attitude (heading, pitch, and roll) sensor, and to incorporate this new instrument into a tightly integrated precision Doppler navigation system for UUVs. The goal is to develop a comparatively low-cost and high-accuracy navigation system to enable small low-cost UUVs to perform science missions requiring high-precision navigation (e.g. high precision hydrographic survey, time-series acoustic and optical survey for environmental assessment) that are presently considered impractical or infeasible with low-cost UUVs.

Our prototype instrument has been developed and tested on the lab bench. Our in-water laboratory tests are underway. The at-sea full-scale oceanographic testing was completed in 2018 and 2019.

Publications: Andrew R. Spielvogel, Abhimanyu S. Shah, and Louis L. Whitcomb, "Online 3-Axis Magnetometer Hard-Iron and Soft-Iron Bias and Angular Velocity Sensor Bias Estimation Using Angular Velocity Sensors for Improved Dynamic Heading Accuracy," *Field Robotics*, 2021. Accepted, in press.

Andrew R. Spielvogel and Louis L. Whitcomb, "A Stable Adaptive Observer for Hard-Iron and Soft-Iron Bias Calibration and Compensation for Two-Axis Magnetometers: Theory and Experimental Evaluation," *IEEE Robotics and Automation Letters*, (5)2:1295-1302, April 2020, http:/dx.doi.org/10.1109/LRA.2020.2967308

Andrew R. Spielvogel and Louis L. Whitcomb, "Adaptive Bias and Attitude Observer on the Special Orthogonal Group for True-North Gyrocompass Systems: Theory and Preliminary Results," *International Journal of Robotics Research*. 39(2–3):321–338, 2020. http://doi.org/10.1177/0278364919881689 Invited paper.

For More Information: dscl.lcsr.jhu.edu

Precision Navigation of Low-Cost Underwater Robotic Vehicles for Ocean Science

PI: Louis L. Whitcomb

- Modeling, Dynamics, Navigation, and Control
- Perception and Cognitive Systems
- Robotics in Extreme Environments

Key Personnel: Louis L. Whitcomb, Zachary Harris, Andres Spielvogel, Abhimanyu Shah, Giangarlo Troni

Funding: NSF

Accomplishments and Status: A novel class of small low-cost unmanned underwater vehicles (UUVs) is beginning to perform oceanographic, environmental assessment, and national security missions that are faster and less expensive than previous methods such as large high-cost UUVs, human-piloted vehicles, and human divers. A significant limitation of small low-cost UUVs is their low-cost navigation systems, which presently limit them to missions requiring comparatively low-precision navigation. This project developed new methods for high-accuracy navigation with low-cost sensors to provide dramatically improved navigation accuracy for low-cost UUVs.

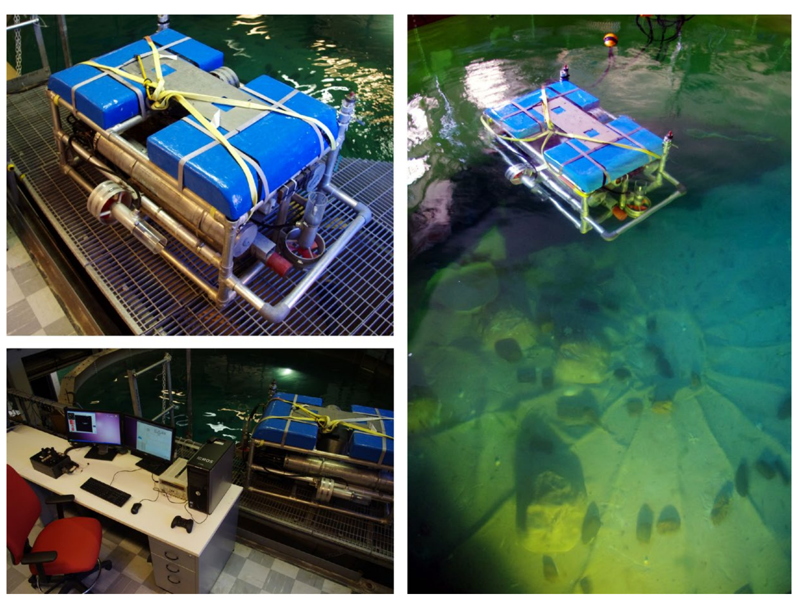
We have (1) employed Doppler sonar velocity measurement and low-cost low-power inertial measurement units to estimate attitude; (2) developed nonlinear model-based state estimators employing a full nonlinear model of the vehicle's second-order plant dynamics; and (3) developed underwater acoustic modem networks to provide simultaneous acoustic communication and acoustic range and range-rate data, and employ these data for improved underwater vehicle navigation.

Publications: Annie M. Mao and Louis L. Whitcomb, "A Novel Quotient Space Approach to Stable Adaptive Model-Based Fault Detection and Isolation: Theory and Preliminary Simulation Evaluation," 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 7119-7126, October 2021. http://doi.org/10.1109/IROS51168.2021.9636026.

Zachary J. Harris and Louis L. Whitcomb, "Cooperative Acoustic Navigation of Underwater Vehicles Without a DVL Utilizing a Dynamic Process Model: Theory and Field Evaluation," *Journal of Field Robotics*, 38(5):700-726, January 2021. https://doi.org/10.1002/rob.22008

Tyler M. Paine and Louis L. Whitcomb, "Uniform Complete Observability of Mass and Inertial Parameters in Adaptive Identification of Rigid Body Plant Dynamics," 2021 IEEE International Conference on Robotics and Automation (*ICRA*), pp. 52-58, May 2021. https://doi.org/10.1109/*ICRA*48506.2021.9561892.

For More Information: dscl.lcsr.jhu.edu



Robotic Environmental Sampling

PI: Marin Kobilarov

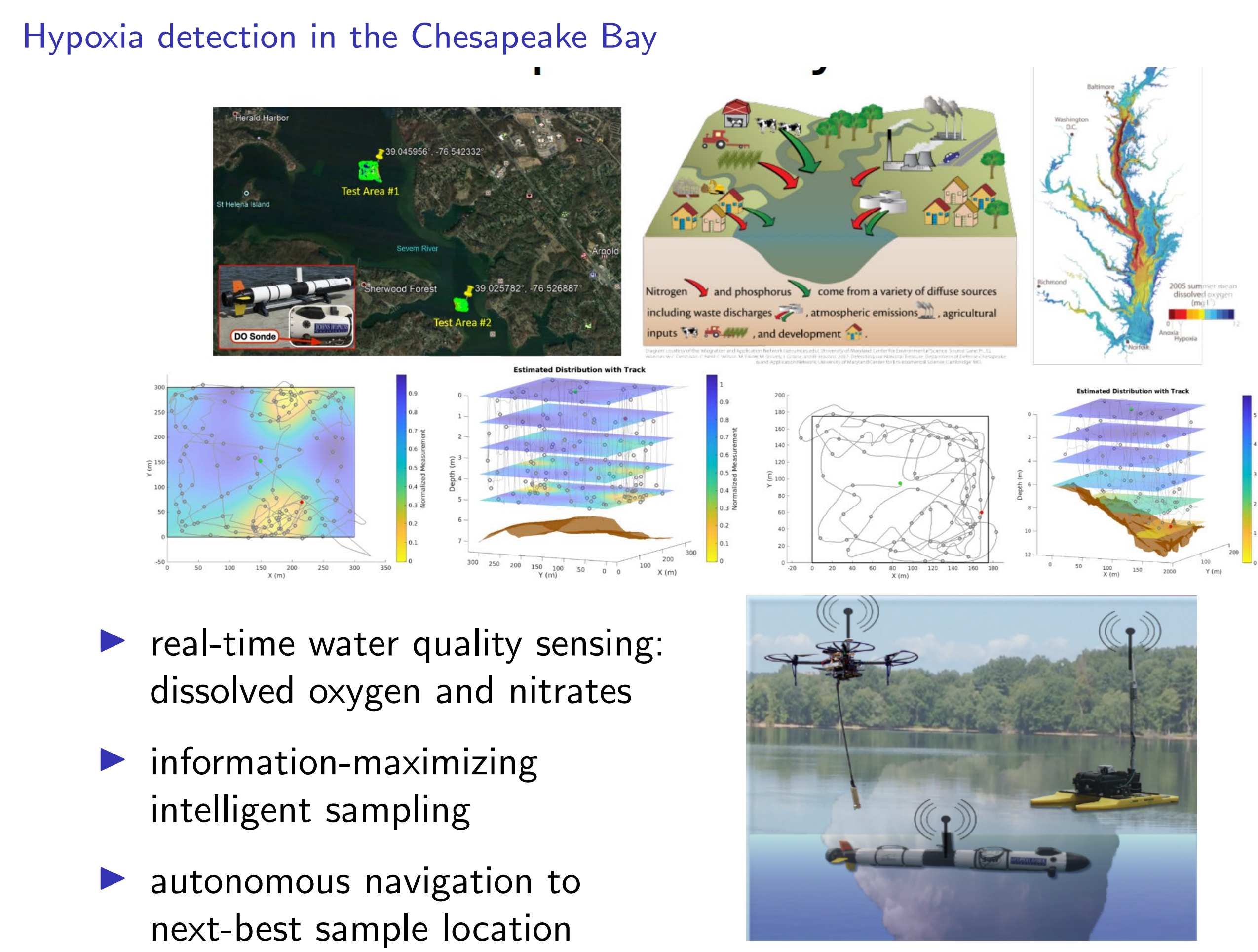
- Modeling, Dynamics, Navigation, and Control
- Robotics in Extreme Environments

Accomplishments and Status: Demonstrated adaptive sampling with underwater vehicles to build informative models of dissolved oxygen in the Chesapeake Bay. As a result, the development and spread of hypoxia (oxygen depletion) could be identified and tracked more accurately than current methods with fixed stations or ship-based sampling.

Funding: USDA NIFA

Key Personnel: Paul Stankiewicz, William Tan, William Ball, Marin Kobilarov

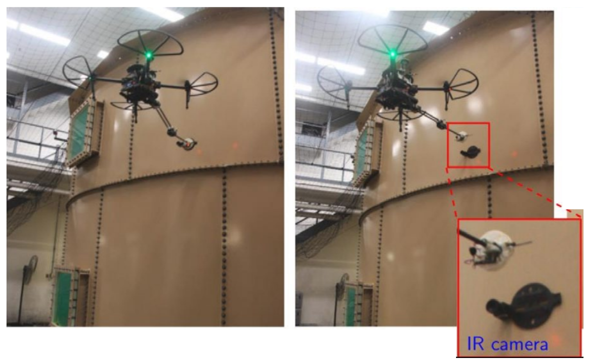
For More Information: asco.lcsr.jhu.edu



Autonomous Aerial Manipulation

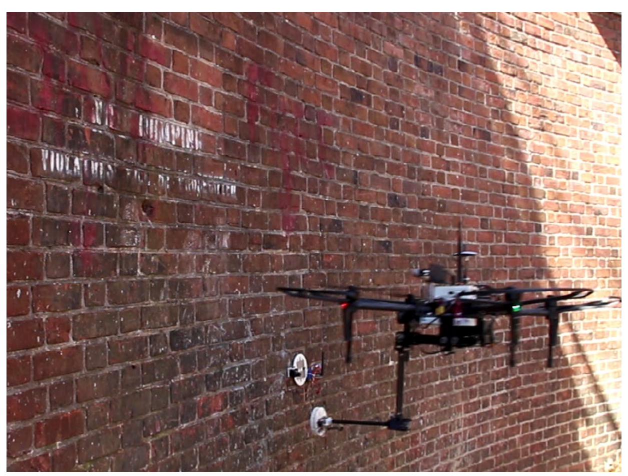
PI: Marin Kobilarov

- Modeling, Dynamics, Navigation, and Control
- Robotics in Extreme Environments



JHU AirGripper performing sensor placement

JHU AirGripper performing package sorting



environmental sensor placement

vehicle for larger payloads

Key Personnel: Gowtham Garimella, Matthew Sheckells, Gabe Baraban, Marin Kobilarov

Funding: NSF

Accomplishments and Status: Developed drones equipped with manipulators and demonstrated autonomous aerial grasping applied to:

- package delivery in a mock-up warehouse setting
- sensor placement on vertical structures for infrastructure inspection.

For More Information: asco.lcsr.jhu.edu

Autonomously Navigating a Surgical Tool Inside the Eye by Learning from Demonstration

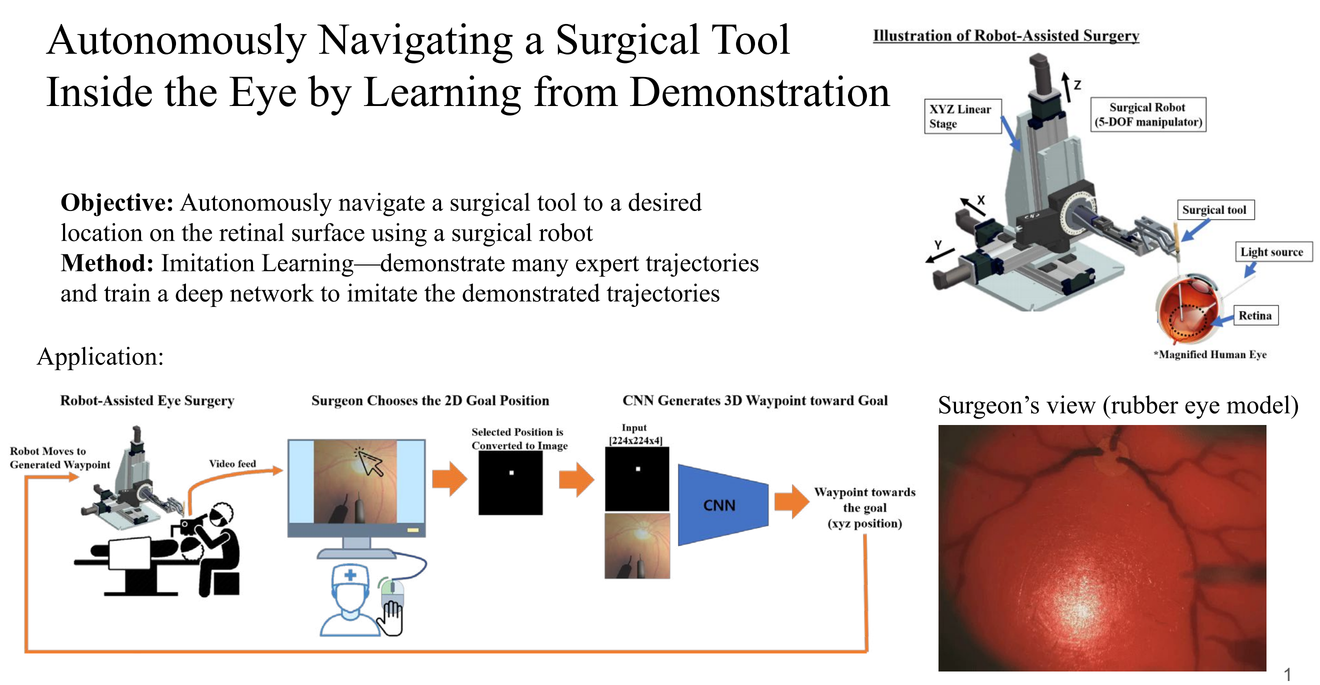
PI: Marin Kobilarov

- Medical Robots and Computer Integrated Interventional Systems

Accomplishment: Developed a system for vision-based autonomous navigation of a micro-manipulator needle to a surgeon-specified goal location on the retina of the eye, using visual feedback supervised learning. Demonstrated vein cannulation using developed system and model-predictive-control, in eye phantoms and cadaveric porcine eyes.

Key Personnel: Ji Woong (Brian) Kim, Peiyao Zhang, Peter Gehlbach, Iulian Iordachita, Marin Kobilarov

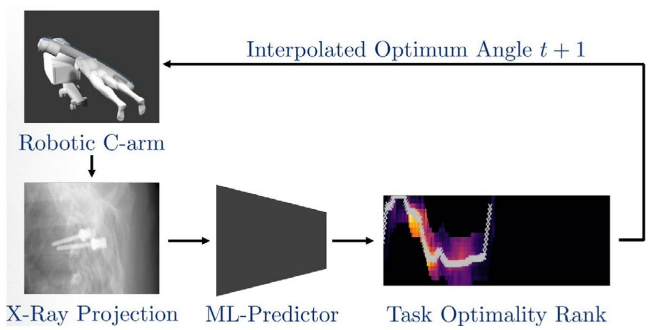
For More Information: mkobila1@jhu.edu

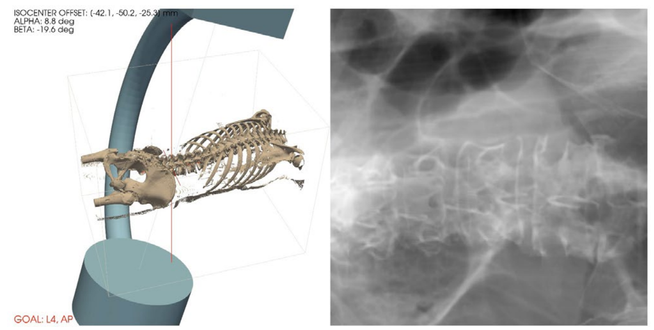


Task-aware and Autonomous C-arm Imaging

PI: Mathias Unberath

- Human-Machine Collaborative Systems
- Medical Robots and Computer Integrated Interventional Systems
- Perception and Cognitive Systems





Accomplishment: C-arm X-ray systems are the workhorse modality for numerous percutaneous procedures across diverse clinical disciplines, enabling more than 17 million interventions during 2006 in the United States alone. This number is projected to further increase, creating a global market of U.S. $3 billion for C-arm X-ray systems by 2023. Use of these systems interventionally, however, requires highly trained surgeons and C-arm technologists, since the software back-end driving these systems is still task-agnostic: The modality has no notion of anatomy, procedural progress, or desired information, effectively degrading even most modern C-arm systems to "medical grade cameras." Surgeons and technologists must actively steer the C-arm to achieve and reproduce radiographs from multiple, well-defined viewpoints to infer procedural progress. This great responsibility is associated with excessive radiation dose to patient and staff, high procedure times, repeat attempts, and—in the worst-case scenarios—adverse outcomes.

A task-aware robotic C-arm system that autonomously acquires and interprets fluoroscopic images best suited for decision making on a patient-specific basis can significantly reduce radiation dose and procedure time, and thus, improve outcome by decreasing the risk for morbidity and mortality. The major obstacle hindering the introduction of autonomous, task-aware imaging modalities is the development of appropriate machine intelligence, the innovation of which becomes possible through novel approaches by ourselves and colleagues that enable machine learning for X-ray-based interventions.

Our first application of such a task-aware and autonomous C-arm system targets cone-beam CT (CBCT) reconstruction for intra-operative verification of metal implant positioning. Metal artifacts in CT arise from a mismatch between physics of image formation and idealized assumptions during tomographic reconstruction. These artifacts are particularly strong around metal implants, inhibiting widespread adoption of 3D CBCT despite clear opportunity for intra-operative verification of implant positioning, e. g. in spinal fusion surgery. On synthetic and real data, we demonstrate that much of the artifact can be avoided by acquiring better data for reconstruction in a task-aware and patient-specific manner, and describe the first step towards the envisioned task-aware CBCT protocol. The traditional short-scan CBCT trajectory is planar, with little room for scene-specific adjustment. We extend this trajectory by autonomously adjusting out-of-plane angulation. This enables C-arm source trajectories that are scene-specific in that they avoid acquiring "poor images," which are characterized by beam hardening, photon starvation, and noise. The recommendation of ideal out-of-plane angulation is performed on the fly using a deep convolutional neural network that regresses a detectability-rank derived from imaging physics.

Funding: R21 Trailblazer

Key Personnel: Mathias Unberath, Benjamin Killeen

Patents and Disclosures: Task-aware and Anatomy-specific Cone-beam Computed Tomography, U.S. Provisional Application Serial No. 62/896,352

3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning

PIs: Mathias Unberath, Russell Taylor, Greg Hager

- Medical Robots and Computer Integrated Interventional Systems
- Perception and Cognitive Systems

Accomplishment: Minimally invasive procedures in the head and neck typically employ surgical navigation systems to provide surgeons with additional anatomical and positional information to avoid critical structures. Computer vision-based navigation systems that rely on the intra-operative endoscopic video stream and do not introduce additional hardware are both easy to integrate into clinical workflow and cost-effective, but require registration of pre-operative data, such as CT scans, to the intra-operative videos. For 3D-to-3D registration algorithms, estimating an accurate and dense intra-operative 3D reconstruction is necessary to ensure acceptable performance of the system. However, obtaining such reconstructions is not trivial, due to problems such as texture less surface, specular reflectance, lack of photometric constancy across frames, and tissue deformation. Several methods have been explored for 3D reconstruction in endoscopy. Multi-view stereo methods, such as Structure from Motion (SfM) and Simultaneous Localization and Mapping (SLAM), are able to reconstruct 3D structure and estimate camera poses in feature-rich scenes. However, the paucity of features in endoscopic images can cause these methods to produce sparse and unevenly distributed reconstructions, which may lead to inaccurate registration.

We research learning-based approaches to 1) identify corresponding points across multiple frames of endoscopic video sequences, 2) use this information to derive sparse reconstructions and relative camera motion that enable the training of deep convolutional neural networks for monocular depth estimation, and 3) fuse monocular depth estimates via the relative camera poses into a volumetric 3D reconstruction of sinus endoscopy with large anatomical coverage. This approach results in sub-millimeter registration errors between endoscopic video and pre-operative CT scans.

Funding: This work was funded in part by NIH R01-EB015530, in part by a research contract from Galen Robotics, in part by a fellowship grant from Intuitive Surgical, and in part by Johns Hopkins University internal funds.

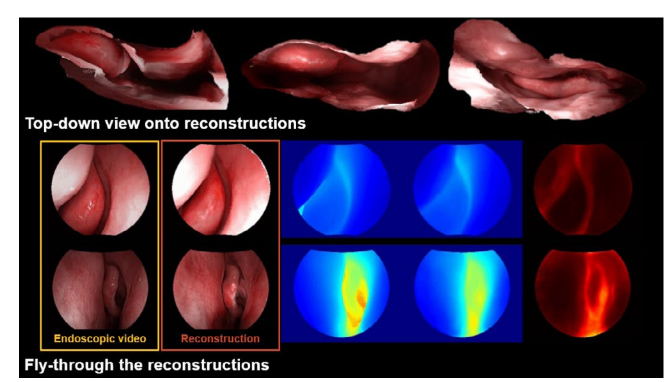
Key Personnel: Xingtong Liu, Ayushi Sinha, Mathias Unberath, Masaru Ishii, Gregory D. Hager, Russell H. Taylor

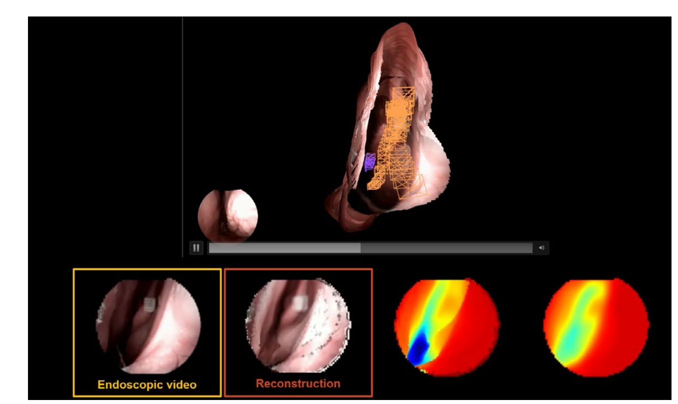
For More Information: arcade.cs.jhu.edu/research

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. (best paper)

X. Liu, A. Sinha, M. Ishii, G. D. Hager, A. Reiter, R. H. Taylor, and M. Unberath, "Dense Depth Estimation in Monocular Endoscopy with Self-supervised Learning Methods", *IEEE Transactions on Medical Imaging*, 2019. 10.1109/TMI.2019.2950936

X. Liu, M. Stiber, J. Huang, M. Ishii, G. D. Hager, R. H. Taylor, and M. Unberath, "Reconstructing Sinus Anatomy from Endoscopic Video—Towards a Radiation-Free Approach for Quantitative Longitudinal Assessment", in Medical Image Computing and Computer Assisted Intervention—MICCAI 2020, Cham, 2020, pp. 3-13





Transparent Machine Learning for Healthcare

PI: Mathias Unberath

- Human-Machine Collaborative Systems
- Perception and Cognitive Systems

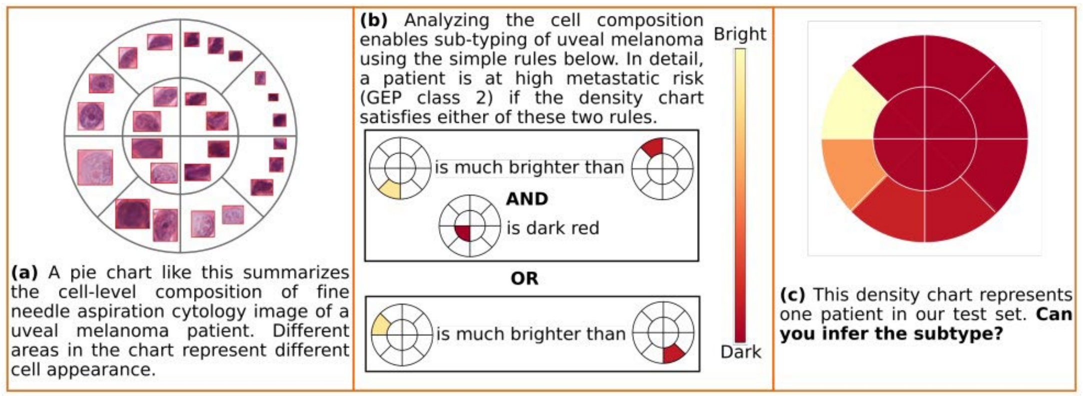
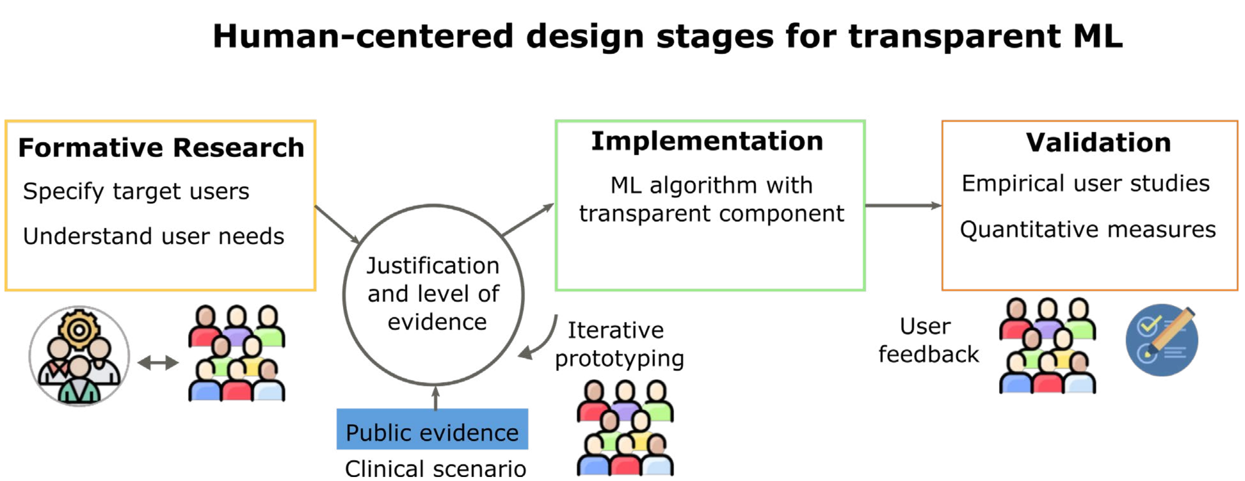


Figure 1. An overview of the automatic interpretable algorithm for uveal melanoma subtyping from cytology images. The algorithm consists of cell instance segmentation to extract cell appearance information that is used to cluster cells of similar appearance in a circular space. Based on a coarse partitioning of the embedding space, which we refer to as a pie chart, shown in (a), we find simple rule sets (b) that enable uveal melanoma subtyping, which otherwise, requires gene analysis. A pie chart of a representative patient is shown in (c) - the patient is at high metastatic risk (GEP class 2).



Accomplishment: Transparency in machine learning, including interpretable or explainable machine learning, attempts to reveal the working mechanisms of complex models, including deep neural networks. Transparent machine learning promises to advance the human factors engineering goals of human-centered AI, such as increasing trust or reducing automation bias, in the target users. We study human-AI interaction and advance the possibilities of transparent model design to develop systems that afford transparency for their envisioned end users and capitalize on the benefits of transparent machine learning.

Funding: Various sources

Key Personnel: Mathias Unberath, Catalina Gomez, Haomin Chen

For More Information: arcade.cs.jhu.edu/research

SyntheX: Scaling Up Learning-based X-ray Image Analysis Through in Silico Experiments

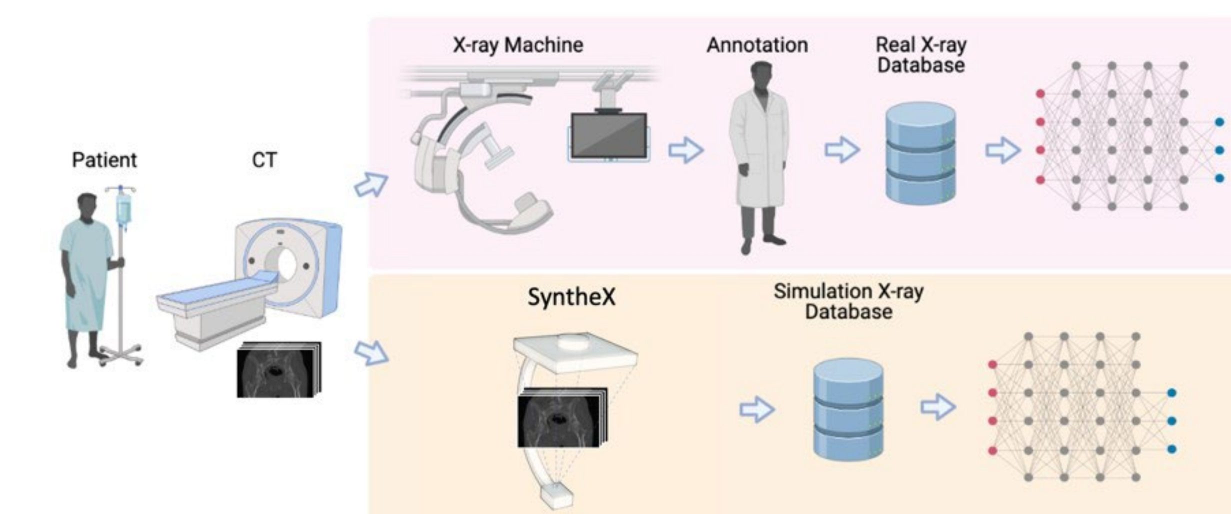
PI: Mathias Unberath

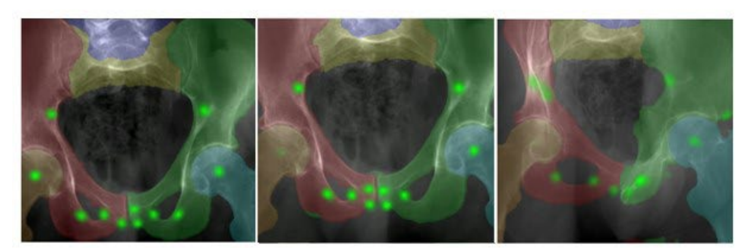
- Medical Robots and Computer Integrated Interventional Systems
- Modeling, Dynamics, Navigation, and Control
- Perception and Cognitive Systems

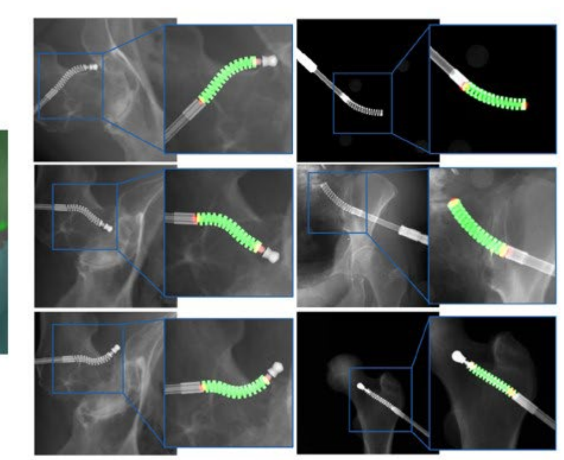
Accomplishment: In this line of work, we advance X-ray and procedural simulation methods from human-based models together with domain transfer techniques to achieve feasible solutions for training AI algorithms on synthetic data while preserving their performance under domain shift for evaluation and deployment in the real world. The SyntheX simulation paradigm allows us to develop learning-based image analysis algorithms for novel procedures or robot mediated workflows, data of which would not otherwise be created.

Key Personnel: Mathias Unberath, Benjamin Killeen, Cong Gao

For More Information: arcade.cs.jhu.edu/research







Mixed Reality for Surgical Guidance

PI: Mathias Unberath

Medical Robots and Computer Integrated Interventional Systems

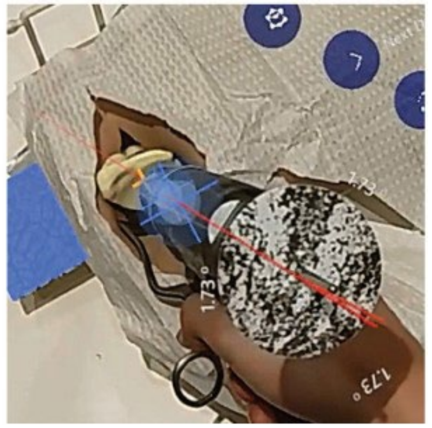
Perception and Cognitive Systems

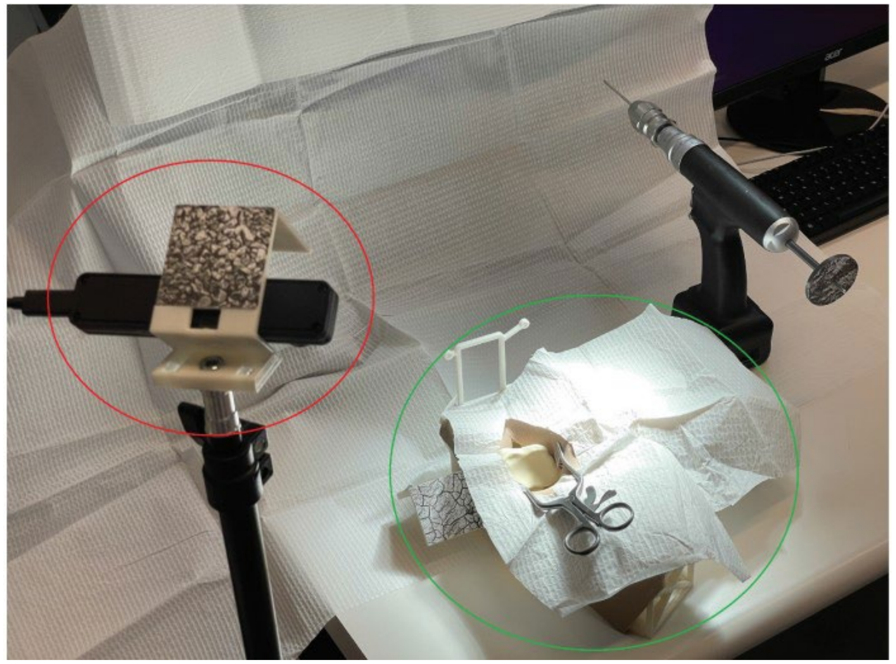
Accomplishment: Augmented and mixed reality headsets combined with powerful computer vision algorithms emerge as powerful systems to achieve high-precision surgery without the need for costly surgical navigation hardware. We advance computer vision techniques and study human perception to develop novel mixed reality solutions that can meet the strict requirements of precision surgery tasks.

Funding: Among others: Arthrex Inc. Sponsored Research Agreement

Key Personnel: Mathias Unberath, Wenhao Gu, Zhaoshuo Max Li, Sue Min Cho

For More Information: arcade.cs.jhu.edu/research



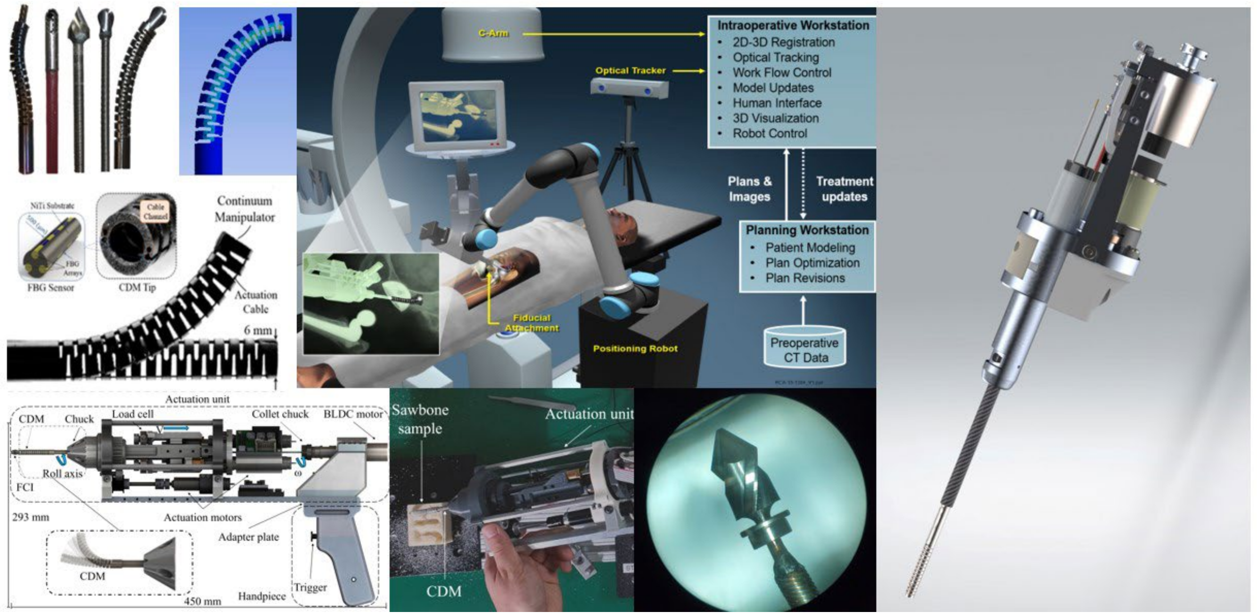


Continuum Robots, Tools, and Algorithms for Tissue Manipulation

PI: Mehran Armand

Medical Robots and Computer Integrated Inverventional Systems

Continuum Manipulators, Tools, and Algorithms for Minimally Invasive Surgery



We are developing a suite of surgical tools for minimally invasive robotic surgery of the hip, knee, and spine using a continuum manipulator. Our system is capable of autonomous, robot-assisted, and hand-held operation, allowing for the surgeon to configure the system to optimize for time, cost, and safety.

Status: We have successfully demonstrated autonomous treatment of osteolysis using feedback from an FBG sensor, as well as stable operation of the CDM for hand-held milling and drilling.

Funding: NIH/NIBIB R01EB016703 , NIH/NIAMS R01AR08315 and CUHK-MRC/JHU-LCSR collaboration

Key Personnel: Justin Ma, Henry Phalen, Golchehr Amirkhani, Justin Ma, David Usevitch, Amit Jain (MD), Julius Oni (MD), Russell Taylor, Mehran Armand

For more information: bigss.lcsr.jhu.edu

Patents and Disclosures: S. Sefati, M. Armand, I. Iurdachita, “Data-Driven Collision Detection for Manipulator Arms,” U.S. Patent Application 20200338723 10/29/2020

F. Alambeigi, R. Seifabadi, M. Armand, “Devices with Low Melting Point Alloy for Control of Device Flexibility,” U.S. Patent Application. 16872519, 09/03/2020

F. Alambeigi, M. Armand, “Steerable Drill for Minimally-Invasive Surgery,” ed: U.S. Patent App. 16/490,751, 2020

M. Armand., M. Moses, M.D. Kutzer, J.E. Tiffany, “Adjustable-Stiffness Morphable Manipulator,” U.S. Patent No. US10259129, 4/16/2019

I. Iordochita , L. Hao, M. Armand, R.H. Taylor, ”Shape Tracking of a Dexterous Continuum Manipulator, ” U.S. Patent No. 10 226304B2, Issued: 3/12/2019

M. Armand, M. Kutzer, C. Brown, R.H. Taylor, “Cable-Driven Morphable Manipulator,“ Patent No. US9737687, 22/8/2017

Perceptual Visualization for Surgical Guidance in Orthopaedics Using Augmented Reality

PI: Mehran Armand

Medical Robots and Computer Integrated Inverventional Systems

Accomplishment: In-situ visualization of anatomical content using augmented reality (AR) has proven to be challenging. Perceptual issues, such as inconsistent occlusion when using AR head-mounted displays frequently lead to perceiving the virtual content floating on top of the real objects. Visualization techniques such as "Focus and Context" enable the visualization of virtual content placed inside real objects. This project aims to enable visual guidance during the performance of orthopedic surgical procedures using AR head-mounted displays.

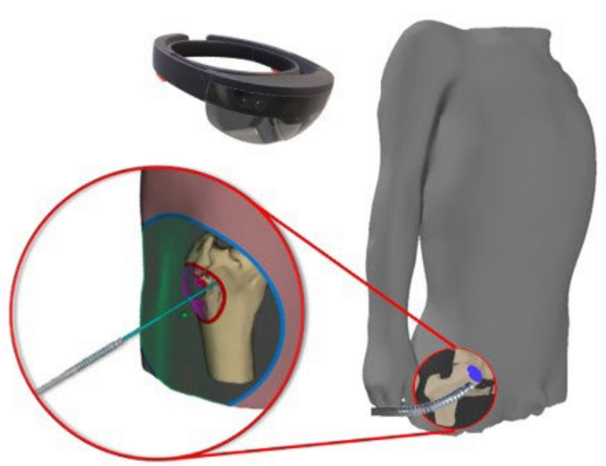
Status: An initial implementation of the visualization techniques has been designed and is ready to be implemented. Future steps include the integration and validation of the visualization techniques under controlled scenarios and surgical environments.

Funding: R01EB017703 and R01AR080315

Key Personnel: Alejandro Martin Gomez, Nassir Navab, Mehran Armand

For More Information: bigss.lcsr.jhu.edu

End-to-End Augmented Reality Framework for In-situ Visualization in Surgical Scenarios



- Visualizing anatomical structures inside a patient's body using augmented reality has proven a challenging task.
- Misleading visual cues can lead to perceive the virtual content floating on top of the body.
- This project integrates visualization techniques that improve the perception of the virtual content by occluding the real objects.
- Our goal is to integrate augmented reality head-mounted displays to provide visual guidance during orthopedical surgical procedures.

JHU Laboratory for Computational Sensing and Robotics

Total Body Imaging for Skin Cancer Detection

PI: Mehran Armand

Medical Robots and Computer Integrated Inverventional Systems

Accomplishment: As many as 1 million people in the United States have melanoma. Based on current recommendations, survivors of the disease and their close family (approximately 4 million in the U.S.) should be followed up annually. In recent years, the state-of-art 3D total body photography systems have been able to document the anatomical location of lesions. However, due to the existing systems' lack of resolution, the clinicians still have to rely on capturing dermatoscopic images for "sequential digital dermoscopic imaging" (SDDI).

We are developing a total body dermatological examination assistive device capable of detecting substantive changes to the skin lesions between successive examinations, regardless of changes to the body and pose of the subject.

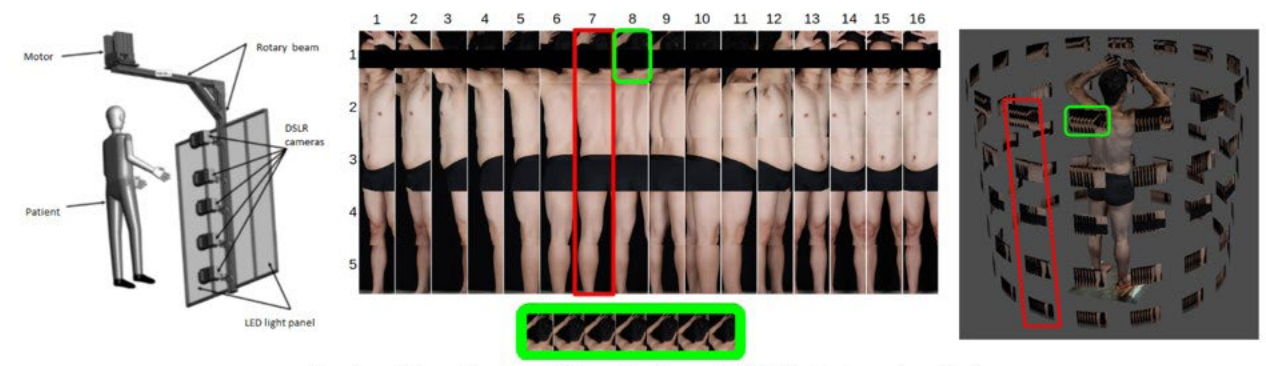
Status: Prototype device and software have been developed and installed at JHU Outpatient Center for a soon-to-begin 100-patient study.

Funding: NSF and NIH STTRs and NIH GPP

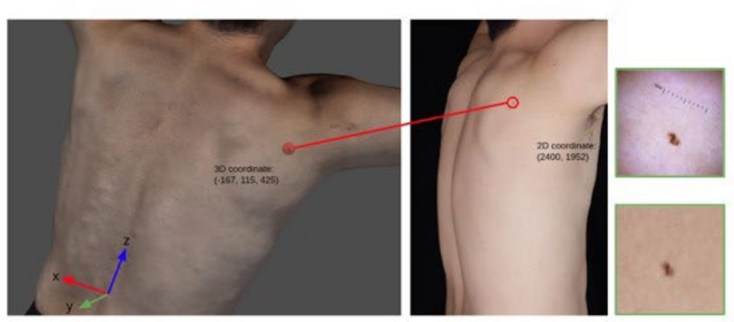
Key Personnel: Wei-lun Huang, Minghao Xue, Nanxi Ye, Nassir Navab, Davood Tashayyod, Jun Kang (MD), Mehran Armand

For More Information: bigss.lcsr.jhu.edu

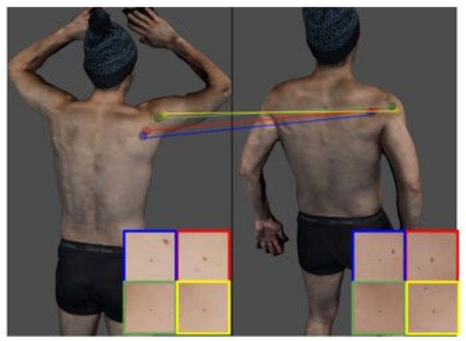
Full Body Imaging System for Skin Cancer Detection: Skin Lesion Documentation and Longitudinal Tracking



System Overview and Visualization of Full Body Imaging Data



Anatomical Record for Skin Lesion



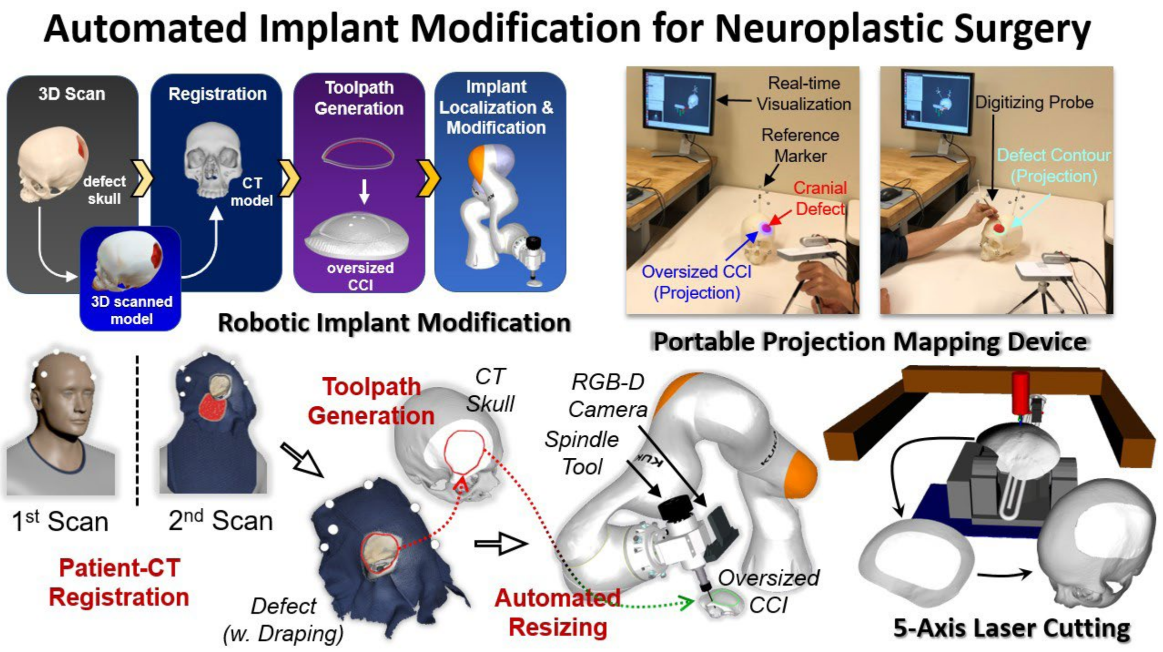
Skin Lesion Matching across Scans

JHU Laboratory for Computational Sensing and Robotics

Automated Implant Modification for Neuroplastic Surgery

PI: Mehran Armand

Medical Robots and Computer Integrated Inverventional Systems



Accomplishments: Conventional cranioplasty using cranial implants is performed in two stages and/or involves imprecise and time-consuming manual implant modifications. The manual manipulations are imprecise and may result in large bone gaps and implant failure with post-surgical complications. We propose computer-aided and robotic techniques for a single-stage cranioplasty with customized implants. In the single-stage cranioplasty, skull resection and implant resizing will happen within a single surgery. We have automated this process to achieve faster and more precise implant resizing. Three major systems have been developed: 1) a Portable Projection Mapping Device; 2) a Robotic Implant Modification Platform; and 3) a 5-Axis Laser Cutting Machine. Using a high-resolution 3D scanner to acquire the geometry of a patient's defect. We then register the geometry to the preoperative implant design using CT data and generating a cutting toolpath. The robot or the customized 3D laser machine will then cut the implant automatically.

Status: Our evaluation showed that systems can achieve faster and more precise implant modification for single-stage cranioplasty.

Funding: JHU/APL, Cohen grant

Key Personnel: Joshua Liu, Wei-Lun Haung, and Chad Gordon, Mehran Armand,

Patents and Disclosures: M. Armand, S. Liu, W.L. Huang, "Portable Projection Mapping Device and Projection Mapping System," WO 2021051126A1

G. Grant, P. Liacouras, C. Gordon, R. Murphy, M. Armand, "Patient-Specific Trackable Cutting Guides," U.S. Patent Application 16857284, 10/29/2020

F. Alambeigi, S. Sefati, R. Murphy, M. Armand, C. R. Gordon, S. Liu, "Cutting Machine for Resizing Raw Implants During Surgery," ed: U.S. Patent 10,603,175, 2020

C. Gordon , M. Armand, R. Murphy, G. Grant, P. Liacouras, K. Wolfe, "Computer-assisted Cranioplasty," U.S. Patent Application 15529036, 9/28/2017

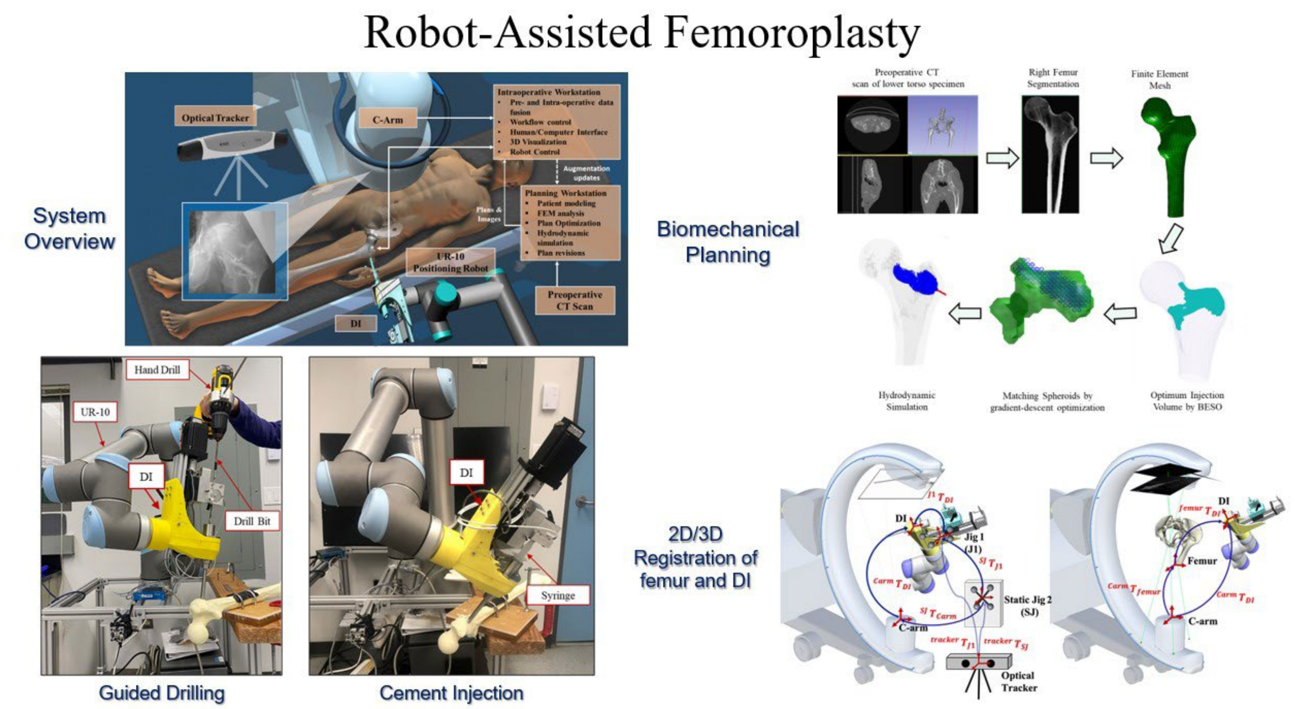
K. Wolfe, C. Gordon, R. Murphy, M. Armand, "Cranial Reference Mount," U.S. Patent Application 15100239 1/5/2017

For More Information: bigss.lcsr.jhu.edu

Robot-Assisted Femoroplasty

PI: Mehran Armand

Medical Robots and Computer Integrated Inverventional Systems



Accomplishments: We have developed robot-assisted system for femoral bone augmentation surgery that implements the concept of intraoperative biomechanical feedback. The system consists of surgical biomechanical planning using hydrodynamics-based bone cement diffusion model, surgical navigation involving 2D/3D registration of preoperative CT scans to the augmented hip bone via acquiring X-ray images, real-time tracking, and an intraoperative monitoring system of the cement shape from X-ray images. Current system advancements include designing a drilling and injection component (DI) capable of both bone drilling and controlled injection of the cement, that is attached to the six DOF positioning robot (UR10, Universal Robots Inc.). We evaluated the feasibility of the robotic system with the use of image-based 2D/3D registration through a cadaveric experiment involving soft tissue. Intraoperative fluoroscopic images are taken from multiple views to perform registration of the femur and DI. Our evaluation showed the superior accuracy and reliability of image-based, robot-assisted bone augmentation. We have also modified a planning paradigm for femur augmentation to lower the injection volume as compared to the previous work. This will likely reduce the risk of thermal necrosis caused by exothermic polymerization of PMMA.

Status: Application demos for treatment of femoroplasty; prototype drilling and injection component exist; integrating robotic system components for OR application and cadaver studies; designing animal study for investigating the safety of the procedure

Funding: NIH/NIBIB, R01EB023939

Key Personnel: Mahsan Bakhtiarinejad, Cong Gao, Mathias Unberath, Russell Taylor, Simon Mears, Julius Oni, Mehran Armand

For More Information: bigss.lcsr.jhu.edu

Robot-Assisted Transcranial Magnetic Stimulation

PI: Mehran Armand

Medical Robots and Computer Integrated Inverventional Systems

Accomplishment: Transcranial magnetic stimulation (TMS) is a noninvasive and painless procedure that utilizes magnetic fields to temporarily stimulate or inhibit nerve cell activities in a target area. The stimulation improves symptoms of depression, and the inhibition can be used in brain mapping research. In the conventional manual method, the operator needs to place the TMS coil to the correct location and orientation using a navigation system. We use a robotic system to improve the placement accuracy and repeatability. In addition, using a projection mapping system, we overlay the target TMS point and underlying brain anatomy to the head of the subject.

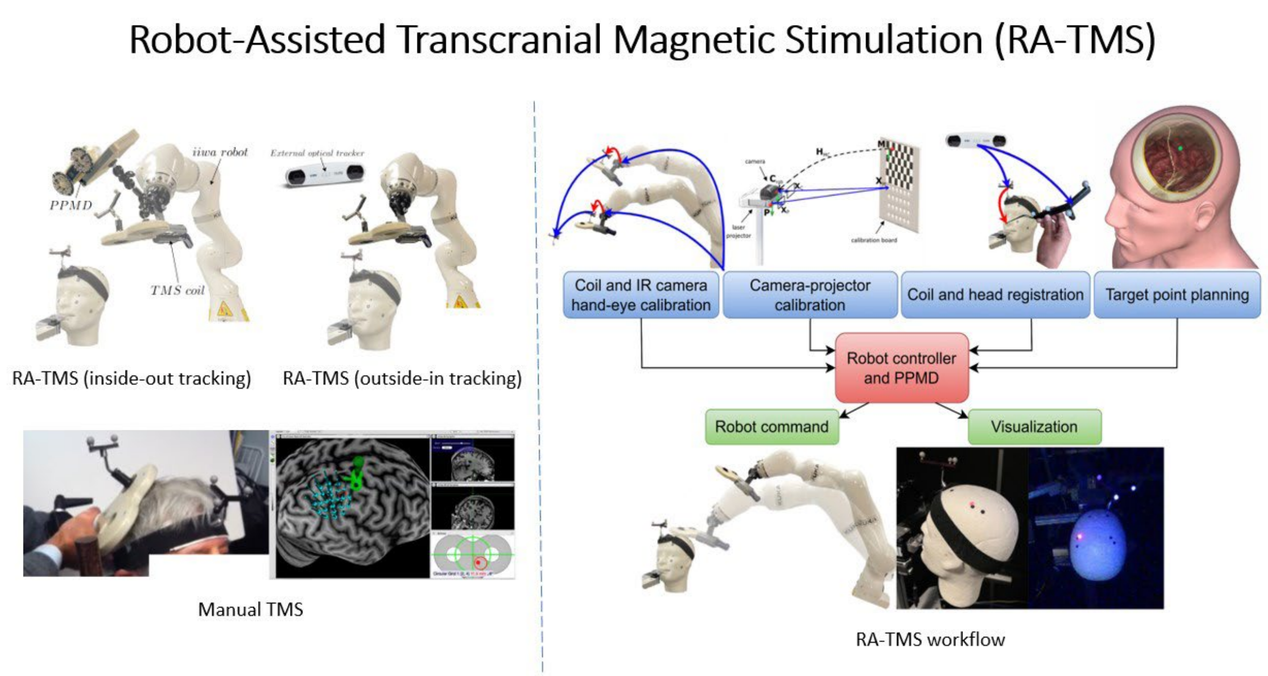
Status: An initial implementation including integrated navigation system, projection mapping system, robot position control has been completed.

Funding: NIH: R01DC018815

Key Personnel: Yiohao Liu, Joshua Liu, Jing Tian (MD), Amir Kheradmand (MD), Mehran Armand

Patents and Disclosures: M. Armand, S. Liu, W.L. Huang, "Portable Projection Mapping Device and Projection Mapping System," WO 2021051126A1

For More Information: bigss.lcsr.jhu.edu



Deep Learning Approach to Photoacoustic Visual Servoing

PI: Muyinatu Bell

Medical Robots and Computer Integrated Inverventional Systems

Perception and Cognitive Systems

Accomplishment: We developed a real-time, photoacoustic visual servoing system that processes information directly from raw acoustic sensor data without requiring image formation or segmentation in order to make robot path planning decisions to track and maintain visualization of tool tips, which is an essential component of multiple robotic surgical and interventional procedures.

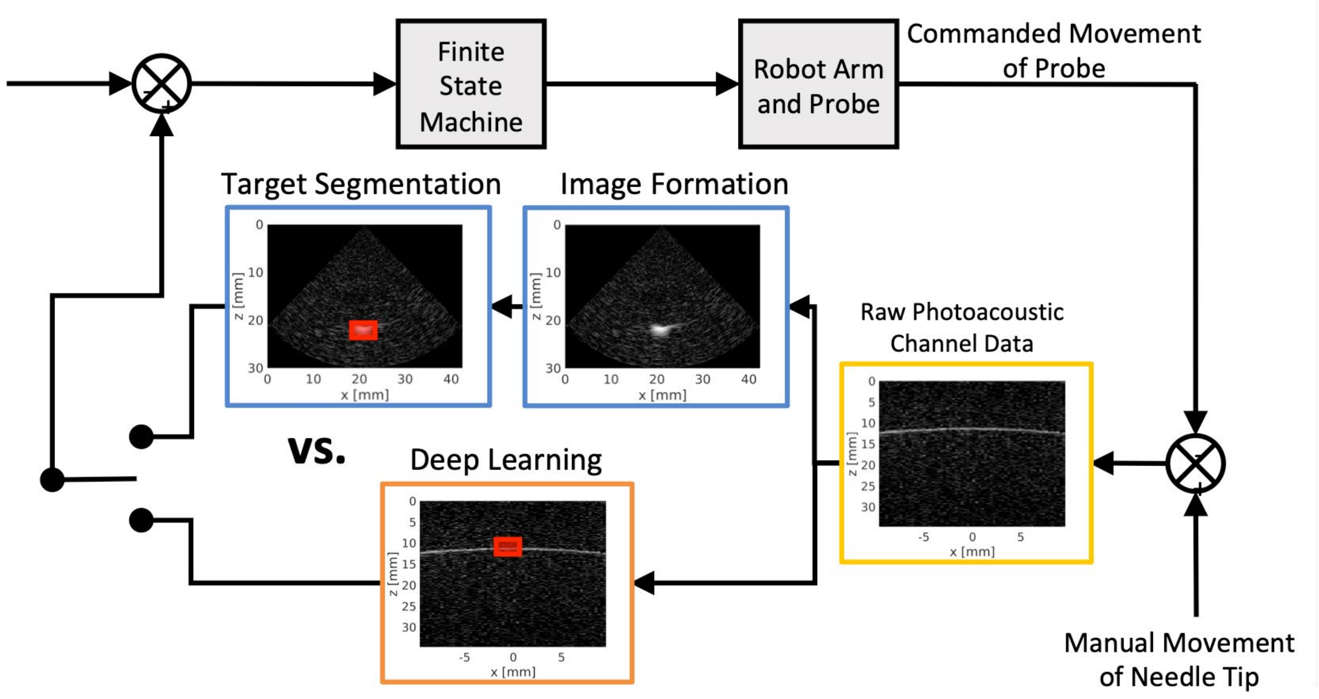
Status: This work was presented at the 2021 IEEE International Conference on Robotics and Automation

Funding: This work is supported by NSF Smart and Connected Health Award IIS-2014088, NIH Trailblazer Award R21 EB025621, and NSF CAREER Award ECCS-1751522.

Key Personnel: Mardava R. Gubbi, Muyinatu Bell, PhD

Patents and Disclosures: Citation: Gubbi MR, Bell MAL, Deep Learning-Based Photoacoustic Visual Servoing: Using Outputs from Raw Sensor Data as Inputs to a Robot Controller, IEEE International Conference on Robotics and Automation (*ICRA*), Xi'an, China, May 30–June 5, 2021

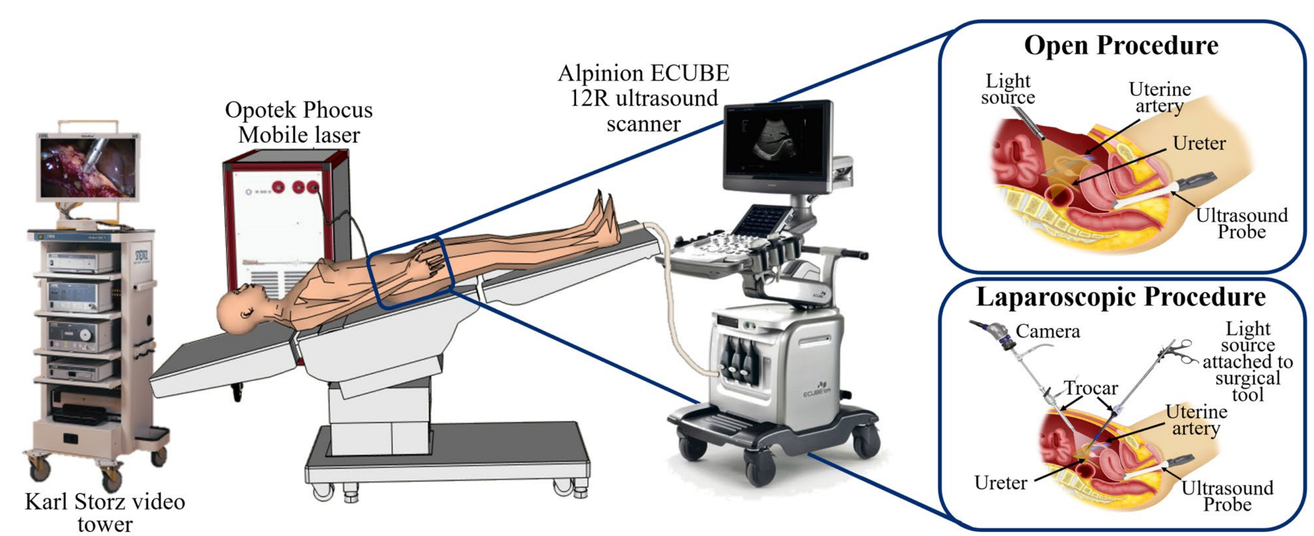
For More Information: pulselab.jhu.edu/wp-content/uploads/2021/03/Gubbi_Bell_ICRA_2021.pdf



Photoacoustic-Guided Hysterectomy

PI: Muyinatu Bell

- Human-Machine Collaborative Systems
- Medical Robots and Computer Integrated Inverventional Systems
- Perception and Cognitive Systems



Accomplishment: This work is the first to demonstrate a novel method for photoacoustic image-guided hysterectomies within the realistic imaging environment of a human cadaver during both open and laparoscopic procedures. With a contrast agent injected into the ureter, two laser wavelengths can be used to create a simultaneous display of the ureter and the uterine artery. This dual-wavelength approach was then integrated to create a novel surgical guidance system by estimating the tool-to-ureter distance and mapping that distance to an audible signal, similar to the parking sensor on a modern automobile. This auditory signal is intended to alert surgeons who are operating too closely to the ureter, which can lead to multiple life-threatening complications caused by accidental injury to the ureter during surgery.

Status: A journal paper describing this contribution was recently published in *IEEE Transactions on Medical Imaging*.

Funding: This work was supported by a Johns Hopkins Discovery Award and NSF CAREER Award (Grant No. ECCS-1751522).

Key Personnel: Alycen Wiacek, Karen Wang, MD, Harold Wu, MD, Muyinatu Bell, PhD

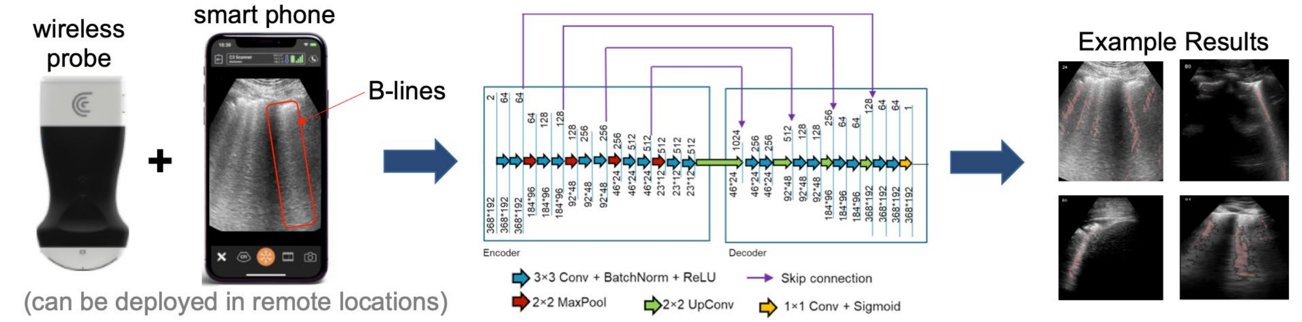
Citation: Wiacek A, Wang KC, Wu H, Bell MAL, “Photoacoustic-Guided Laparoscopic and Open Hysterectomy Procedures Demonstrated with Human Cadavers,” *IEEE Transactions on Medical Imaging*, 40(12):3279-3292, 2021. The authors additionally thank John Thate and Karl Storz Endoskope for the generous use of their laparoscopic equipment; Michelle Graham and Eduardo Gonzalez for their assistance during the cadaver studies; and the Johns Hopkins Carnegie Center for Surgical Innovation for infrastructure support.

For More Information: ieeexplore.ieee.org/document/9438623

Deep Learning COVID-19 Features in Lung Ultrasound Images

PI: Muyinatu Bell

- Perception and Cognitive Systems



Accomplishment: We are developing a deep learning approach to detect COVID-19 features in lung ultrasound images. Deep neural networks were trained with simulated ultrasound data and tested on 51 in vivo B-mode images from COVID-19 patients. Our networks achieved 86% accuracy to detect the same (55% of cases) or more (45% of cases) B-lines than human observers. This work is beneficial for assisting less experienced physicians with identifying B-line features for COVID-19 detection and diagnosis.

Status: This work was accepted for presentation at the 2022 SPIE Medical Imaging Conference

Funding: This work was supported by the Computational Sensing and Medical Robotics Research Experience for Undergraduates Program (Grant No. EEC 1852155), the NIH Trailblazer Award (Grant No. R21-EB025621), and the NIH Trailblazer Award Supplement (Grant No. R21-EB025621-03S).

Key Personnel: Benjamin Frey, Lingyi Zhao, PhD, Tiffany Fong, MD, Muyinatu Bell, PhD

Citation: Benjamin Frey, Lingyi Zhao, Muyinatu Bell, "Multi-Stage Investigation of Deep Neural Networks for COVID-19 B-line Feature Detection in Simulated and In Vivo Lung Ultrasound Images," *SPIE Medical Imaging*, 2022

Interactive Flying Frustums

PI: Nassir Navab

- Human-Machine Collaborative Systems
- Medical Robots and Computer Integrated Interventional Systems
- Perception and Cognitive Systems

Accomplishment: *IEEE Transactions on Medical Imaging* 2020

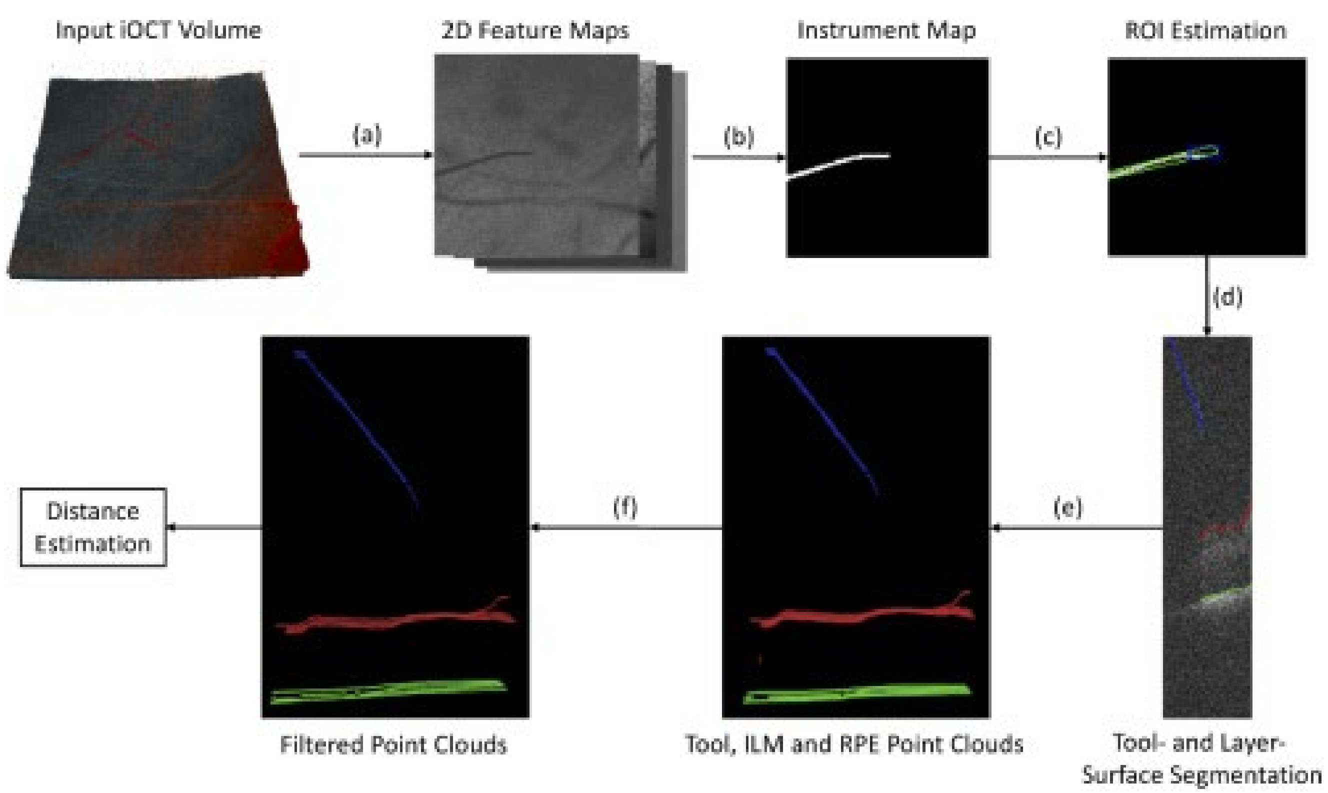
Development and Pre-Clinical Analysis of Spatiotemporal-Aware Augmented Reality in Orthopedic Interventions

Status: Full pre-clinical user study in collaboration with Greg Osgood and Alex Johnson from Johns Hopkins School of Medicine

Funding: Internal

Key Personnel: Nassir Navab, Alejandro Martin Gomez, Greg Osgood, Mehran Armand, Alex Johnson

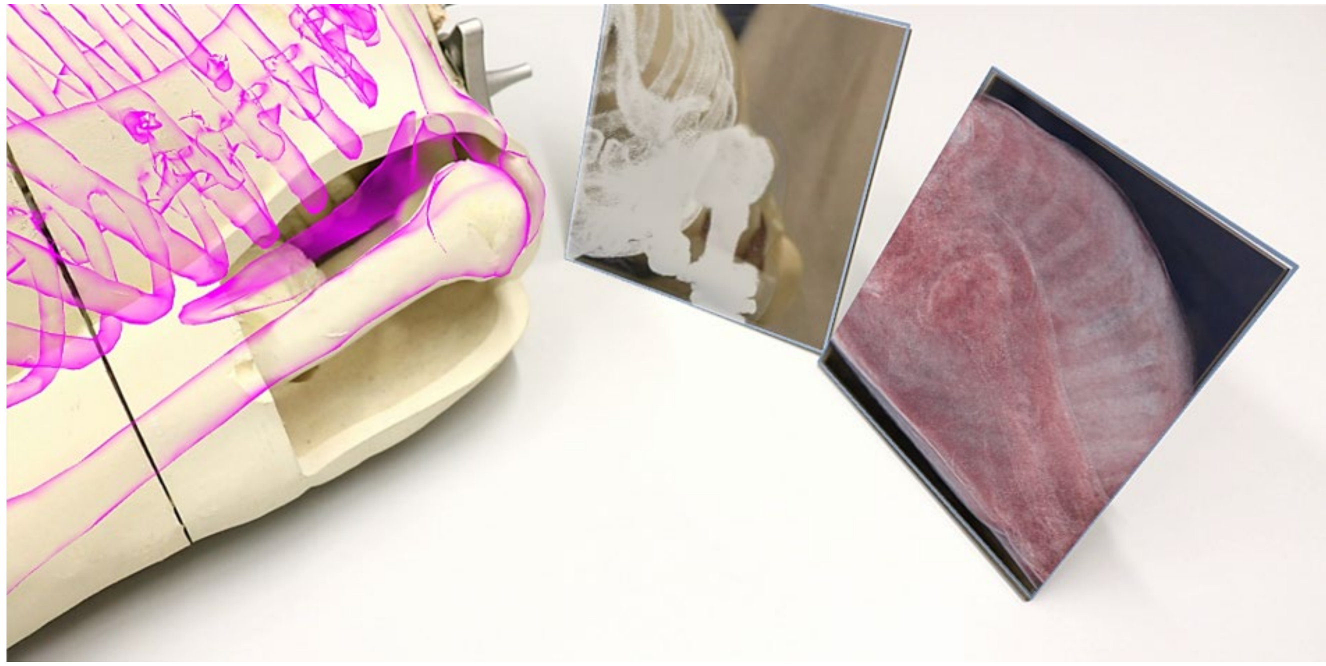
For More Information: medicalaugmentedreality.org/camc.html



Augmented Mirrors

PI: Nassir Navab

- Human-Machine Collaborative Systems
- Medical Robots and Computer Integrated Interventional Systems
- Perception and Cognitive Systems



Accomplishment: IEEE International Symposium on Mixed and Augmented Reality 2020

Augmented Mirrors (integration of physical mirrors into mixed-reality environments to dynamically reflect the real and virtual content of the scene)

Status: Concept design and demonstration of potential use cases of the technology in industrial and medical scenarios

Funding: Internal

Key Personnel: Nassir Navab, Alejandro Martin Gomez, Greg Osgood, Mehran Armand, Alex Johnson,

For More Information: medicalaugmentedreality.org/#publications

iOCT-Guided Robot-Assisted Sub Retinal Injection

PI: Nassir Navab

- Human-Machine Collaborative Systems
- Medical Robots and Computer Integrated Interventional Systems
- Perception and Cognitive Systems

Accomplishment: *Biomedical Optics Express* 2021

Real-Time Tool to Layer Distance Estimation for Robotic Subretinal Injection using Intraoperative 4D OCT.

IEEE International Conference on Robotics and Automation 2022 (Submitted)

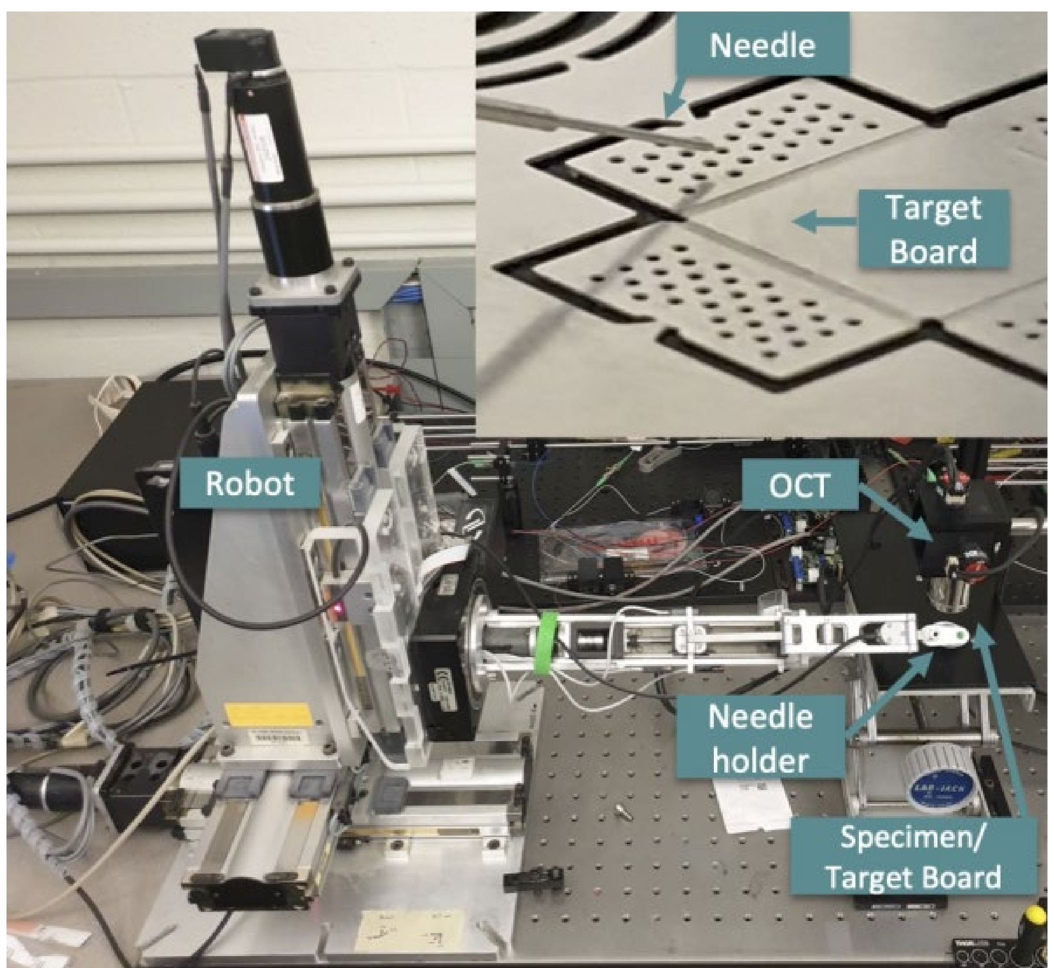
Towards Autonomous Subretinal Injections: OCT Guided Robotic Injection System

Status: Design and evaluation of an algorithm to estimate the distance between an injection needle and the surface boundaries of retinal layers from iOCT volumes. Preliminary evaluation of a framework to plan and select targets in OCT volumes and to control a surgical robot to reach the desired targets.

Funding: R01: NIH

Key Personnel: Nassir Navab, Alejandro Martin Gomez, Iulian Iordachita, Peter Gehlbach

For More Information: osapublishing.org/boe/fulltext.cfm?uri=boe-12-2-1085&id=446953



A User's Guide to System Identification for Sensorimotor Control

PI: Noah J. Cowan

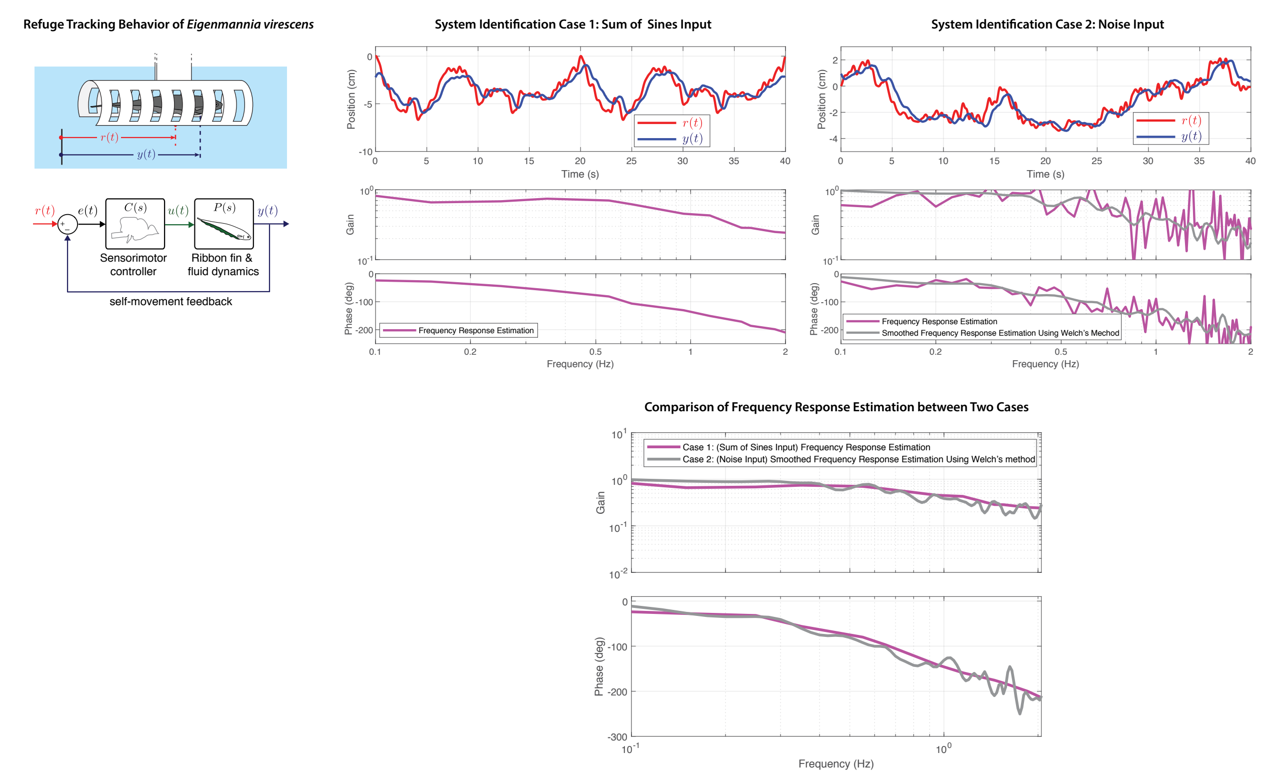
- Bio-Robotics
- Modeling, Dynamics, Navigation, and Control
- Perception and Cognitive Systems

Accomplishment: Mathematical models are widely used to study animal behaviors. But for high-level tasks like sensorimotor processing, dynamics cannot be easily predicted by simple physical models. In these cases, data-driven system identification techniques are essential. We have developed a set of best practices for locomotor system identification that can be applied across animal taxa, including humans.

Status: We have performed linear and nonlinear system identification of closed-loop sensorimotor behavior from cockroaches, to fish, to humans. For sensorimotor control systems like reaching to a target, we have developed a set of best practices by comparing the performance of several approaches to system identification. The results we present here focus on system identification of refuge tracking responses in the weakly electric glass knifefish, Eigenmannia virescens, because it is a champion animal model for sensorimotor control, but the recommendations apply across taxa, including humans.

Funding: This work was supported by a collaborative National Science Foundation (NSF) Award to Noah J Cowan (1557895) and Eric S Fortune (1557858).

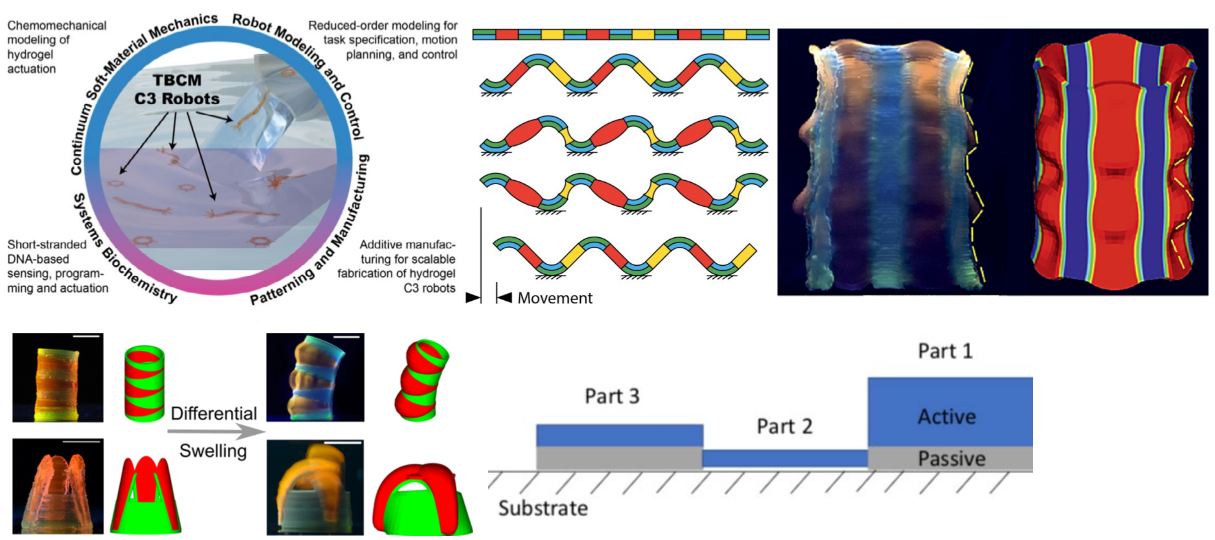
Key Personnel: Yu Yang; Yuqing (Eva) Pan; Ismail Uyanik; Noah J Cowan



Programming Thermobiochemomechanical (TBCM) Multiplex Robot Gels

PI: Noah J. Cowan

Bio-Robotics
Modeling, Dynamics, Navigation, and Control



Accomplishment: The combination of stimulus-responsive and non-responsive gels make possible the ability to direct controlled shape changes within structures, including elongation, bending, and twisting. Systematically interconnecting these actively controlled components leads to small scale robotic systems that can be controlled to locomote on substrates in aqueous environments. Using geometric mechanics, we designed a simple robot-gait that is being tested in a gel simulation based on ABAQUS, and is leading to new robotic designs that are currently being fabricated by our JHU collaborators. Our work consolidates stimulus-responsive structures with design evaluation tools examined in previous studies and provides insight to future robot-gait design rules.

Status: During the first year, we surveyed the literature on differential geometry and motion planning tools. These tools enable the evaluation of robot designs by optimizing the best gait within a given design. We recently designed and built an automated experiment rig for gel imaging so that our theoretical models can be tested experimentally. Future work will include alternatively optimizing robot-gait designs within certain constraints in simulation, realization of simulation results, and optimization for real robots.

Funding: This work was supported by a collaborative National Science Foundation (NSF) Award to David Gracias, Thao (Vicky) Nguyen, Rebecca Schulman, and Noah J Cowan (1830893).

Key Personnel: David Gracias, Thao (Vicky) Nguyen, Rebecca Schulman, Noah J Cowan, Kuan-lin Chen, Ruohong Shi, Aishwarya Pantula, Siming Deng

Human Sensory-Motor Control

PI: Noah J. Cowan

Bio-Robotics
Modeling, Dynamics, Navigation, and Control
Perception and Cognitive Systems

Accomplishment: Understanding how animals, including humans, plan and conduct movements—and how those movements are impaired by neurodegenerative diseases—remains one of the grand challenges of neuroscience and medicine. We are addressing this challenge by performing human motor control experiments both in healthy individuals and in those with neural disorders, and developing and testing COVID-19 safety-conscious ship-to-home VR-based interventions.

Status: During the pandemic, we developed and deployed a VR-based system in collaboration with our colleagues at JHU (Bastian lab), and performed extensive human subjects experiments in both healthy participants and in those with cerebellar ataxia. We are currently finalizing the data analysis and preparing the work for publication. We have also developed, in collaboration with researchers at the University of Michigan, a theoretical understanding of how individuals manage long-latency feedback, and are making progress in understanding how that capability is impaired for ataxic individuals.

Funding: This work is supported by a collaborative National Science Foundation (NSF) Award to Noah Cowan, James Freudenberg, Brent Gillespie, and Amy Bastian (1825489).

Key Personnel: Noah Cowan, Di Cao, Amy Bastian, Jim Freudenberg, and Brent Gillespie

Telerobotic Satellite Servicing

PI: Peter Kazanzides

- Human-Machine Collaborative Systems,
- Modeling, Dynamics, Navigation, and Control
- Perception and Cognitive Systems
- Robotics in Extreme Environments

Accomplishment: Research in support of NASA's OSAM-1 mission to demonstrate telerobotic refueling of a satellite on orbit, subject to multi-second ground-to-orbit communication delays. Recent accomplishments include: (1) the Worksite Registration Tool (WRT) software to create a 3D model of the space environment from a robotic camera survey, (2) an interactive planning capability that enables operators to plan, preview, and then execute robotic motions while avoiding collisions, and (3) a computer vision method to measure and control tool engagement during thermal blanket cutting.

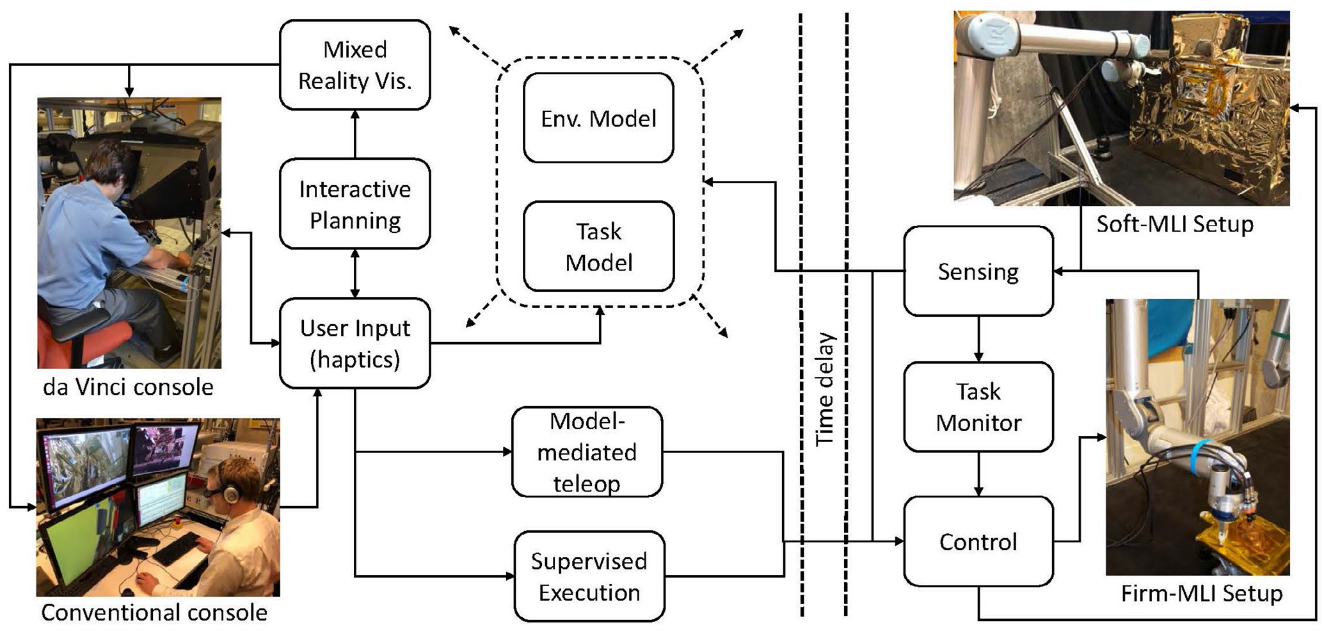
Status: The Worksite Registration Tool (WRT) software was transferred to NASA and is being integrated into the ground system for the OSAM-1 mission. Performing experiments at JHU to evaluate the interactive planning software and the tool engagement measurement software.

Funding: NASA NNG15CR66C

Key Personnel: Peter Kazanzides, Louis Whitcomb, Simon Leonard, Balazs Vagvolgyi, Anton Deguet, Will Pryor

For More Information: smarts.lcsr.jhu.edu/research/telerobotic-satellite-servicing

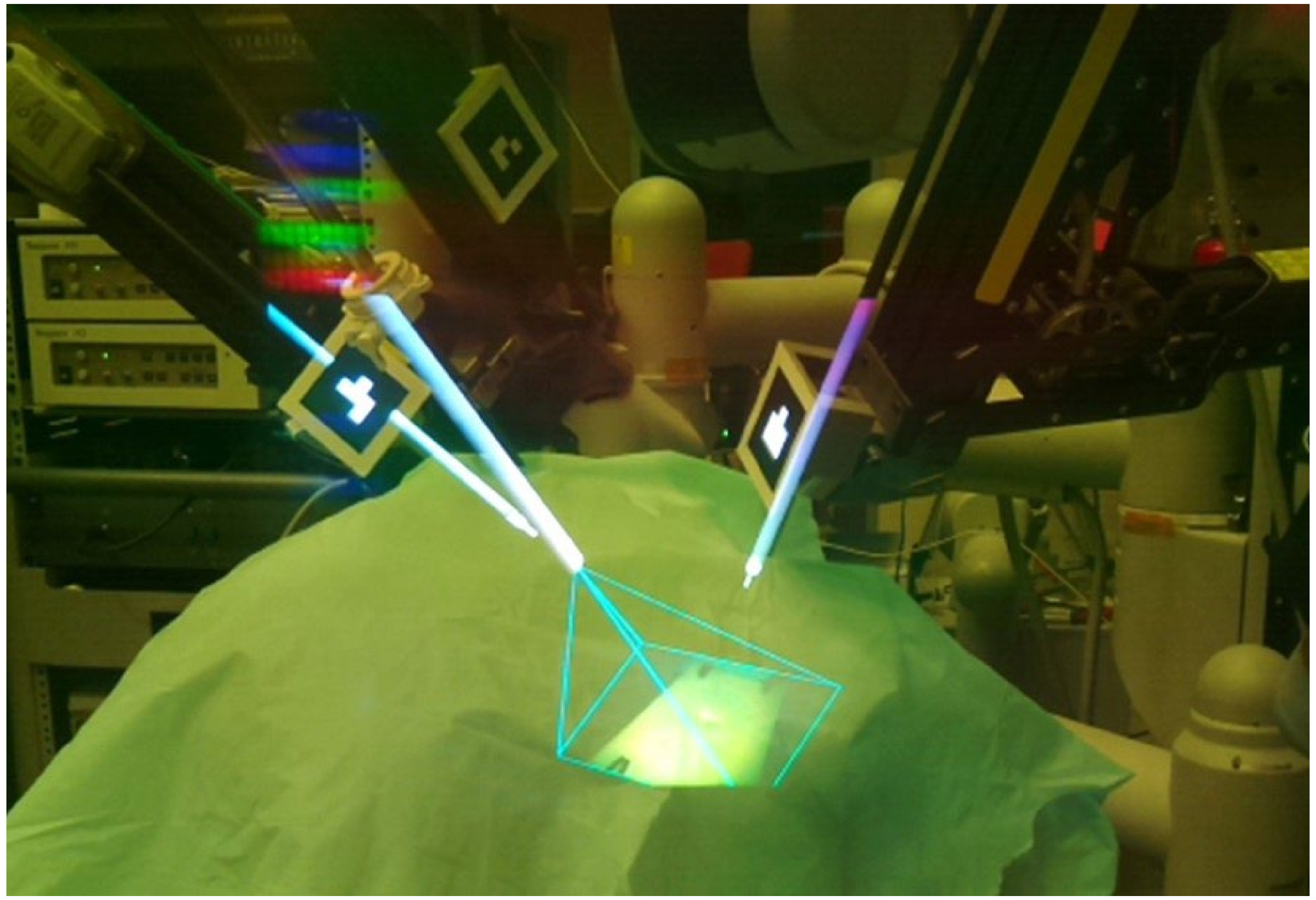
W. Pryor, B.P. Vagvolgyi, W.J. Gallagher, A. Deguet, S. Leonard, L.L. Whitcomb, P. Kazanzides, "Experimental Evaluation of Teleoperation Interfaces for Cutting of Satellite Insulation," IEEE Intl. Conf. on Robotics and Automation (*ICRA*), pp. 4775-4781, May 2019.



Augmented Reality Assistance for Robotic Surgery

PI: Peter Kazanzides

- Human-Machine Collaborative Systems
- Medical Robots and Computer Integrated Interventional Systems



Accomplishment: We have several completed and ongoing research projects that involve augmented reality (AR) on a head-mounted display (HMD). Our initial work integrated an optical tracking system with an HMD to create a "head-mounted navigation system" for neurosurgery. As HMD technology improved, we explored the use of AR for training of combat medics. During this project, we also developed an improved calibration method for optical see-through HMDs. Our current projects involve AR for ventriculostomy (left figure), for the bedside assistant in robotic surgery (right figure), and as an interface to control a prosthetic hand. The lab has several HMDs, including Microsoft Hololens (Versions 1 and 2) and Epson Moverio BT-200/BT-300.

Status: Currently working on a markerless approach to eliminate the requirement to attach markers to the robot

Funding: Intuitive Surgical Technology Research Grant

Key Personnel: Peter Kazanzides, Nick Greene

Patents and Disclosures: Yes. Patent will be issued imminently

For More Information: smarts.lcsr.jhu.edu/research

Force Estimation for Surgical Robotics

PI: Peter Kazanzides

Medical Robots and Computer Integrated Interventional Systems

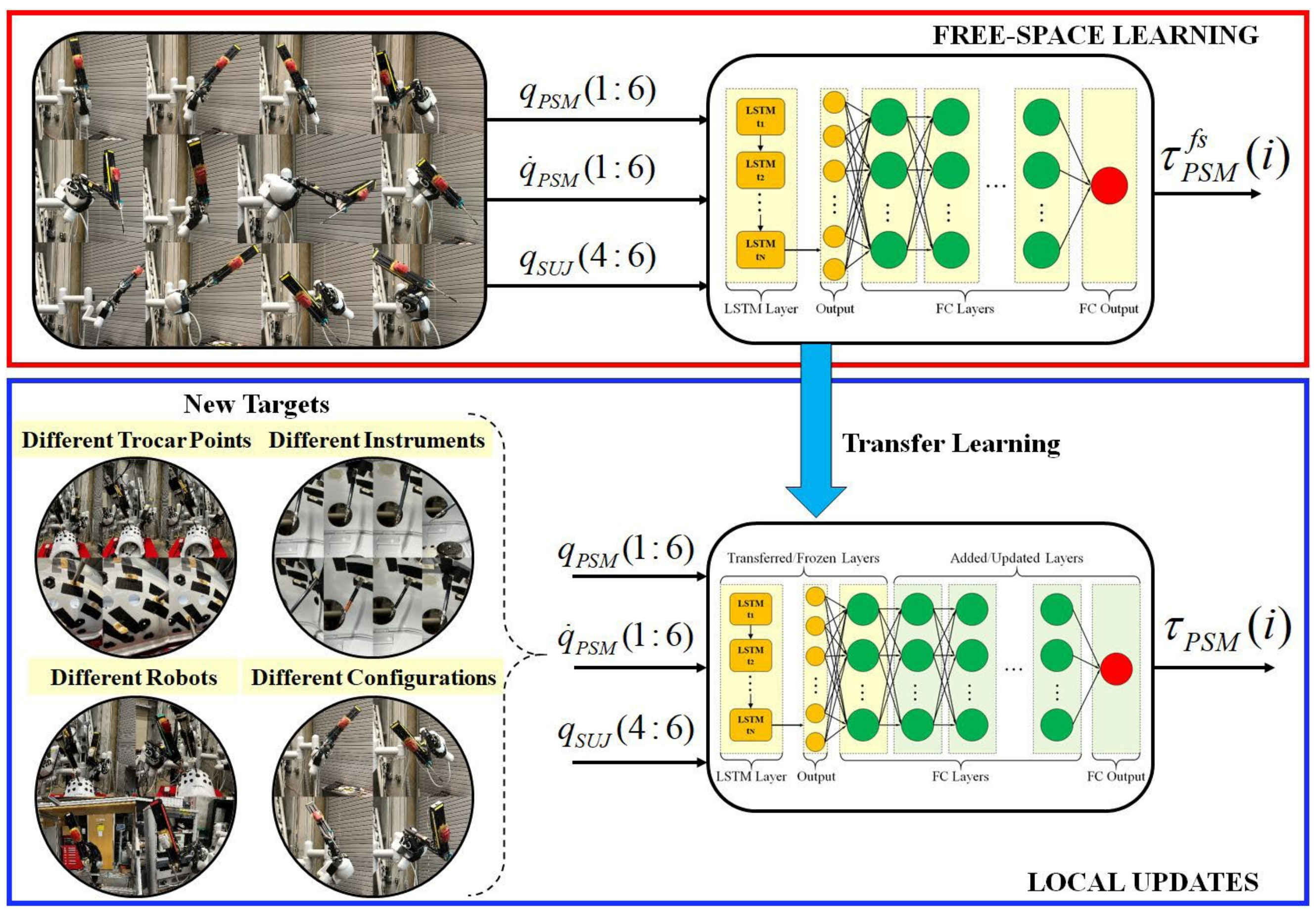
Accomplishment: Developed neural networks to estimate external forces on da Vinci Research Kit (dVRK) based on measured joint positions, velocities, and torques. Recent accomplishments include compensation for trocar interaction effects, instrument changes, and different robots.

Status: Methods have been implemented for real-time use with dVRK. Next step includes applications for bilateral teleoperation and autonomous force control.

Funding: NSF OISE 1927354

Key Personnel: Peter Kazanzides, Jintan Zhang, Juan Antonio Barragan

For More Information: smarts.lcsr.jhu.edu/research

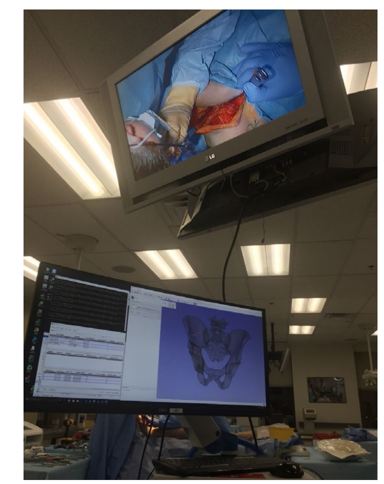


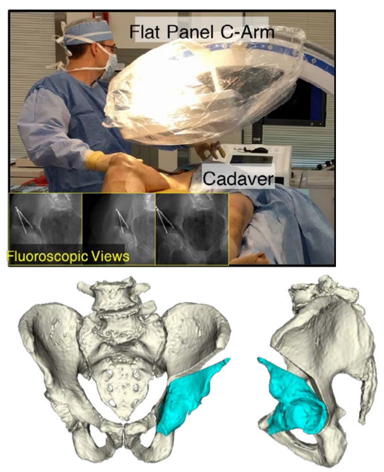
X-ray Image-based Navigation for Periacetabular Osteotomy with Intraoperative Biomechanical Feedback

PIs: Russell Taylor, Mehran Armand

Medical Robots and Computer Integrated Interventional Systems

Fiducial-Free Pose Estimation of Periacetabular Osteotomy Fragments with Intraoperative X-ray Navigation





Accomplishment: We have developed processing to use intraoperative 2D X-ray imaging for anatomical pose estimation of intact and fractured bone structures. Our approach differs from existing systems by not requiring the use of optical tracking devices or external fiducial objects.

Status: The navigation system tested with cadaver experiments. Optimal screw placement simulated. Open source libraries and compiled binaries are available at https://github.com/rg2/xreg.

Funding: NIH/NIBIB R21EB020113, JHU/APL graduate student scholarship

Key Personnel: Mehran Armand, Russell Taylor, Robert Grupp, Mahsan Bakkhtiar Nejad

Patents and Disclosures: Robert Grupp and Russell H. Taylor, "Fast and Automatic Periacetabular Osteotomy Fragment Pose Estimation Using Intraoperatively Implanted Fiducials and Single-View Fluoroscopy," PCT Application 62/896,271, filed 9/4/2020.

Key publications: R. B. Grupp, R. A. Hegeman, R. J. Murphy, C. P. Alexander, Y. Otake, B. A. McArthur, M. Armand, and R. H. Taylor, "Pose Estimation of Periacetabular Osteotomy Fragments with Intraoperative X-Ray Navigation," *IEEE Trans Biomed Eng.*, vol. 67- 2, pp. 441-452, Feb., 2020. Epub 8 March 2019 10.1109/TBME.2019.2915165

R. B. Grupp, R. J. Murphy, R. A. Hegeman, C. P. Alexander, M. Unberath, Y. Otake, B. A. McArthur, M. Armand, and R. H. Taylor, "Fast and Automatic Periacetabular Osteotomy Fragment Pose Estimation using Intraoperatively Implanted Fiducials and Single-view Fluoroscopy," *Physics in Medicine and Biology*, vol. 65- 24, 8 Dec, 2020. June 26 https://doi.org/10.1088/1361-6560/aba089 10.1088/1361-6560/aba089

R. B. Grupp, M. Unberath, C. Gao, R. A. Hegeman, R. J. Murphy, C. P. Alexander, Y. Otake, B. A. McArthur, M. Armand, and R. H. Taylor, "Automatic Annotation of Hip Anatomy in Fluoroscopy for Robust and Efficient 2D/3D Registration," International *Journal of Computer Assisted Radiology and Surgery*, 2020/04/24, 2020. https://doi.org/10.1007/s11548-020-02162-7 10.1007/s11548-020-02162-7

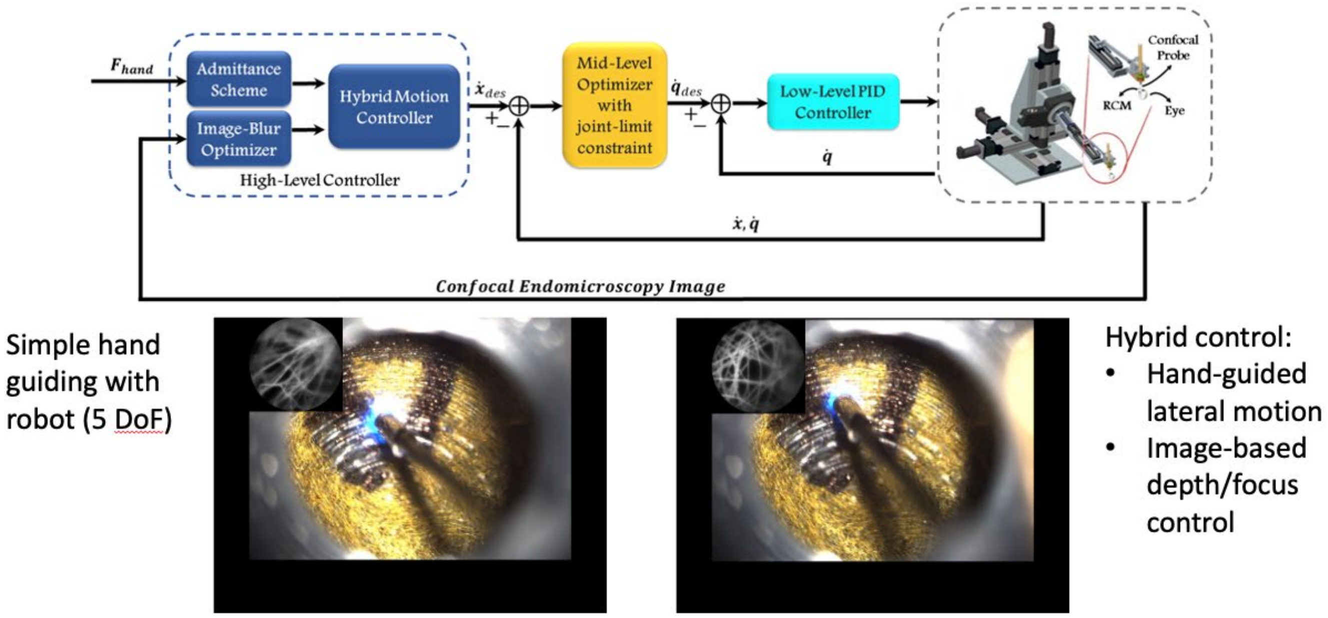
For More Information: bigss.lcsr.jhu.edu

Robot-assisted Confocal Endoscopic Imaging for Retinal Surgery

PI: Russell Taylor

Human-Machine Collaborative Systems

Medical Robots and Computer Integrated Interventional Systems



Accomplishment: We have developed a novel semi-autonomous control framework enabling probe-based confocal laser endomicroscopy (pCLE) scan of retinal tissue.

This method combines real-time image-based autonomous control of the probe-to-tissue distance with virtual fixtures to assist lateral scanning of the probe across the retinal surface. It was implemented using the dVRK software framework developed at JHU and demonstrated on using the JHU "eye robots" developed here for retinal microsurgery.

Status: Working demonstration

Funding: This work was funded in part by: NSF NRI Grants IIS-1327657, 1637789; Natural Sciences and Engineering Research Council of Canada (NSERC) Postdoctoral Fellowship #516873; Johns Hopkins internal funds; Robotic Endobronchial Optical Tomography (REBOT) Grant EP/N019318/1; EP/P012779/1 Micro-robotics for Surgery; and NIH R01 Grant 1R01EB023943-01.

Key Personnel: JHU: Zhaoshuo Li, Mahya Shahbazi, Preetham Chalasani, Niravkumar Patel, Peter L. Gehlbach, Iulian Iordachita, Russell H. Taylor

Hamlyn Centre for Medical Robotics: Eimear O' Sullivan, Haojie Zhang, Khushi Vyas, Guang-Zhong Yang

Any other info: This was a joint project with the Hamlyn Centre for Medical Robotics

Z. Li, M. Shahbazi, N. Patel, E. O. Sullivan, P. Chalasani, H. Zhang, K. Vyas, A. Deuget, P. L. Gehlbach, I. Iordachita, G.-Z. Yang, and R. H. Taylor, "An Image-Based Control Framework for Teleoperated Semi-Autonomous Retina Endomicroscopy Scanning," in Int. Symposium of Medical Robotics (ISMR), Atlanta, Georgia, April 4-5, 2019.

Z. Li, M. Shahbazi, N. Patel, E. O. Sullivan, H. Zhang, K. Vyas, P. Chalasani, P. L. Gehlbach, I. Iordachita, G.-Z. Yang, and R. H. Taylor, "A Novel Semi-Autonomous Control Framework for Retina Confocal Endomicroscopy Scanning," in International Conference on Intelligent Robots and Systems (IROS), Macao, Nov. 4-8, 2019.

For More Information: rht@jhu.edu

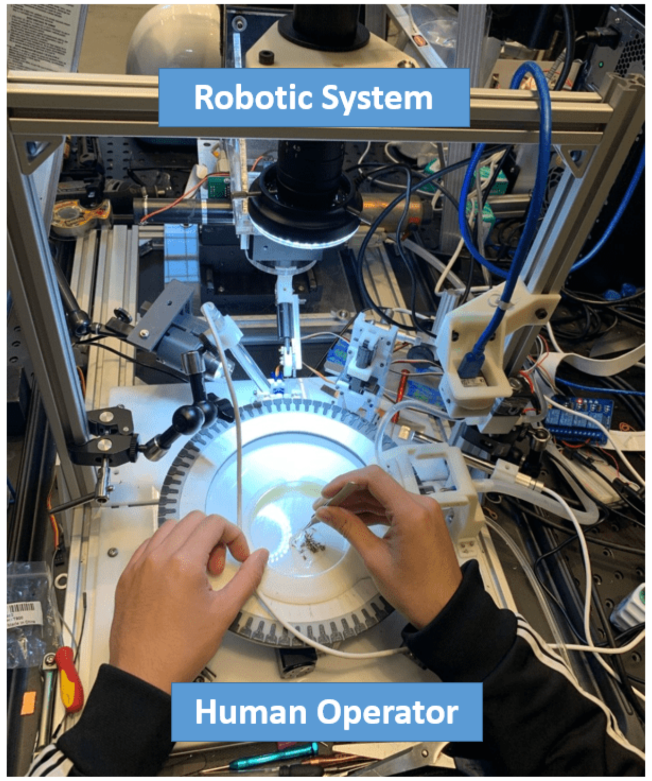
Automated Mosquito Salivary Gland Removal

PI: Russell Taylor

Human-Machine Collaborative Systems

Accomplishment: In collaboration with Sanaria, Inc., we have developed novel apparatus to assist in the extraction of salivary glands from mosquitoes, in order to address a significant barrier for large-scale production of a malaria vaccine developed by Sanaria. In an undergraduate project, we developed production fixtures that enable human operators to perform key steps of this process in parallel, resulting in a roughly two-fold increase in per-mosquito dissection rate while also significantly reducing the training time required for a production worker to reach peak proficiency from 29 weeks to 1.5 weeks. Subsequently, we have been working with Sanaria to develop a fully automated mosquito dissection system, using key insights drawn from our manual system.

Status: Sanaria is pursuing further development of the manual production fixtures for good-manufacturing-practice (GMP) while we are working with Sanaria on the automated system.



Funding: This work was supported in part by NIH SBIR grants R43AI112165 and R44AI134500. Additionally, H. Phalen is supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1746891.

Key Personnel (*current*): JHU: Russell Taylor, Iulian Iordachita, Balazs Vagvolgyi, Simon Leonard, Anna Goodridge, Vishnu Kolal, Jiaxin Luo, Miles Liu, Yuxin Chen, Wanze Li, Alan Lai, Stephen Hoffman (Sanaria), Sumana Chakravarty (Sanaria), Kim Lee Sim (Sanaria),

Past personnel: Greg Chirikjian, Mariah Schrum, Amanda Canezin, Henry Phalen, Akash Chaurasia, Matthew Fernandez, Jialan Ma, Disha Mishra, Disha Sarawgi, Andrew Shaughnessy, Hongtao Wu, Mengdi Xu, Shengnan Lu, Michael Pozin, Jin Seob Kim, Nicholas Lamaison, Can Kocabalkani, Prasad Vagdargi

Patents and Disclosures: US Patent Application US 2017 /0355951 Al, R. H. Taylor, A. Canezin, M. Schrum, G. Chirikjian, M. Laskowski, S. Chakravarty, and S. Hoffman, "Mosquito Salivary Gland Extraction Device and Methods of Use," filed Dec 14, 2017.

US Patent Application 62888160, R. H. Taylor et al., "Apparatus and Method of Use for an Automated Mosquito Salivary Gland Extraction Device," filed 16 August, 2019.

Any other info:

H. Phalen, P. Vagdargi, M. L. Schrum, S. Chakravarty, A. Canezin, Michael Pozin, S. Coemert, I. Iordachita, S. L. Hoffman, G. S. Chirikjian, and R. H. Taylor, "A Mosquito Pick-and-Place System for PfSPZ-based Malaria Vaccine Production," *IEEE Trans. Automation Science and Engineering*, vol. 18- 1, pp. 299-310, 2020.

W. Li, Z. Zhang, Z. He, P. Vora, A. Lai, B. Vagvolgyi, S. Leonard, A. Goodridge, I. Iordachita, S. Chakravarty, K. L. Sim, S. L. Hoffman, and R. H. Taylor, "Progress in Development of an Automated Mosquito Salivary Gland Extractor: A Step Forward to Malaria Vaccine Mass Production," in IEEE CASE, Prague, October, 2021 (Best Paper Finalist).

For More Information: rht@jhu.edu

Steady-Hand Robot for Head-and-Neck Surgery

PI: Russell Taylor

Human-Machine Collaborative Systems

Medical Robots and Computer Integrated Interventional Systems

Accomplishment: We have developed a prototype "steady-hand" robot for head-and-neck microsurgery. The robot was specifically designed for tremor-free operation of long tools reaching into holes while keeping the mechanism as much as possible out of the surgeon's line of sight. The control resembles power steering in a car. Both the robot and the surgeon hold the tool. The robot senses forces on the tool and moves to comply. Since the robot is doing the motion, there is no tremor, and the robot can also implement "virtual fixtures" to help guide the motion or enforce safety barriers. The robot can also be integrated with surgical navigation systems

Status: Prototype robot exists; application demos for laryngeal, sinus, open microsurgery; developing additional components for OR integration and otology; patents issued and others in prosecution; technology licensed to Galen Robotics, Inc., a startup company making a clinical/commercial version. Advanced R&D work continues in LCSR under a Master Agreement with Galen.

Funding: JHU internal funds, JHU Cohen Fund; Maryland Innovation Initiative; contract with Galen Robotics; NIH Training Grant T32 DC000027 ; NIH award K08DC019708

Key Personnel: Current WSE: Russell Taylor, Iulian Iordachita, Anna Goodridge, Zhaoshuo Li, Vishnu Kolal; JHU SOM: Francis Creighton, Deepa Galaiya, Lee Akst, Masaru Ishii, Jeremy Richmon, Matt Stewart, Wade Chien, Henry Brem; Galen Robotics: Bruce Lichorowic, Dave Saunders, Florin Neacsu , Dave Levi

Past (partial list): Can Kocabalkanli, Kevin Gilboy, Alan Lai, Seena Vafaeem Lihang Feng, Preetham Chalasani, Marcin Balicki, Kevin Olds, Paul Wilkening, Yunus Sevimli, Paul Wilkening, Thomas Keady, Mariah Schrum, Joe Peine, Chris Razavi, Olivia Puleo

Patents and Disclosures: Patents and Disclosures: These include US Patents 8,199,429 B2, 9,554,865, 9,872,198 B2, 10,166,008, Japan Patent 232410, Japan Patent 6366506, among others.

Selected papers: K. C. Olds, P. Chalasani, P. Pacheco-Lopez, I. Iordachita, L. M. Akst, and R. H. Taylor, "Preliminary Evaluation of a New Microsurgical Robotic System for Head and Neck Surgery," in IEEE Int. Conf on Intelligent Robots and Systems (IROS), Chicago, Sept 14-18, 2014. pp. 1276–1281.

Akst, K. Olds, M. Balicki, P. Chalasani, and R. Taylor, "Robotic Microlaryngeal Phonosurgery: Testing of a "Steady-Hand Platform, in *Laryngoscope*, vol. 128-, pp. 126-132, Jan., 2018. May 12 10.1002/lary.26621, PMID: 28498632

C. R. Razavi, F. X. Creighton, P. R. Wilkening, J. Peine, R. H. Taylor, and L. M. Akst, "Real-time Robotic Airway Measurement: An Additional Benefit of a Novel Steady-hand Robotic Platform," in *Laryngoscope*, pp. 324–329, Feb., 2019. Nov. 15, 2018 DOI: 10.1002/lary.27435

C. R. Razavi, P. R. Wilkening, R. Yin, S. R. Barber, R. H. Taylor, J. P. Carey, and F. X. Creighton, "Image-Guided Mastoidectomy with a Cooperatively Controlled ENT Microsurgery Robot," in *Otolaryngology–Head and Neck Surgery*, p. 0194599819861526, 2019. https://doi.org/10.1177/0194599819861526

A. S. Ding, S. A. Capostagno, C. R. Razavi, Z. Li, R. H. Taylor, J. P. Carey, and F. X. Creighton, "Volumetric Accuracy Analysis of Virtual Safety Barriers for Cooperative-Control Robotic Mastoidectomy," in *Otology & Neurotology*, vol. 42-10, pp. e1513-1517, 2021.

Related Projects: Enhanced Navigation for Endoscopic Sinus Surgery through Video Analysis

Real-time Modeling and Registration of 3D Surgical Field from Surgical Microscope Data

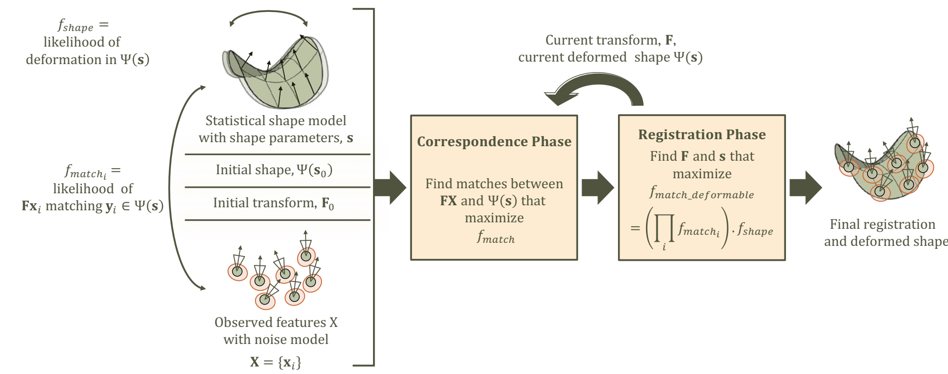
Virtual Reality Simulator for Temporal Bone Surgery

For More Information: rht@jhu.edu

Deformable Registration using Statistical Shape Models

PI: Russell Taylor

Perception and Cognitive Systems



Accomplishment: We have developed a paradigm that enables deformable registration between points generated from a shape and a statistical model of that shape, based on extensions of the "most likely point" paradigm introduced by Billings, et al. The purpose of this system is to allow inference of anatomical shapes from partial images. For instance, during an endoscopic examination of the nasal cavity, the field of view of the observer is limited to that of the endoscope, and usually a preoperative CT of the patient is not used for context and localization. Using this registration paradigm, the examiner can gain context cues without the need of a CT by using a statistical model of the nasal cavity to which points from endoscopic video can be deformably registered, and inferring the specific patient's nasal cavity. This paradigm can also be used on non-medical data, for instance, inferring facial expressions using points sampled from faces and deformably registering to a facial expression model. Our current experiments show promising submillimeter results on both simulation and clinic data.

Status: Three different algorithms have been built using this paradigm, and several experiments with simulated and in vivo clinic data have shown that submillimeter registrations and reconstructions can be achieved using these algorithms. This work has also been used in registration of both CT-derived and statistical models of sinus anatomy to endoscopic video.

Funding: NIH Grant R01 EB015530

Key Personnel: Ayushi Sinha, Seth D. Billings, Xingtong Liu, Austin Reiter, Masaru Ishii, Gregory D. Hager, Russell H. Taylor

Selected Papers: S. Billings and R. Taylor, "Generalized Iterative Most-Likely Oriented Point (G-IMLOP) Registration," in *Int. J. Computer Assisted Radiology and Surgery*, vol. 8–10, pp. 1213–1226, 2015. DOI 10.1007/s11548-015-1221-2

Sinha, S. Leonard, A. Reiter, M. Ishii, R. H. Taylor, and G. D. Hager, "Automatic Segmentation and Statistical Shape Modeling of the Paranasal Sinuses to Estimate Natural Variations," in *Proc. SPIE 9784, Medical Imaging 2016: Image Processing*, San Diego, Feb. 27, 2016. pp. 97840D.1-8.

A. Sinha, S. D. Billings, A. Reiter, X. Liu, M. Ishii, G. D. Hager, and R. H. Taylor, "The Deformable Most-likely-point Paradigm," in *Medical Image Analysis*, vol. 55, pp. 148-164, July, 2019.

A. Sinha, M. Ishii, G. D. Hager, and R. H. Taylor, "Endoscopic Navigation in the Clinic: Registration in the Absence of Preoperative Imaging," in *Int J CARS*, vol. 14-, pp. 1495-1506, 2019. 10.1007/s11548-019-02005-0

Sinha, X. Liu, M. Ishii, G. D. Hager, and R. H. Taylor, "Recovering Physiological Changes in Nasal Anatomy with Confidence Estimates," in *Uncertainty for Safe Utilization of Machine Learning in Medical Imaging and Clinical Image-Based Procedures*, Shenzhen, 2019, pp. 115-124

See also Image-based Modeling and Analysis of Anatomic Structures in the Human Temporal Bone

For More Information: rht@jhu.edu

Enhanced Navigation for Endoscopic Sinus Surgery through Video Analysis

PIs: Russell Taylor, Mathias Unberath, Gregory Hager

Human-Machine Collaborative Systems

Medical Robots and Computer Integrated Interventional Systems

Accomplishment: We have developed methods for reconstructing the shape of surfaces in the sinus cavity directly from untracked endoscopic video sequences and then registering them to patient CT or to statistical models of anatomy. This enables surgical navigation without external tracking devices and also enables combining anatomic labels and other information with real time video displays to assist the surgeon.

Funding: R01 EB015530, Galen Robotics, Johns Hopkins University internal funds

Key Personnel: A. Sinha, X. Liu, B. Vágvölgyi, S. Leonard, S. Billings, A. Reiter, S. Vedula, M. Ishii, M. Unberath, R.H. Taylor, G. D. Hager, S. Vedula

Selected papers: S. D. Billings, A. Sinha, A. Reiter, S. Leonard, M. Ishii, G. D. Hager, and R. H. Taylor, “Anatomically Constrained Video-CT Registration via the V-IMLOP Algorithm,” in *Medical Image Computing and Computer Assisted Interventions* (MICCAI), Athens, October 18-20, 2016. pp. 133-141.

S. Leonard, A. Sinha, A. Reiter, M. Ishii, G. L. Gallia, R. H. Taylor, and G. D. Hager, “Evaluation and Stability Analysis of Video-Based Navigation System for Functional Endoscopic Sinus Surgery on In-Vivo Clinical Data,” in *IEEE Trans Med Imaging*, vol. 37- 10, pp. 2185 - 2195, 2018. 10.1109/TMI.2018.2833868

A. Sinha, M. Ishii, G. D. Hager, and R. H. Taylor, “Endoscopic Navigation in the Clinic: Registration in the Absence of Preoperative Imaging”, *Int J CARS*, vol. 14-, pp. 1495-1506, 2019. 10.1007/s11548-019-02005-0

See Also: *3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning*

For More Information: rht@jhu.edu, unberath@jhu.edu, or hager@jhu.edu

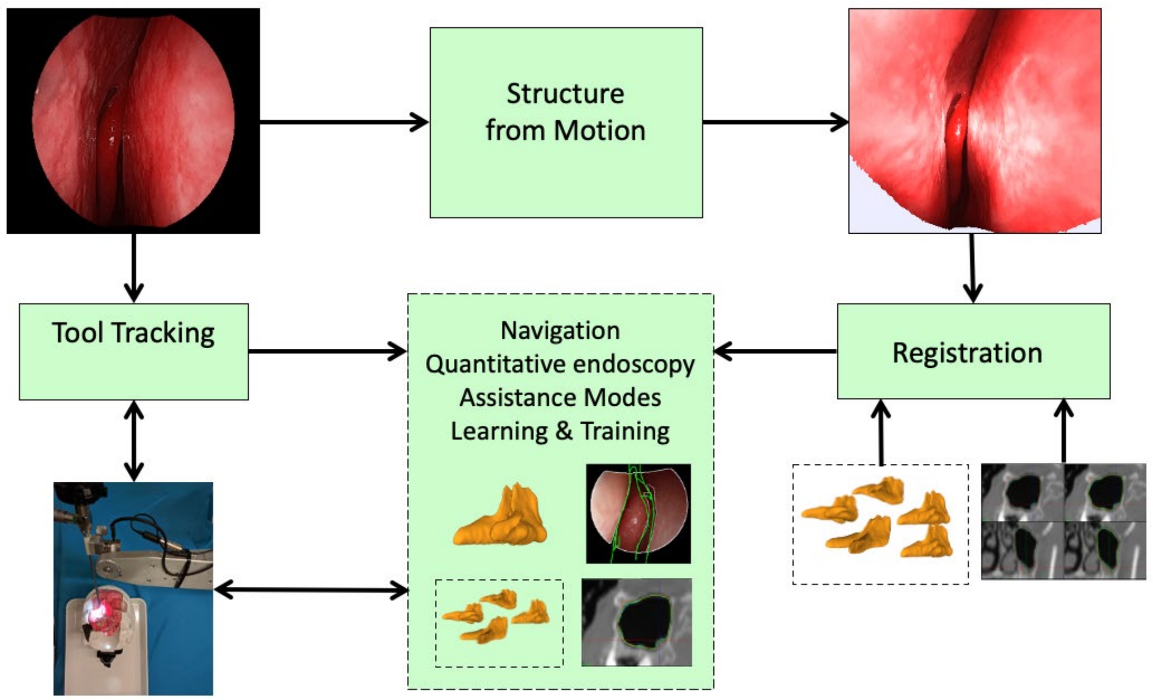
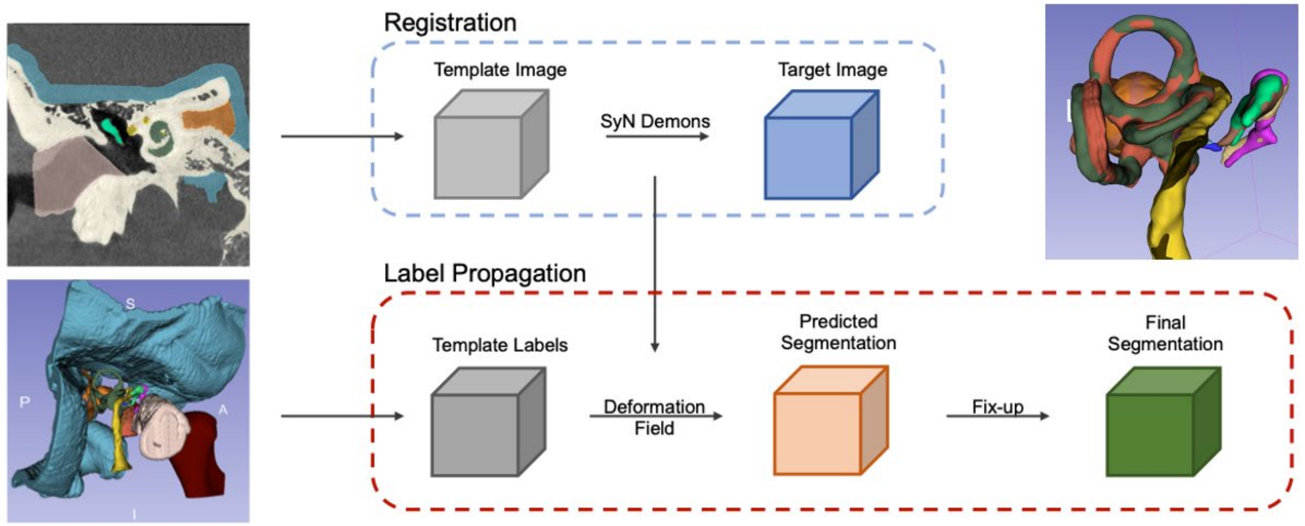


Image-based Modeling and Analysis of Anatomic Structures in the Human Temporal Bone

PI: Russell Taylor, Francis Creighton

Perception and Cognitive Systems



Accomplishment: We have developed automated segmentation methods and statistical models of anatomic structures in the human temporal bone based on high-resolution cone-beam CT (CBCT) images and have applied these models to study inter-patient variability of these structures. Future uses of these methods include patient-specific surgical planning, image-derived patient-specific virtual fixtures for robotic surgery, outcome studies, and surgical training.

Status: Active project with initial results published.

Funding: NIH T32 Training Grant (T32 DC000027); NIH award K08DC019708; Johns Hopkins internal funds

Key Personnel: Andy S. Ding, Alexander Lu, Jeffrey Siewerdsen, Russell H. Taylor, Francis X. Creighton

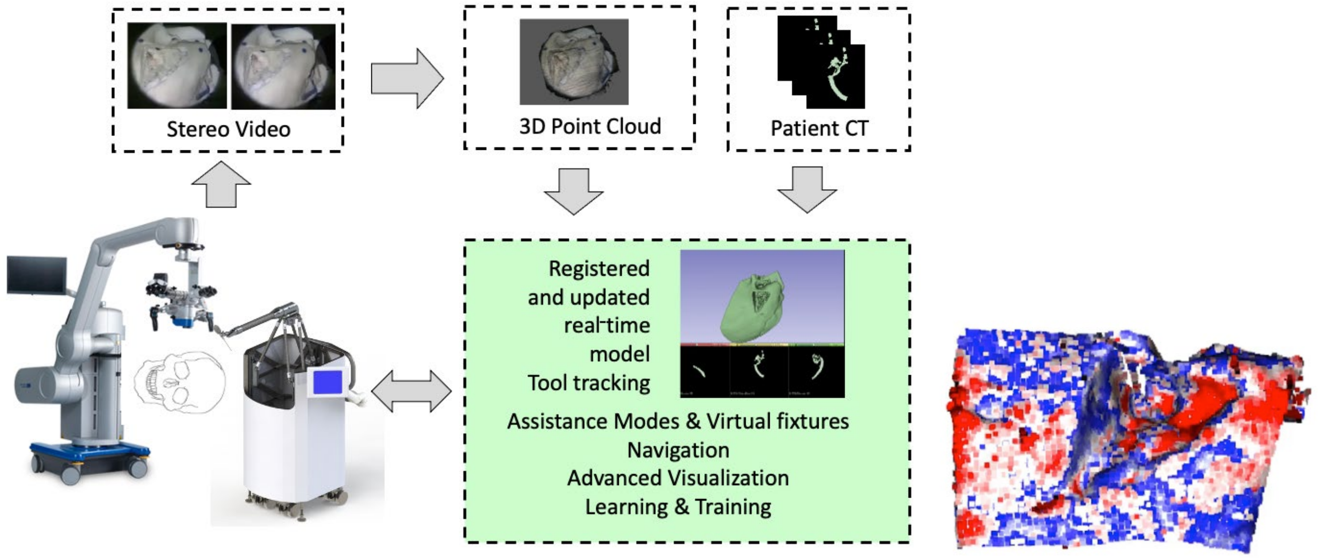
Selected Papers: A. S. Ding, A. Lu, Z. Li, D. Galaiya, J. H. Siewerdsen, R. H. Taylor, and F. X. Creighton, "Automated Registration-Based Temporal Bone Computed Tomography Segmentation for Applications in Neurotologic Surgery," in *Otolaryngology–Head and Neck Surgery*, Sept. 7, 2021 https://doi.org/10.1177/01945998211044982 10.1177/01945998211044982

For More Information: rht@jhu.edu or francis.creighton@jhmi.edu

Real-time Modeling and Registration of 3D Surgical Field from Surgical Microscope Data

PIs: Russell Taylor, Mathias Unberath

Perception and Cognitive Systems



Registration of recovered point cloud to temporal bone phantom

Accomplishment: We are developing efficient real-time methods for recovering dense point cloud representations of surgical field from stereo data captured from stereo microscopes and for using them to maintain real-time models of the surgical field. The primary motivating application for this work is image-guided otologic structures. However, the basic method is applicable in other surgical and non-surgical applications.

Status: We have developed an efficient transformer-based method for recovering dense point clouds and have evaluated this method on multiple image streams. In one evaluation experiment on a temporal bone phantom, registration of the recovered point cloud to a temporal bone phantom produced an RMS match error of ~1.1 mm. In subsequent work done in collaboration with the Chinese University of Hong Kong, these methods were combined with tool segmentation algorithms developed at CUHK and applied to stereo endoscopic data. Work is continuing at JHU to develop efficient and robust tool segmentation methods for skull base surgery.

Funding: This work was supported by a research agreement between JHU and the Hong Kong Multi-Scale Medical Robotics Center; a research agreement between JHU and Galen Robotics; NIH award K08DC019708; equipment support from Haag-Streit; and Johns Hopkins internal funds.

Key Personnel: (*JHU*) Zhaoshuo Li, Xingtong Liu, Nathan Drenkow, Andy Ding, Sue Min Cho, Francis X. Creighton, Russell H. Taylor, Mathias Unberath; (CUHK): Qi Dou, Yonghao Long

Selected Papers: Z. Li, X. Liu, N. Drenkow, A. Ding, F. X. Creighton, R. H. Taylor, and M. Unberath, "Revisiting Stereo Depth Estimation from a Sequence-to-Sequence Perspective with Transformers," in *Proc. IEEE/CVF International Conference on Computer Vision*, 2021. pp. 6197-6206.

Y. Long, Z. Li, C. H. Yee, C. F. Ng, R. H. Taylor, M. Unberath, and Q. Dou, "E-DSSR: Efficient Dynamic Surgical Scene Reconstruction with Transformer-Based Stereoscopic Depth Perception," in *Medical Image Computing and Computer Assisted Intervention: MICCAI*, 9/27-10/1, 2021. pp. 415–425.

For More Information: rht@jhu.edu or unberath@jhu.edu

Virtual Reality Simulator for Temporal Bone Surgery

PIs: Adnan Munawar, Russell Taylor, Mathias Unberath, Peter Kazanzides, Francis Creighton

Human-Machine Collaborative Systems

Medical Robots and Computer Integrated Interventional Systems

Accomplishment: We have developed a virtual reality simulator for skull base surgery, based on segmented CT models of the anatomy and the AMBF simulation environment developed by Adnan Munawar. Initial uses for this system include surgical training and generation of training data for machine learning applications. Further anticipated uses will include integration with an actual robot to provide online situational awareness during robotic surgery applications.

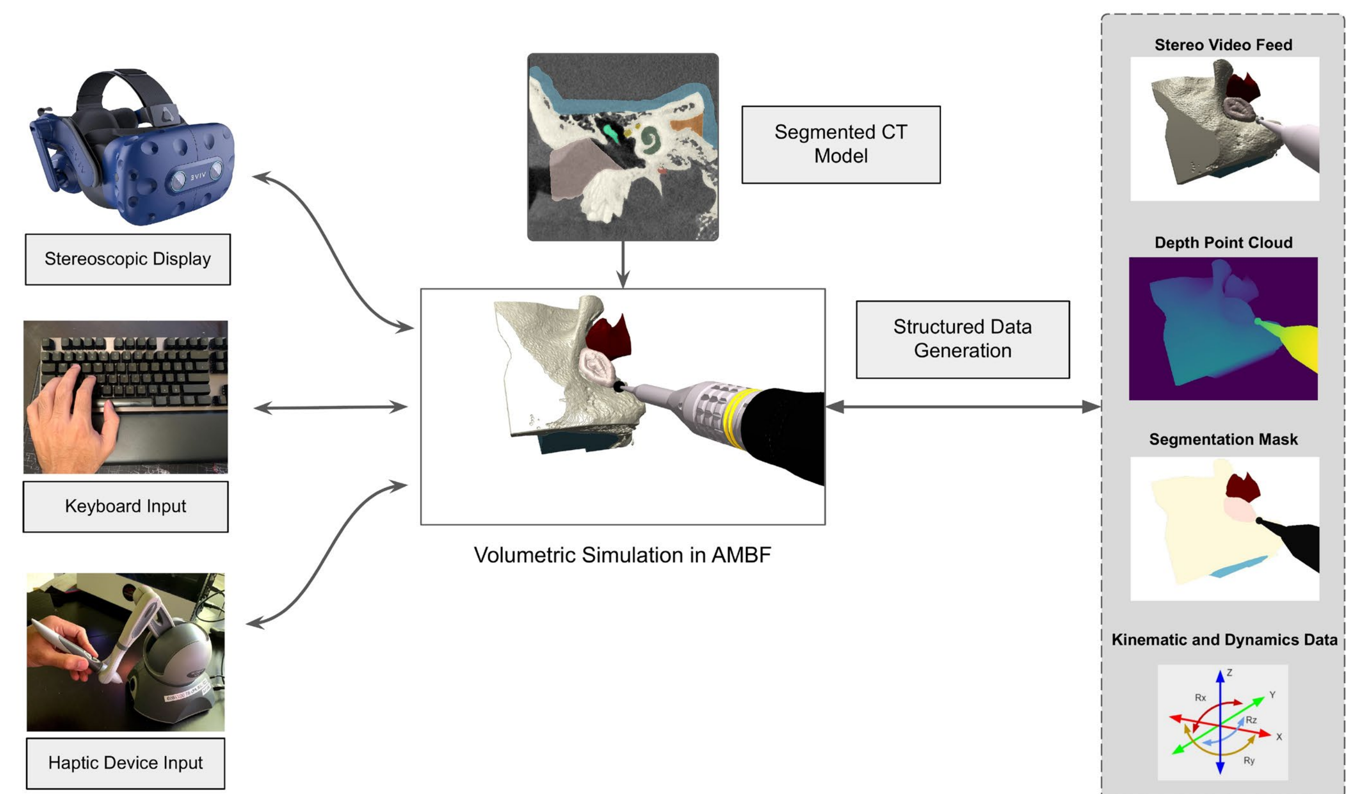
Status: Initial system developed

Funding: This work was supported by a research agreement between JHU and the Hong Kong Mult-Scale Medical Robotics Center; a research agreement between JHU and Galen Robotics; NIH award K08DC019708; equipment support from Intuitive Surgical; and Johns Hopkins internal funds.

Key Personnel: Adnan Munawar, Zhaoshuo Li, Punit Kunjam, Nimesh Nagururu, Andy S. Ding, Peter Kazanzides, Francis X. Creighton, Russell H. Taylor, Mathias Unberath

For More Information: A. Munawar, Z. Li, P. Kunjam, N. Nagururu, A. S. Ding, P. Kazanzides, T. Looi, F. X. Creighton, R. H. Taylor, and M. Unberath, "Virtual Reality for Synergistic Surgical Training and Data Generation," in *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, pp. 1–9, 2021. https://doi.org/10.1080/21681163.2021.1999331 10.1080/21681163.2021.1999331

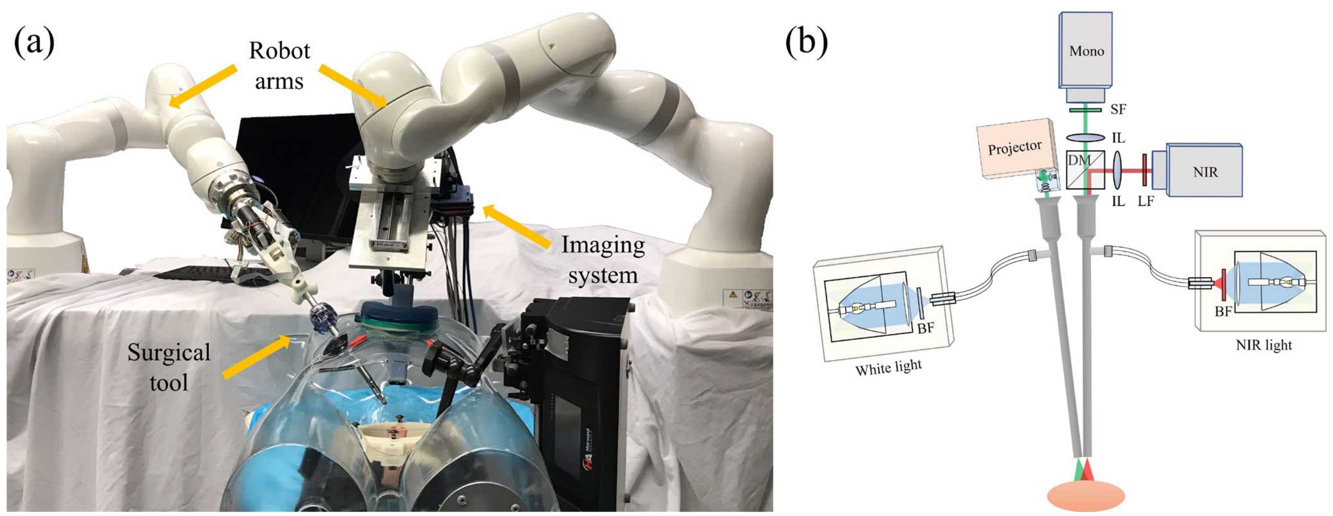
rht@jhu.edu, amunawa2@jh.edu, or francis.creighton@jhmi.edu



Endoscopic Fringe Projection Profilometry

PI: Jin U. Kang

Medical Robots and Computer Integrated Inverventional Systems



Accomplishment: We use a KUKA LBR MED robot for robot assisted intestine anastomosis. The robot consists of two robotic arms. One is holding the surgical tool for a precise and stable control. The other one is holding the endoscopic fringe projection profilometry imaging system, which measures the sample surface with point cloud data. We develop algorithms using the acquired point cloud for automatic landmark localization and surgical planning.

Status: Ongoing

Funding: NIH R01EB020610

Key Personnel: Shuwen Wei, Michael Kam, Yaning Wang, Justin D. Opfermann, Hamed Saeidi, Michael H. Hsieh, Axel Krieger, Jin U. Kang

Artificial intelligence Optical Coherence Tomography Guided Deep Anterior Lamellar Keratoplasty (AUTO-DALK)

PI: Jin U. Kang

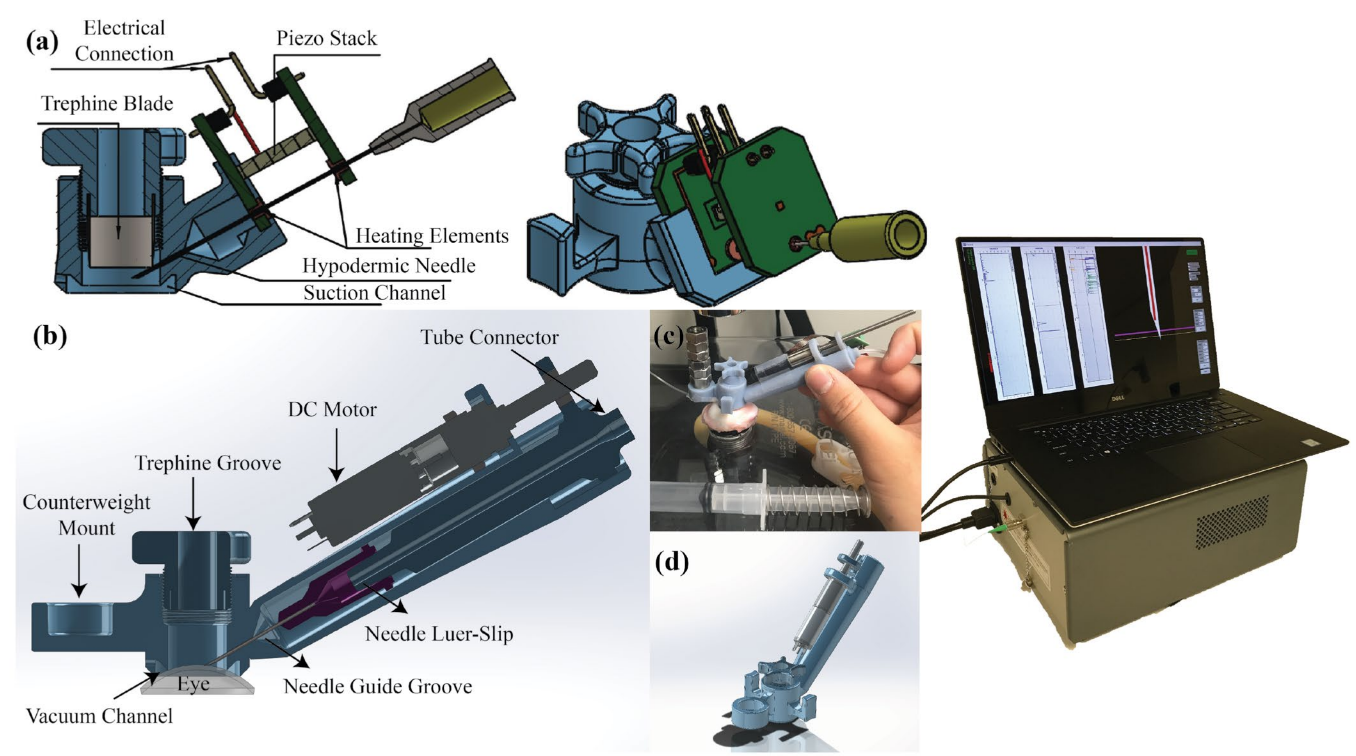
Medical Robots and Computer Integrated Interventional Systems

Accomplishment: Contemporary ocular surgeries are performed by skilled surgeons through operating microscopes, utilizing freehand techniques and manually operated precision micro-instruments, where the outcomes are often limited by the surgeon's skill levels and experiences. To overcome these human factors, we have assembled an interdisciplinary team including a clinician-scientist and eye surgeon, an optical device scientist and medical robotic engineers to translate existing and developing technologies in our laboratories into precision, "deep- learning" artificial intelligence (AI) guided robotic ocular surgical devices for precise automated Deep Anterior Lamellar Keratoplasty (AUTO-DALK). Here, we build upon our previous and ongoing work in robust fiber optic common-path optical coherence tomography (CP-OCT) and AI-guide system based on convolutional neural network (CNN) robotic microsurgical tools that enable clinicians to precisely guide surgical tools at micron scale. The proposed AUTO- DALK surgical tool system is capable of one-dimensional real-time depth tracking, motion compensation, and detection of early instrument contact with tissue, which enables clinicians to perform DALK precisely and safely.

Status: on going

Funding: NIH 1R01EY032127-01

Key Personnel: Shoujing Guo, Yaning Wang, Jin U. Kang



INDEX

Armand, Mehran
Biomechanical- and Image-Guided Surgical Systems 28
Continuum Robots, Tools, and Algorithms for Tissue Manipulation 77
Perceptual Visualization for Surgical Guidance in Orthopaedics Using Augmented Reality 78
Total Body Imaging for Skin Cancer Detection 79
Automated Implant Modification for Neuroplastic Surgery.... 80
Robot-Assisted Femoroplasty....81
Robot-Assisted Transcranial Magnetic Stimulation 82
X-ray Image-based Navigation for Periacetabular Osteotomy with Intraoperative Biomechanical Feedback....95

Bell, Muyinatu
Photoacoustic & Ultrasonic Systems Engineering 34
Deep Learning Approach to Photoacoustic Visual Servoing.... 83
Photoacoustic-Guided Hysterectomy 84
Deep Learning COVID-19 Features in Lung Ultrasound Images.... 85

Boctor, Emad
Medical UltraSound Imaging and Intervention Collaboration....6
Co-Robotic Ultrasound Tomography Framework for In Vivo Prostate Imaging....55

Brown, Jeremy D.
Haptics and Medical Robotics 26
Anthropomorphically Driven Upper-Extremity Prosthesis....61
Robot-Assisted Minimally Invasive Surgical Training....62
Neuroergonomic Evaluation on Haptic Feedback in Upper-Extremity Prostheses....63
Sensorimotor-Inspired Control for Upper-Extremity Prostheses.... 64
Haptic Perception and Task Performance During Non-Transparent Teleoperation 65

Cowan, Noah J.
Locomotion In Mechanical and Biological Systems 24
A User's Guide to System Identification for Sensorimotor Control.... 89
Programming Thermobiochemomechanical (TBCM) Multiplex Robot Gels.... 90
Human Sensory-Motor Control 91

Dahbura, Anton
Assured Autonomous Control of ICU Ventilators.... 42

Hager, Gregory
Computational Interaction and Robotics 22
The Language of Surgery Project....56
Machines with Imagination: Learning from Description through Synthesis and Analysis.... 57
3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning....73
Enhanced Navigation for Endoscopic Sinus Surgery through Video Analysis 100

Huang, Chien-Ming
Intuitive Computing....36
Human-Robot Co-Navigation 51
Human-Machine Teaming for Medical Decision Making 52
Accessible Robot Programming 53
Socially Assistive Robots for Behavioral Interventions 54

Iordachita, Iulian
Advanced Medical Instrumentation and Robotics Research 8
Enabling Technology for Image-Guided Robot-Assisted Sub-Retinal Injections 58
Adaptive Percutaneous Prostate Interventions using Sensorized Needle 59
MRI Compatible Robot for Improved Pain Injections in Adults and Children 60
Automated Mosquito Salivary Gland Removal 97

Kang, Jin U.
Photonics and Optoelectronics 38
Endoscopic Fringe Projection Profilometry 104
Artificial intelligence Optical Coherence Tomography Guided Deep Anterior Lamellar Keratoplasty (AUTO-DALK) 105

Kazanzides, Peter
Sensing, Manipulation, and Real-Time Systems 12
Telerobotic Satellite Servicing....92
Augmented Reality Assistance for Robotic Surgery....93
Force Estimation for Surgical Robotics.... 94
Virtual Reality Simulator for Temporal Bone Surgery....103

Kobilarov, Marin
Autonomous Systems, Control and Optimization....16
Robotic Environmental Sampling 69
Autonomous Aerial Manipulation....70
Autonomously Navigating a Surgical Tool Inside the Eye by Learning from Demonstration 71

Krieger, Axel
Intelligent Medical Robotic Systems & Equipment 18
Autonomous Robotic Soft Tissue Surgery 43
Image Guided Interventions and Planning.... 44
Autonomous Robotic Ultrasound.... 45
Magnetically Actuated Microrobots.... 46
Cardiac Planning and Patient Specific Implant Design 47

Li, Chen
Terradynamics....10
The Terradynamics of Biological Movement in Complex Terrain.... 48
Neuromechanics of Legged Locomotion on Energy Landscapes of Complex Terrains.... 49
Simulation of Multi-Legged Robot Locomotor Transitions to Traverse Rocky Martian Terrain 50

Navab, Nassir
Computer Aided Medical Procedures....32
Interactive Flying Frustums 86
Augmented Mirrors....87
iOCT-Guided Robot-Assisted Sub Retinal Injection 88

Taylor, Russell
Computer-Integrated Interventional Systems Lab 20
Assured Autonomous Control of ICU Ventilators.... 42
3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning....73
X-ray Image-based Navigation for Periacetabular Osteotomy with Intraoperative Biomechanical Feedback....95
Robot-assisted Confocal Endoscopic Imaging for Retinal Surgery 96
Automated Mosquito Salivary Gland Removal....97
Steady-Hand Robot for Head-and-Neck Surgery 98
Deformable Registration using Statistical Shape Models.... 99
Enhanced Navigation for Endoscopic Sinus Surgery through Video Analysis 100
Image-based Modeling and Analysis of Anatomic Structures in the Human Temporal Bone....101
Real time Modeling and Registration of 3D Surgical Field from Surgical Microscope Data....102
Virtual Reality Simulator for Temporal Bone Surgery....103

Unberath, Mathias
Advanced Robotics and Computationally Augmented Environments.... 30
Task-aware and Autonomous C-arm Imaging....72
3D Reconstruction of Sinus Anatomy from Monocular Endoscopic Video using Self-supervised Learning....73
Transparent Machine Learning for Healthcare....74
SyntheX: Scaling Up Learning-based X-ray Image Analysis Through In Silico Experiments....75
Mixed Reality for Surgical Guidance 76
Real Time Modeling and Registration of 3D Surgical Field from Surgical Microscope Data....102
Virtual Reality Simulator for Temporal Bone Surgery....103

Whitcomb, Louis
Dynamical Systems and Control 14
Development of Nereid Under-Ice (NUI): An Underwater Robot for Oceanographic Exploration Under Polar Ice.... 66
Development of a Low-Cost True-North Seeking Fiber Optic Gyrocompass for Precision Underwater Robot Navigation....67
Precision Navigation of Low-Cost Underwater Robotic Vehicles for Ocean Science.... 68
Telerobotic Satellite Servicing....92

2022

BIOROBOTICS

HUMAN MACHINE COLLABORATIVE SYSTEMS

MEDICAL ROBOTS AND COMPUTER INTEGRATED INTERVENTIONAL SYSTEMS

MODELING, DYNAMICS, NAVIGATION, AND CONTROL

PERCEPTION AND COGNITIVE SYSTEMS

ROBOTICS IN EXTREME ENVIRONMENTS

LABORATORY FOR
Computational
Sensing + Robotics