

Peter Kazanzides

PERSONAL DATA

Birth date	August 14, 1961
Birth place	Jersey City, New Jersey
Citizenship	USA
Family	Married, two children
Professional Address	Department of Computer Science The Johns Hopkins University Baltimore, Maryland 21218
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EDUCATION

- Ph.D. Electrical Engineering – Brown University, May 1988
Thesis: Design and construction of a real-time multiprocessor system (SIERA), which was applied to two different robots. Development and implementation of a compliant control strategy which enables a robot to interact with an imprecisely known environment.
- Sc.M. Applied Mathematics – Brown University, May 1987
- Sc.M. Electrical Engineering – Brown University, May 1985
Thesis: Modeling of a hydraulic actuator and design of digital control laws. Analyzed the effects of non-linearities in the model and the control laws and presented experimental results to verify the theory.
- Sc.B. Electrical Engineering (Honors, Magna Cum Laude) – Brown University, May 1983
- A.B. Computer Science – Brown University, May 1983

RESEARCH SUMMARY

My research activities are in computer-assisted surgery and space telerobotics, which share the common themes of human/machine interfaces to keep the human in the loop, real-time sensing to account for uncertainty, and system engineering to enable deployment in the real world. Surgical robotics requires a partnership between man and machine that must operate in an unstructured environment with constraints on visibility, accessibility, and sterility. My research has focused on the integration of information from various sources, such as preoperative and intraoperative imaging and force sensing, to address these challenges. I have also applied these techniques to space robots; specifically, for a telerobotic system for satellite servicing, which is subject to time delays of 2-7 seconds.

In 1989, while developing a robot for orthopaedic surgery, I pioneered the use of force-controlled guidance as a surgical robot interface. More recently, I have been applying virtual fixtures as guidance and safety constraints and have performed research in augmented reality interfaces for both medical and space applications. My current research interests include the integration of real-time sensor feedback, including model-based and data-driven (machine learning) approaches, to enable

robotic assistance in more challenging environments. I am also exploring the use of sensor fusion, incorporating different tracking technologies such as electromagnetic, optical, and inertial, to improve the robustness of tracking technology for applications in robotics, surgical navigation, and augmented reality.

These applications have also motivated me to define and develop enabling systems and architectures. A surgical robot, with associated information sources, generally requires concurrent processing, with low-latency exchange of information. My research involves the application of component-based software engineering concepts to provide a uniform programming model that spans from multi-threaded systems to multi-process and multi-processor systems. This research is embodied in the open-source cisst libraries and Surgical Assistant Workstation (SAW) software. As a service to the research community, I have disseminated the hardware and software to control research da Vinci Systems at more than forty institutions worldwide, with additional sites in process.

WORK HISTORY

<i>Research Professor, Dept. of Computer Science</i>	<i>July 2014 – present</i>
<i>Associate Research Professor, Dept. of Computer Science</i>	<i>Sept. 2008 – June 2014</i>
<i>Assistant Research Professor, Dept. of Computer Science</i>	<i>Dec. 2002 – Sept. 2008</i>

Chief Systems and Robotics Engineer, Center for Computer-Integrated Surgical Systems and Technology, Johns Hopkins Univ., Baltimore, MD

Leading development of open source CISST/SAW software package, custom hardware, and open source da Vinci Research Kit (dVRK). Managing several projects, including development of robot systems for neurosurgery, prostate brachytherapy, orthopaedics, and satellite servicing and research in augmented reality head-mounted displays.

<i>Co-founder and Director of Robotics and Software, Integrated Surgical Systems, Davis, CA</i>	<i>Nov. 1990 – June 2002</i>
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Formed ISS to develop and commercialize the ROBODOC® Surgical Assistant for human use. Designed and implemented the electronics and software, achieving major improvements in the user interface, safety systems, accuracy, maintainability and cost. Worked with robot manufacturer to customize industrial robot for medical use. Assisted with development of engineering processes appropriate for a medical device manufacturer, including production of standard operating procedures, written specifications, formal design reviews, manufacturing procedures, and configuration management and change control. Participated in ISO9001 certification and CE marking, including EMC certification for emissions and immunity. Obtained 510(K) clearance from FDA for ORTHODOC planning system. Program Manager for \$4 million NIST ATP joint venture (ISS, IBM and Johns Hopkins Univ.) investigating the application of robotics to total hip revision surgery. Assisted with the acquisition of IMMI in Lyon, France to increase technology portfolio and enter neurosurgery business. Extensive experience in field service and customer support including installation of systems at clinical trial sites, training of personnel, support during surgical procedures, and system maintenance. Managed inter-disciplinary group of 3-7 engineers.

<i>Visiting Associate Research Engineer, University Of California, Davis, CA</i>	<i>Mar. 1990 – Nov. 1990</i>
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Continued work on hip replacement robot that was started as joint project between IBM and UC Davis. Brought robot into veterinary operating room, where it was used for 26 canine surgeries, all successful. Refined system based on clinical feedback.

Post-Doctoral Researcher, IBM T.J. Watson Research Center, Yorktown Heights, NY

Mar. 1989 – Mar. 1990

Performed research on medical applications of robotics. Developed compliant control strategies and robot software for total hip replacement surgery. Integrated force sensor, pitch axis, and signal processor with IBM robot.

PROFESSIONAL ACTIVITIES

Editorial Boards

Editorial Board, International Journal of Medical Robotics and Computer Assisted Surgery, Wiley, 2019

Associate Editor, IEEE International Conference on Robotics and Automation (ICRA), 2011-2018

Associate Editor, IEEE International Conference on Intelligent Robots and Systems (IROS), 2011

Conference and Workshop Committees

Co-organizer of Tutorials on Medical Robotics at MICCAI 2005, MICCAI 2006, and ICRA 2007.

Co-organizer of Workshop on Medical Robotics at MICCAI 2006, Copenhagen, Denmark, Oct 5, 2006

Working Group member, High Confidence Medical Device Software and Systems workshop, Philadelphia, PA, June, 2005

Program Committee, 1st Intl. Conf. on Complex Medical Engineering (CME) 2005, Takamatsu, Japan

Program Committee, 2nd Intl. Conf. on Complex Medical Engineering (CME) 2007, Beijing, China

Program Committee, Medical Image Computing and Computer Assisted Interventions (MICCAI) 2008, New York, NY

Co-organizer of Workshop on Systems and Architectures for Computer Assisted Interventions at MICCAI 2008-2013

Area Chair, 1st Intl. Conf. on Information Processing in Computer-Assisted Interventions (IPCAI) 2010, Geneva, Switzerland

Breakout Session Lead, Medical Robotics, NSF 2014 National Workshop on Research Frontiers in Medical Cyber-Physical Systems, Feb. 2014.

Co-organizer of Workshop on Community Consensus Benchmarks for Clinical Translation of Medical Robots at IROS 2014, Chicago, IL, Sept. 2014

Co-organizer of Workshop on Shared Frameworks for Medical Robotics Research at ICRA 2015, Seattle, WA, May 2015

Organizer of Workshop on Shared Platforms for Medical Robotics Research at IROS 2017, Vancouver, Canada, Sept. 2017.

Co-organizer of Workshop on Supervised Autonomy in Surgical Robotics at ICRA 2018, Brisbane, Australia, May 2018.

Organizer of Tutorial on Collaborative Robotics Toolkit (CRTK) and Open Platforms for Medical Robotics Research at IROS 2018, Madrid, Spain, Oct. 2018.

Organizer of Workshop on Data-Driven Methods for Robotic Minimally-Invasive Surgery at International Symposium on Medical Robotics (ISMR), Atlanta, Georgia, Apr. 2019.

Organizer of Workshop on Open Platforms for Medical Robotics Research at International Symposium on Medical Robotics (ISMR), Atlanta, Georgia, Nov. 2021.

Organizer of Raven/dVRK Surgical Robotics Research Symposium, Online, March 2021, July 2021.

Program Committee of Hamlyn Symposium, London, UK, June 2017-2022
Program Committee, IEEE International Conference on Robotic Computing, 2017-2022

Other Committees

ASTM working group F04.05 developing standards for Computer Assisted Orthopaedic Surgery (CAOS) Systems, 2004-2010
Engineering Faculty Academic Advisory Committee (EFAAC), Johns Hopkins University, Whiting School of Engineering, (aka WSE Faculty Senate), elected 2021.

HONORS AND AWARDS

- Computerworld/Smithsonian Award in Medicine – awarded to ISS, Inc., June 1992
- IBM Graduate Predoctoral Fellowship – Brown University, academic years 1985 - 1988
- Thomas Carpenter Premium Award, recognizing top student in graduating class – Brown Univ., May 1983
- Magna Cum Laude and Honors in Engineering – Brown University, May 1983

ACADEMIC ADVISING

Ph.D. Theses Advised

Mohammad Matinfar, *Precise Irradiation and Delivery of Complex Dose Volumes for Small Animal Research*, Computer Science, The Johns Hopkins University, January 2011.

Tian Xia, *Model Driven Robotic Assistance for Human-Robot Collaboration*, Computer Science, The Johns Hopkins University, October 2013.

Min Yang Jung, *State-based Safety of Component-based Medical and Surgical Robot Systems*, Computer Science, The Johns Hopkins University, May 2015.

Hasan Tutkun Sen, *Robotic System and Co-manipulation Strategy for Ultrasound Guided Radiotherapy*, Computer Science, The Johns Hopkins University, April 2016.

Zihan Chen, *A Scalable, High-Performance, Real-Time Control Architecture with Application to Semi-Autonomous Teleoperation*, The Johns Hopkins University, October 2017.

Bongjoon (Nathan) Cho, *Forward and Inverse Treatment Planning Solutions for Small Animal Radiation Research*, The Johns Hopkins University, October 2017.

Long Qian, *Augmented Reality Assistance for Surgical Interventions using Optical See-Through Head-Mounted Displays*, The Johns Hopkins University, April 2020.

Ehsan Azimi, *Interactive Platform for Medical Procedures in Mixed Reality*, The Johns Hopkins University, July 2020.

Jie Ying Wu, *Using High-Level Processing of Low-Level Signals to Actively Assist Surgeons with Intelligent Surgical Robots*, The Johns Hopkins University, August 2021.

Ph.D. Theses Advised (as secondary advisor or reader)

Ankur Kapoor, *Motion Constrained Control of Robots for Dexterous Surgical Tasks*, Computer Science, The Johns Hopkins University, August 2007.

Amen Ra Mashariki, *Development of a Model Driven Architecture and Software Quality Based Framework for a Robust Distributed Medical Software System*, Industrial Manufacturing and Information Engineering, Morgan State University, May 2008.

Marcin Balicki, *Augmentation Of Human Skill In Microsurgery*, Computer Science, The Johns Hopkins University, February 2014.

Paul Thienphrapa, *A Minimally Invasive Surgical System for 3D Ultrasound Guided Robotic Retrieval of Foreign Bodies from a Beating Heart*, Computer Science, The Johns Hopkins University, March 2014.

Wen Liu, *Augmented Reality and Intraoperative C-Arm Cone-Beam Computed Tomography for Image-Guided Robotic Surgery*, Computer Science, The Johns Hopkins University, June 2014.

Kevin Olds, *Robotic Assistant Systems for Otolaryngology-Head and Neck Surgery*, Biomedical Engineering, The Johns Hopkins University, March 2015.

Hyun Jae Kang, *Medical Ultrasound Imaging and Interventional Component (MUSiiC) Framework for Advanced Ultrasound Image-guided Therapy*, Computer Science, The Johns Hopkins University, July 2015.

Seth Billings, *Probabilistic Feature-Based Registration for Interventional Medicine*, Computer Science, The Johns Hopkins University, Aug. 2015.

Omid Mohareri, *Image and Haptic Guidance for Robot-Assisted Laparoscopic Surgery*, Electrical and Computer Engineering, University of British Columbia, Oct. 2015.

Jelena Frtunikj, *Safety Framework and Platform for Functions of Future Automotive E/E Systems*, Institute for Informatics, Technical University of Munich (TUM), June 2016.

Jonathan Bohren, *Intent-Recognition-Based Traded Control for Telerobotic Assembly over High-Latency Telemetry*, Dept. of Mechanical Engineering, Johns Hopkins University, Jan. 2017.

Piyamate Wisanuvej, *Robotic Manipulators for Single Access Surgery*, Dept. of Computing, Imperial College (London, UK), July 2018.

Preetham Chalasani, *Complementary Situational Awareness for an Intelligent Telerobotic Surgical Assistant System*, Dept. of Computer Science, Johns Hopkins University, Oct. 2018.

Adnan Munawar, *An Asynchronous Simulation Framework for Multi-User Interactive Collaboration: Application to Robot-Assisted Surgery*, Robotics Engineering, Worcester Polytechnic Institute, December 2019.

Kim Lindberg Schwaner, *Autonomy for Surgical Robot Systems*, University of Southern Denmark, September 2021.

Byeol Star Kim, *Advances in Diagnosis and Surgery of Congenital Heart Disease through Novel Virtual Reality Systems for Design, Simulation, and Planning Methods*, Dept. of Mechanical Engineering, Johns Hopkins University, November 2021.

M.S. Theses Advised or Co-Advised:

Jack Li, *Design and Validation of an Image-Guided Optical Probe Insertion Robot for Small Animal Research*, Mechanical Engineering, The Johns Hopkins University, February 2005.

Karsten Seidl, *Optical Measurement of Needle Insertion Depth*, Ilmenau University of Technology (Germany), December 2006.

Tamas Haidegger, *Improving the Accuracy and Safety of a Robotic System for Neurosurgery*, Control Engineering and Information Technology, Budapest University of Technology and Economics (Hungary), May 2008.

Mitch Williams, *A Modular Framework for Clinical Decision Support Systems*, Computer Science, The Johns Hopkins University, May 2009.

Fran Wu, *A Modular Framework and Algorithm for Clinical Decision Support Systems*, Computer Science, The Johns Hopkins University, October 2009.

Pramod Verma, *Augmented Reality Based 3D UI for Medical Interventions*, Computer Science, The Johns Hopkins University, October 2010.

Isha Kandaswamy, *Development, analysis and modeling of forces for cutting satellite insulation in telerobotic servicing missions*, Computer Science, The Johns Hopkins University, August 2012.

Yang Wang, *Robotic System with Multiplex Power Transmission for MRI-Guided Prostate Percutaneous Interventions*, Robotics, The Johns Hopkins University, May 2016.

Current Graduate Students

Will Pryor, Ph.D. student (since 2017)

Keshuai Xu, Ph.D. student (since 2018)

Dayeon Kim, Ph.D. student (since 2019)

Nick Greene, Ph.D. student (since 2020)

Hisashi Ishida, Ph.D. student (since 2021)

Juan Antonio Barragan, Ph.D. student (since 2021)

Advising Activities at Morgan State University (MSU)

Jointly mentored undergraduate and graduate students with Dr. LeeRoy Bronner, through two research projects:

1. Architecture and middleware for distributed medical devices (2003-2008): 4 MSU graduate students, including one co-advised Ph.D. thesis (Amen Ra Mashariki)

2. Intelligent management and dissemination of research information (2005-2008): 2 MSU graduate students, 2 MSU undergraduate students

Both of these projects also involved frequent interactions with JHU graduate and undergraduate students.

Other Academic Advising

Research Experience for Undergraduates (REU): mentored 1-2 summer students per year since 2004

Mentor for several project teams for 600.446 (Computer-Integrated Surgery II)

Mentor for many JHU undergraduate students. Following are some whose work received recognition:

- Pauline Pelletier, recipient of 2006 Michael J. Muuss Research Award, in project with Morgan State University.
- Praneeth Satta, recipient of the Pistritto Undergraduate Research Fellowship for the academic year 2011-2012 and the Provost Undergraduate Research Award (PURA) in 2013.
- Martin Kelly, recipient of the Pistritto Undergraduate Research Fellowship for the academic year 2012-2013.
- Junxiang (Jim) Wang, recipient of the Provost Undergraduate Research Award (PURA) in summer 2022.

PUBLICATIONS

Book Chapters:

1. Lasso, A., Kazanzides, P., "System Integration", *Handbook of Medical Image Computing and Computer Assisted Intervention*, Academic Press, pp 861-891, 2020.
2. Taylor, R. H., Kazanzides, P., Fischer, G. S., Simaan, N., "Medical Robotics and Computer-Integrated Interventional Medicine," *Biomedical Information Technology (2nd Edition)* (edited by D. Feng), Academic Press, pp 617-672, 2020.
3. Taylor, R.H., Kazanzides, P., "Medical Robotics and Computer-Integrated Interventional Medicine," *Advances in Computers* (edited by M. Zelkowitz), Academic Press, Vol. 73, pp 219-260, 2008.
4. Kazanzides, P. "Robots for Orthopaedic Joint Reconstruction," *Robotics in Surgery: History, Current and Future Applications* (edited by R. Faust), Nova Science Publishers, pp 61-94, 2007.
5. Taylor, R., Kazanzides, P. "Medical Robotics and Computer-Integrated Interventional Medicine," *Biomedical Information Technology* (edited by D. Feng), Academic Press, pp 393-416, 2007.
6. Mittelstadt, B., Kazanzides, P., Zuhars, J., Williamson, B., Cain, P., Smith, F., Bargar, W.L., "The Evolution of a Surgical Robot from Prototype to Human Clinical Use," *Computer Integrated Surgery* (edited by R.H. Taylor, S. Lavallée, G.C. Burdea, R. Mösges), MIT Press, Cambridge, MA, 1996.
7. Taylor, R.H., Mittelstadt, B.D., Paul, H.A., Hanson, W., Kazanzides, P., Zuhars, J.F., Williamson, B., Musits, B.L., Glassman, E., Bargar, W.L. "An Image-Directed Robotic System for Precise

Orthopaedic Surgery," *Computer Integrated Surgery* (edited by R.H. Taylor, S. Lavallée, G.C. Burdea, R. Mösges), MIT Press, Cambridge, MA, 1996.

Journal Papers:

1. Qian, L., Song, T., Unberath, M., Kazanzides, P., "AR-Loupe: Magnified augmented reality by combining an optical see-through head-mounted display and a loupe," *IEEE Trans. on Visualization and Computer Graphics*, Vol. 28, No. 7, pp. 2550-2562, July 2022.
2. Connolly, L., Deguet, A., Leonard, S., Tokuda, J., Ungi, T., Krieger, A., Kazanzides, P., Mousavi, P., Fichtinger, G., Taylor, R.H., "Bridging 3D Slicer and ROS2 for Image-Guided Robotic Interventions," *Sensors*, Vol. 22, July 2022.
3. Munawar, A., Wu, J.Y., Fischer, G.S., Taylor, R.H., Kazanzides, P., "An open simulation environment for learning and practice of robot-assisted surgical suturing," *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 3843-3850, April 2022.
4. Yilmaz, N., Zhang, J., Kazanzides, P., Tumerdem, U., "Transfer of learned dynamics between different surgical robots and operative configurations," *Intl. Journal of Computer Assisted Radiology and Surgery (IJCARS)*, vol. 17, pp. 903-910, April 2022.
5. Xu, K., Jiang, B., Moghekar, A., Kazanzides, P., Boctor, E., "AutoIn-Focus, a new paradigm for ultrasound-guided spine intervention: a multiplatform validation study," *Intl. Journal of Computer Assisted Radiology and Surgery (IJCARS)*, vol. 17, pp. 911-920, March 2022.
6. Munawar, A., Li, Z., Kunjam, P., Nagururu, N., Ding, A.S., Kazanzides, P., Looi, T., Creighton, F.X., Taylor, R.H., Unberath, M., "Virtual reality for synergistic surgical training and data generation," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, 2021, presented at AE-CAI 2021.
7. Kazanzides, P., Vagvolgyi, B.P., Pryor, W., Deguet, A., Leonard, S., Whitcomb, L.L., "Teleoperation and visualization interfaces for remote intervention in space," *Frontiers in Robotics and AI*, vol. 8, Dec. 2021.
8. Vagvolgyi, B.P., Khrenov, M., Cope, J., Deguet, A., Kazanzides, P., Manzoor, S., Taylor, R.H., Krieger, A., "Telerobotic operation of intensive care unit ventilators", *Frontiers in Robotics and AI*, vol. 8, pp. 1-15, June 2021.
9. Munawar, A., Wu, J.Y., Taylor, R.H., Kazanzides, P., Fischer, G.S., "A framework for customizable multi-user teleoperated control", *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 3256-3263, April 2021.
10. Lin, H., Gao, Q., Chu, X., Dou, Q., Deguet, A., Kazanzides, P., Au, K.S., "Learning deep nets for gravitational dynamics with unknown disturbance through physical knowledge distillation: Initial feasibility study", *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 2658-2665, April 2021.
11. Wu, J.Y., Tamhane, A., Kazanzides, P., Unberath, M., "Cross-modal self-supervised representation learning for gesture and skill recognition in robotic surgery", *Intl. Journal of Computer Assisted Radiology and Surgery (IJCARS)*, vol. 16, pp. 779-787, March 2021.
12. Yasin, R., Chalasani, P., Zevallos, N., Shahbazi, M., Li, Z., Deguet, A., Kazanzides, P., Choset, H., Taylor, R.H., Simaan, N., "Evaluation of hybrid control and palpation assistance for situational awareness in telemanipulated task execution", *IEEE Trans. on Medical Robotics and Bionics*, vol. 3, no. 1, pp. 31-43, Feb. 2021.
13. Sefati, S., Hegeman, R., Alambeigi, F., Iordachita, I., Kazanzides, P., Khanuja, H., Taylor, R., Armand, M., "A surgical robotic system for treatment of pelvic osteolysis using an FBG-equipped

- continuum manipulator and flexible instruments”, *IEEE/ASME Trans. on Mechatronics*, vol. 26, no. 1, pp. 369-380, 2020.
14. Wu, J.Y., Kazanzides, P., Unberath, M., “Leveraging vision and kinematics data to improve realism of biomechanic soft tissue simulation for robotic surgery”, *Intl. Journal of Computer Assisted Radiology and Surgery (IJCARS)*, vol. 15, pp. 811-818, April 2020.
 15. Qian, L., Wu, J.Y., DiMaio, S.P., Navab, N., Kazanzides, P., “A review of augmented reality in robotic-assisted surgery”, *IEEE Transactions on Medical Robotics and Bionics*, vol. 2, no. 1, pp. 1-16, Feb 2020.
 16. Chrysilla, G., Eusman, N., Deguet, A., Kazanzides, P., “A compliance model to improve the accuracy of the da Vinci Research Kit (dVRK)”, *Acta Polytechnica Hungarica, Special Issue on Platforms for Medical Robotics Research*, vol. 16, no. 8, pp. 49-60, 2019.
 17. Lin, H., Hui, C.-W. V., Wang, Y., Deguet, A., Kazanzides, P., Au, K. W. S., “A reliable gravity compensation control strategy for dVRK robotic arms with nonlinear disturbance forces”, *IEEE Robotics and Automation Letters*, vol. 4, no. 4, pp. 3892-3899, Oct. 2019.
 18. Huang, P., Su, L., Chen, S., Cao, K., Song, Q., Kazanzides, P., Iordachita, I., Bell, M.A.L., Wong, J.W., Li, D. and Ding, K., “2D ultrasound imaging based intra-fraction respiratory motion tracking for abdominal radiation therapy using machine learning”, *Physics in Medicine & Biology*, vol. 64, no.18, Sept. 2019.
 19. Qian, L., Plopski, A., Navab, N., Kazanzides, P., “Restoring the awareness in the occluded visual field for optical see-through head-mounted displays”, *IEEE Trans. on Visualization and Computer Graphics*, vol. 24, no. 11, pp. 2936-2946, Nov 2018.
 20. Qian, L., Deguet, A., Kazanzides, P., “ARssist: augmented reality on a head-mounted display for the first assistant in robotic surgery”, *IET Healthcare Technology Letters*, vol. 5, no. 5, pp. 194-200, Oct 2018.
 21. Vagvolgyi, B.P., Pryor, W., Reedy, R., Niu, W., Deguet, A., Whitcomb, L.L., Leonard, S., Kazanzides, P., “Scene modeling and augmented virtuality interface for telerobotic satellite servicing”, *IEEE Robotics and Automation Letters*, vol. 3, no. 4, pp. 4241-4248, Oct. 2018.
 22. Cho, N., Wong, J., Kazanzides, P., “Fast inverse planning of beam directions and weights for small animal radiotherapy”, *IEEE Trans. on Radiation and Plasma Medical Sciences*, Vol. 2, No. 3, pp. 215-222, May 2018.
 23. Cho, N., Tsiamas, P., Velarde, E., Tryggestad, E., Jacques, R., Berbeco, R., McNutt, T., Kazanzides, P., Wong, J. “Validation of GPU-accelerated superposition-convolution dose computations for the small animal radiation research platform (SARRP)”, *Medical Physics*, Vol. 45, No. 5, pp. 2252-2265, May 2018.
 24. Wang, Z., Liu, Z., Ma, Q., Cheng, A., Liu, Y.-h., Kim, S., Deguet, A., Reiter, A., Kazanzides, P., Taylor, R.H., “Vision-based calibration of dual RCM-based robot arms in human-robot collaborative minimally invasive surgery”, *IEEE Robotics and Automation Letters*, Vol. 3, No. 2, pp. 672-679, April 2018.
 25. Yang, G.-Z., Cambias, J., Cleary, K., Daimler, E., Drake, J., Dupont, P. E., Hata, N., Kazanzides, P., Martel, S., Patel, R. V., Santos, V. J., Taylor, R. H. “Medical robotics – regulatory, ethical, and legal considerations for increasing levels of autonomy”, *Science Robotics*, Vol. 2, No. 4, March 2017.

26. Gandhi, N., Allard, M., Kim, S., Kazanzides, P., Bell, M.A.L., “Photoacoustic-based approach to surgical guidance performed with and without a da Vinci robot,” *Journal of Biomedical Optics*, Vol. 22, No. 12, pp. 121606:1-12, Dec. 2017.
27. Wang, Z., Lee, S.C., Zhong, F., Navarro-Alarcon, D., Liu, Y., Deguet, A., Kazanzides, P., Taylor, R.H., “Image-based trajectory tracking control of 4-DoF laparoscopic instruments using a rotation distinguishing marker,” *IEEE Robotics and Automation Letters*, Vol. 2, No. 3, pp. 1586-1592, July 2017.
28. Qian, L., Barthel, A., Johnson, A., Osgood, G., Kazanzides, P., Navab, N., Fuerst, B., “Comparison of optical see-through head-mounted displays for surgical interventions with object-anchored 2D display,” *Intl. J. of Computer Assisted Radiology and Surgery (IJCARS)*, Vol. 12, No. 6, pp. 901-910, June 2017.
29. Wang, L., Chen, Z., Chalasani, P., Yasin, R.M., Kazanzides, P., Taylor, R.H., Simaan, N. “Force-controlled exploration for updating virtual fixture geometry in model-mediated telemanipulation,” *ASME Journal of Mechanisms and Robotics*, Vol. 9, No. 2, Apr 2017.
30. Kim, S., Kazanzides, P., “Fiducial-based registration with a touchable region model,” *Intl. J. of Computer Assisted Radiology and Surgery (IJCARS)*, Vol. 12, No. 2, pp. 277- 289, Feb 2017.
31. Sen, H.T., Bell, M.A.L., Zhang, Y., Ding, K., Bector, E., Wong, J., Iordachita, I., Kazanzides, P., “System integration and preliminary in-vivo experiments of a robot for ultrasound guidance and monitoring during radiotherapy,” *IEEE Trans. on Biomedical Engineering*, 2016.
32. Sen, H.T., Cheng, A., Ding, K., Bector, E., Wong, J., Iordachita, I., Kazanzides, P., “Cooperative Control with Ultrasound Guidance for Radiation Therapy”, *Frontiers in Robotics and AI*, Vol. 3, Aug. 2016.
33. Bell, M.A.L., Kumar, S., Kuo, L., Sen, H.T., Iordachita, I., Kazanzides, P., “Toward standardized acoustic radiation force-based ultrasound elasticity measurements with robotic force control”, *IEEE Transactions on Biomedical Engineering*, Nov. 2015.
34. He, C., Kazanzides, P., Sen, H.T., Kim, S., Liu, Y., “An Inertial and Optical Sensor Fusion Approach for Six Degree-of-Freedom Pose Estimation”, *Sensors*, Vol. 15, No. 7, pp 16448-16465, July 2015.
35. Bell, M.A.L., Ostrowski, A.K., Li, K., Kazanzides, P., Bector, E.M., “Localization of transcranial targets for photoacoustic-guided endonasal surgeries,” *Photoacoustics*, Vol. 3, No. 2, pp. 78–87, June 2015.
36. Billings, S., Kang, H.J., Cheng, A., Bector, E., Kazanzides, P., Taylor, R., “Minimally invasive registration for computer-assisted orthopedic surgery: combining tracked ultrasound and bone surface points via the P-IMLOP algorithm”, *Intl. Journal of Computer Assisted Radiology and Surgery*, April 2015.
37. Jung, M.Y., Balicki, M., Deguet, A., Taylor, R.H., Kazanzides, P., “Lessons Learned from the Development of Component-Based Medical Robot Systems”, *Journal of Software Engineering for Robotics (JOSER)*, Vol. 5, no. 2, pp 25-41, Sept. 2014.
38. Bell, M.A.L., Sen, H.T., Iordachita, I., Kazanzides, P., Wong, J., “In vivo reproducibility of robotic probe placement for a novel ultrasound-guided radiation therapy system”, *Journal of Medical Imaging*, Vol. 1, No. 2, 025001, pp 1-9, July 2014.
39. Kouskoulas, Y., Platzer, A., Kazanzides, P., “Formal Methods for Robotic System Control Software,” *Johns Hopkins APL Technical Digest*, Vol. 32, No. 2, pp 490-498, Sept. 2013.

40. Kouskoulas, Y., Fu, M., Shao, Z., Kazanzides, P., “Applying Mathematical Logic to Create Zero-Defect Software,” *Johns Hopkins APL Technical Digest*, Vol. 32, No. 2, pp 490-498, Sept. 2013.
41. Otake, Y., Armand, M., Armiger, R., Kutzer, M., Basafa, E., Kazanzides, P., Taylor, R., “Intraoperative Image-based Multi-view 2D/3D Registration for Image-guided Orthopaedic Surgery: Incorporation of Fiducial-based C-arm Tracking and GPU-acceleration,” *IEEE Trans. on Medical Imaging*, Vol. 31, No. 4, pp 948-962, April 2012.
42. Ren, H., Kazanzides, P., “Investigation of attitude tracking using an integrated inertial and magnetic navigation system for hand-held surgical instruments”, *IEEE/ASME Trans. on Mechatronics*, Vol. 17, No. 2, pp 210-217, April 2012.
43. Ren, H., Rank, D., Merdes, M., Stallkamp, J., Kazanzides, P., “Multisensor Data Fusion in an Integrated Tracking System for Endoscopic Surgery,” *IEEE Trans. on Info. Tech. in Biomed.*, Vol. 16, No. 1, pp 106-111, Jan 2012.
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14. Kennedy, C., Iordachita, I., Burdette, C., Kronreif, G., Ptacek, W., Kazanzides, P., Song, D., Fichtinger, G., "Robotically Assisted Needle Placement for Prostate Brachytherapy," *48th AAPM (Medical Physics) Annual Meeting*, Orlando, FL, Aug. 2006.
15. Kazanzides, P., DiMaio, S., Cleary, K., Fichtinger, G., Taylor, R., "System Architecture and Toolkits for Image-Guided Intervention Systems," *Medicine Meets Virtual Reality 14*, Long Beach, CA, January 2006.

Patents:

1. “Image Directed Robotic System For Precise Robot Surgery Including Redundant Consistency Checking” – U.S. Patent Number 5,086,401, Issued February 4, 1992.
2. Image Directed Robotic System For Precise Robot Surgery Including Redundant Consistency Checking” – U.S. Patent Number 5,299,288, Issued March 29, 1994.
3. “Image Directed Robotic System For Precise Robot Surgery Including Redundant Consistency Checking” – U.S. Patent Number 5,408,409, Issued April 18, 1995.
4. “System and Method for Cavity Generation for Surgical Planning and Initial Placement of a Bone Prosthesis” – U.S. Patent Number 5,824,085, Issued October 20, 1998.
5. “Methods and Apparatus for Registering CT-Scan Data to Multiple Fluoroscopic Images” – U.S. Patent Number 5,951,475, Issued September 14, 1999.
6. “Adaptive and Reconfigurable System for DC Motor Control” – U.S. Patent Number 7,835,630, Issued November 16, 2010.
7. “Interactive User Interfaces for Robotic Minimally Invasive Surgical Systems” – U.S. Patent Number 8,398,541, Issued March 19, 2013.
8. “Teleoperative-cooperative robotic system” – U.S. Patent No. 9,770,828, Issued Sept. 26, 2017.
9. “Systems and methods for interactive user interfaces for robotic minimally invasive surgical systems” – U.S. Patent No. 9,795,446, Issued Oct. 24, 2017 (divisional of U.S. Patent No. 8,398,541).
10. “Surgical system user interface using cooperatively-controlled robot” – U.S. Patent No. 9,815,206, Issued Nov. 14, 2017.
11. “Method and system for transcranial photoacoustic imaging for guiding skull base surgeries” – U.S. Patent 10,531,828, Issued Jan. 14, 2020.
12. “Augmented reality display for surgical procedures” – U.S. Patent 11,244,508, Issued Feb. 8, 2022.
13. “Interactive user interfaces for minimally invasive telesurgical systems” – U.S. Patent 11,259,870, Issued March 1, 2022 (divisional of U.S. Patent No. 9,795,446).
14. “Calibration system and method to align a 3D virtual scene and a 3D real world for a stereoscopic head-mounted display” – US Patent 11,386,572, Issued July 12, 2022.

PRESENTATIONS SINCE 2005

1. “Building (Safe) Clinical Systems,” *MICCAI Tutorial on Computer Integrated Surgery*, Palm Springs, CA, October 26, 2005.
2. “Building (Safe) Clinical Systems,” *MICCAI Tutorial on Computer Integrated Surgery*, Copenhagen, Denmark, October 01, 2006.
3. “IGT System Engineering,” (invited) *NCIGT/NAMIC Workshop on Open System Architecture for Image-Guided Therapy*, Rockville, Maryland. October 19, 2006.
4. “Surgical Robots and Phantom (Artifact) Devices,” (invited) *ASTM Workshop on Medical Devices Metrology and Standards Needs*, Atlanta, Georgia. November 14, 2006.
5. “IGT Software Architecture at JHU,” (invited) *NAMIC Project Week*. Boston, MA. June 27, 2006.

6. "Image Guided Robots for Cancer Research," (invited) *ERC Seminar Series*. Johns Hopkins University, September 27, 2006.
7. "Robots for Cancer Research and Neurosurgery," (invited) *Seminar Series*, Yale University. January 30, 2007.
8. "Building (Safe) Clinical Systems," *ICRA Tutorial on Computer-Integrated Surgery & Interventional Robotics*, Rome, Italy. April 10, 2007.
9. "Robots for Bone Cutting," (invited) *Seminar series*. Technical University of Munich. July 18, 2007.
10. "Medical Robotics: State of the Art and Current Challenges," (invited) *Guest lecturer for EMTM 695 class*, University of Pennsylvania. October 26, 2007.
11. "Small Animal Radiation Research Platform (SARRP): Design and Calibration," (invited) *AAPM Focused Research Meeting (FOREM) on Small Animal Conformal Irradiation*, Washington University, St. Louis, May 1, 2008.
12. "Medical Robotics: State of the Art and Current Challenges," (invited) *Guest lecturer for EMTM 695 class*, University of Pennsylvania. October 3, 2008.
13. "Medical Robotics: State of the Art and Future Challenges," (invited) *Seminar Series*, Worcester Polytechnic Institute (WPI), November 12, 2008.
14. "Image-guided robots for small animal research and clinical use," (invited) *I4M Seminar Series*, Johns Hopkins University, December 4, 2008.
15. "Medical Robots and their Control Paradigms," (invited) *CDC Workshop in honor of William A. Wolovich*, Cancun, Mexico, December 7, 2008.
16. "Developing and Validating Clinical Systems," *Winter School on Medical Robotics and Computer-Integrated Interventional Systems*, Baltimore, MD, January 15, 2009.
17. "Medical Robotics: State of the Art and Current Challenges," (invited) *Guest lecturer for EMTM 695 class*, University of Pennsylvania. October 16, 2009.
18. "Medical Robotics: State of the Art and Future Challenges," (invited) *2nd GMSI International Symposium*, University of Tokyo, April 27, 2010.
19. "Medical Robotics: State of the Art and Current Challenges," (invited) *Guest lecturer for EMTM 695 class*, University of Pennsylvania, January 21, 2011.
20. "Evolution of surgical robotics: from bone milling and teleoperation to human/machine collaborative systems," (invited) *1st Computer Integrated Surgery (CIS) Workshop*, Budapest, June 18, 2011.
21. "Medical Robotics: State of the Art and Current Challenges," (invited) *Guest lecturer for EMTM 695 class*, University of Pennsylvania, January 20, 2012.
22. "Research Overview of the Sensing, Manipulation and Real Time Systems (SMARTS) Lab," *LCSR/CISST Seminar Series*, Johns Hopkins University, February 15, 2012.
23. "Enabling technologies for telerobotic and co-robotic servicing of space assets," (invited) *Lockheed Martin NexTech II*, Johnson Space Center, Houston, Texas, March 7, 2012.
24. "Robotic Surgery: from Prostates to Satellites," *Future In-Space Operations (FISO) Working Group*, April 11, 2012.

25. "Enabling Technologies for Remote Robotic Telemanipulation with Time Delay," *ICRA 2012 Workshop on Robotic Satellite Servicing*, May 14, 2012.
26. "Sensing, Manipulation, and Real-Time Systems for Computer-Integrated Surgery," (invited) *Children's National Medical Center Seminar Series*, December 19, 2012.
27. "Medical Robotics: State of the Art and Current Challenges," (invited) *Guest lecturer for EMTM 695 class*, University of Pennsylvania, January 19, 2013.
28. "Medical Robotics: State of the Art and Current Challenges," (invited) *Guest lecturer for EMTM 695 class*, University of Pennsylvania, January 4, 2014.
29. "An Open-Source Research Kit for the da Vinci® Surgical System," (invited) *Design of Medical Devices Conference*, University of Minnesota, April 15, 2015.
30. "Robot-Assisted Skull Base Surgery," (invited) *Design of Medical Devices Conference*, University of Minnesota, April 15, 2015.
31. "Remote Teleoperation for Satellite Servicing (Satellite Surgery)", *European Space Agency (ESA)*, Noordwijk, Holland, Sept 8, 2015.
32. "The Robodoc® Experience: Lab Prototype to Commercial Product", (invited) *Hamlyn Workshop on Surgical Robotics: First in Human*, London, England, June 28, 2017.
33. "The da Vinci Research Kit as an Open Platform for Image-Guided Surgery", (invited) *Seminar Series*, Children's National Medical Center (CNMC), Washington, DC, Oct. 19, 2017.
34. "Robotics and Mixed Reality to Assist Human Task Performance", *LCSR Seminar Series*, Johns Hopkins University, March 10, 2021.
35. "Model-Based Teleoperation for Satellite Servicing", *JHU Applied Physics Lab (APL) Seminar*, July 27, 2021.
36. "Designing and Validating Safe Medical Robots", *Guest lecture, Medical Robotics System Design (EN.530.721)*, Johns Hopkins University, October 6, 2021.
37. "Robotics and Mixed Reality for Collaborative Tasks", *Politecnico di Milano Seminar (Virtual)*, November 10, 2021.
38. "Telerobotics in space and medicine", *Robotics: Science and Systems (RSS) Workshop, Toward Robot Avatars: Perspectives on the ANA Avatar XPRIZE Competition (Virtual)*, July 1, 2022.

RESEARCH FUNDING

Current:

Title: **AccelNet: International Collaboration to Accelerate Research in Robotic Surgery**
Dates: 9/1/19 – 8/31/24
Grantor: National Science Foundation (NSF)
Award Number: OISE 1927354
Amount: \$948,426
Summary: Enhance a growing network of networks which supports research in learning of surgical tasks, under clinically-realistic conditions, to improve computer assistance and enable autonomous actions during minimally-invasive robotic surgery.
Role: Principal Investigator

Title: **Technology Development for Robotic Servicing**
Dates: 10/1/16 – 8/31/22 (renewable)
Grantor: National Aeronautics and Space Administration (NASA)
Award Number: NNG15CR66C
Amount: \$3,350,696
Summary: Support the research for satellite servicing technologies by developing and testing methods to compensate for time delay in remote teleoperated procedures, with augmented visualization of the remote environment.
Role: Principal Investigator

Title: **Markerless Tracking for Augmented Reality**
Dates: 1/1/21 – 8/31/22
Grantor: Intuitive Surgical (Technology Research Grant)
Amount: \$60,000
Summary: Develop a markerless approach for localizing an HMD (Microsoft HoloLens 2), with respect to robotic instruments, to support augmented reality visualization for the bedside assistant during da Vinci robotic surgery.
Role: Principal Investigator

Title: **Pupillometry-based Tools for Continuous Cognitive Effort Monitoring in Robotic Surgery**
Dates: 1/1/22-12/31/22
Grantor: Intuitive Surgical (Technology Research Grant)
Amount: \$60,000
Summary: The goal of this proposal is to integrate eye tracking hardware with the da Vinci Surgical Robot, including both the da Vinci Research Kit (dVRK) and possibly clinical systems, and to use the feedback to estimate cognitive load.
Role: co-Investigator

Title: **Addressing Lumbar Puncture Challenges Using Patch Ultrasound and Augmented Reality**
Dates: 5/1/21 – 10/31/22
Grantor: National Institutes of Health (NIH)
Award Number: EB031731
Amount: \$311,922
Summary: Develop a navigation system featuring a patient-anchored ultrasound patch and an augmented reality display to provide real-time image guidance during lumbar puncture procedures.
Role: co-Investigator

Title: **Image-Guided Robotic Interventions**
Dates: 6/1/20 – 5/31/25
Grantor: Multi-Scale Medical Robotics Center (Hong Kong)
Amount: \$2,595,971
Summary: Perform research in image-guided robotic interventions, including the development of image-based automation in robotic surgery, high performance robotic systems for intra-operative MRI-guided interventions, image-guided robotic platform for minimally invasive orthopaedic surgery, and a low-cost surgical robotic arm system for universal surgeries.
Role: co-Investigator

Completed:

Title: **Patient-Specific Narrow Beam Breast CT**
Dates: 5/1/21 – 4/30/22
Grantor: National Institutes of Health (NIH)
Award Number: CA250653
Amount: \$374,273
Summary: Develop the fluence modulation and detection assemblies for a Dedicated Breast CT (DBCT) prototype system.
Role: co-Investigator

Title: **Robot-Assisted Femoroplasty with Intraoperative Biomechanical Feedback**
Dates: 8/1/17 – 7/31/21
Grantor: National Institutes of Health (NIH)
Award Number: EB023939
Amount: \$1,848,735
Summary: The goal is to develop a technology that enables the surgeon to determine the bone fracture risk level, obtain an optimized surgical plan based on computerized mechanical analysis, perform a minimally invasive hip augmentation with intraoperative biomechanical feedback, and verify the outcome.
Role: co-Investigator

Title: **NRI: Collaborative Research: Software Framework for Research in Semi-Autonomous Teleoperation**
Dates: 10/1/16 – 9/30/20
Grantor: National Science Foundation (NSF)
Award Number: IIS 1637789
Amount: \$969,800
Summary: Create a software framework that builds on the successful Raven II and dVRK open research platforms, integrates other research robot systems, and makes extensive use of simulators and low-cost input devices to target a much larger community.
Role: Principal Investigator

Title: **Augmented reality interface for vision-based monitoring and control using smart goggles**
Dates: 1/1/19-12/31/20
Grantor: Korea Institute of Machinery and Materials (KIMM)
Amount: \$82,992
Summary: Provide an augmented reality interface on a head-mounted display (HMD) that will enable a person to select an object in the environment as a target for autonomous grasping by a prosthetic arm.
Role: Principal Investigator

Title: **Evaluation of Augmented Reality Guidance for the First Assistant**
Dates: 7/1/19-3/31/21
Grantor: Intuitive Surgical (Clinical Research Grant)
Amount: \$60,000
Summary: Evaluate the use of a head-mounted display (HMD) to provide augmented reality guidance for the first assistant in robotic surgery.
Role: Principal Investigator

Title: **NRI-Large: Complementary Situational Awareness for Human-Robot Partnerships**
Dates: 10/1/13 – 9/30/19
Grantor: National Science Foundation (NSF)
Award Number: 1327657
Amount: \$561,787
Summary: The goal is to establish the foundations for complementary situational awareness (CSA), which is the simultaneous perception of the environment and operational constraints, and apply this concept to human-robot task execution in minimally-invasive robotic surgery.
Role: Senior Personnel

Title: **Augmented Reality Head Mounted Display for Patient-Side Surgical Assistant**
Dates: 1/1/18 – 12/31/18
Grantor: Intuitive Surgical (Technology Research Grant)
Amount: \$50,000
Summary: Improve the ergonomics and situational awareness of patient-side (bedside) assistants in da Vinci surgical procedures via the use of augmented reality on an optical see-through head-mounted display (HMD).
Role: Principal Investigator

Title: **A New Robotic Platform for Image-Guided Orthopaedic Surgery**
Dates: 5/1/14 – 12/31/18
Grantor: Think Surgical
Amount: \$620,000
Summary: The goals are to investigate new robotic platforms for orthopaedic surgery, develop technologies for minimally invasive registration using ultrasound and x-ray, and demonstrate a robot-assisted femoroplasty application.
Role: Principal Investigator

Title: **Image-Guided Workstation and Tools for the Treatment of Bone Defects**
Dates: 9/30/13 – 6/30/18
Grantor: National Institutes of Health (NIH)
Award Number: EB016703
Amount: \$401,056
Summary: The goal is to develop an image-guided workstation that uses novel morphable robotic surgical tools that will enable a next generation level of minimally- and less-invasive procedures allowing access to regions not currently accessible with conventional surgical tools. The system and devices will enable treatment of bone defects such as metastatic bone disease or severe osteoporosis in several areas in the body.
Role: co-Investigator

Title: **Optimizing the methods and infrastructure for IGRT**
Dates: 4/1/14 – 3/31/18
Grantor: Elekta Ltd
Amount: \$79,710
Summary: Development of robotic solutions for monitoring of fractionated radiotherapy procedures.
Role: co-Investigator

Title: Juxtapia CAMMRAD Platform for Improving Trauma Skills Training
Dates: 10/1/15 – 9/29/17
Grantor: Department of Defense (DoD)
Award Number: W81XWH-15-C-0156
Amount: \$640,000
Summary: Develop an augmented reality head-mounted display that can be used for training of combat medics, with the eventual goal of providing assistance during battlefield situations.
Role: Principal Investigator (of JHU subcontract)

Title: NRI-Small: Managing Uncertainty in Human-Robot Cooperative Systems
Dates: 10/1/12 – 9/30/16
Grantor: National Science Foundation (NSF)
Award Number: 1208540
Amount: \$1,000,000
Summary: This proposal focuses on the development of a Co-Robot Interface (CRI) that enables information exchange and collaboration between a human and one or more robots in co-robotic (human-in-the-loop) systems, with applications in robotic surgery and satellite servicing.
Role: Principal Investigator

Title: SSCO Technology Development for Robotic Servicing of Orbital Space Assets
Dates: 10/1/13 – 9/30/16
Grantor: National Aeronautics and Space Administration (NASA)
Award Number: NNG14CR58C, NNG10CR16C, Tasks 197.04 and 1197.04
Amount: \$421,280 (Y1), \$424,393 (Y2), \$ 438,501 (Y3)
Summary: Perform research into the induced time-delay for remote tele-operated satellite servicing procedures, such as those to cut and manipulate the outer layer of insulation that covers a satellite fuel port.
Role: Principal Investigator (of JHU subcontract)

Title: ERC-Small Business: Ultrasound-Guided Robotic Brachytherapy Needle-Insertion System with Intraoperative Re-Optimization
Dates: 1/31/13 – 5/31/16
Grantor: National Science Foundation (NSF)
Award Number: 1246356
Amount: \$133,345
Summary: The goal is to integrate a transrectal ultrasound (TRUS)-guided robot and a C-arm fluoroscope for precise placement and localization of implanted radioactive seeds in relation to the prostate.
Role: Principal Investigator (of JHU subcontract)

Title: Robotic System with Multiplexed DOF Control for Minimally Invasive Interventions
Dates: 6/1/12 – 4/30/16
Grantor: National Institutes of Health (NIH)
Award Number: GM100589
Amount: \$220,735
Summary: Develop a new, low-cost drive mechanism for a class of surgical robots that do not require multiple simultaneous degrees-of-freedom. The basic concept is to have a smaller number of motors (as little as one motor) that can switch between driving each of the robot's axes.
Role: co-Principal Investigator

Title: Calibration and control for robot-assisted orthopaedic surgery
Dates: 6/1/10 – 12/31/15
Grantor: Curexo Technology Corporation
Award Number: N/A

Amount: \$567,403
Summary: Develop methods to improve the accuracy of the robot system. This includes development of the kinematic model, as well as novel methods for kinematic parameter estimation that do not require special hardware, such as an optical tracking system.
Role: Principal Investigator

Title: **Integrated 3D X-Ray/ultrasound guided radiation therapy of soft tissue targets**
Dates: 10/1/11 – 9/30/15
Grantor: NIH
Award Number: R01 A161613-01
Amount: \$1,333,898
Summary: The goal of this project is to develop an integrated 3D x-ray/ultrasound imaging system to provide on-board guidance for hypofractionated radiation therapy.
Role: Co-Investigator

Title: **Calibration and commissioning of a Small Animal Radiation Research System**
Dates: 3/1/12 – 12/31/14
Grantor: Gulmay Medical
Award Number: N/A
Amount: \$110,000
Summary: This grant supports the continued development and maintenance of the Small Animal Radiation Research Platform (SARRP) developed at JHU and commercialized by Gulmay Medical. This includes the development of a GPU-accelerated radiation treatment planning system and the construction of a collimator with independent jaws.
Role: co-Principal Investigator

Title: **Enabling Technologies for Remote Robotic Telemanipulation with Time Delay**
Dates: 5/1/11 – 9/30/13
Grantor: National Aeronautics and Space Administration (NASA)
Award Number: NNX10AD17A
Amount: \$921,500
Summary: This is the first phase of a program of research to develop an information-rich telemanipulation environment together with a set of tools specifically designed for in-orbit manipulation and servicing of space hardware. The initial project is to develop and demonstrate a telerobotic system that can assist with removal of the insulating blanket flap that covers the spacecraft's fuel access port
Role: Principal Investigator (of JHU sub-contract)

Title: **Robot-assisted prostate surgery using augmented reality with deformable models**
Dates: 9/1/11 – 8/31/12 (extended to 8/31/13)
Grantor: National Institutes of Health (NIH)
Award Number: R43 EB014074
Amount: \$33,022 (JHU portion)
Summary: The goal of this project is to develop an augmented reality display that fuses a pre-operative MRI model of the prostate, tumor and surrounding tissues with the da Vinci system laparoscopic video, while compensating for non-rigid prostate tissue deformation using intra-operative transrectal ultrasound (TRUS) imaging.
Role: co-Principal Investigator

Title: **A Microsurgical Assistant System.**
Dates: 6/1/08 – 5/30/14
Grantor: National Institutes of Health
Award Number: 1 R01 EB 007969-01 A1
Amount: \$5,795,410 (5 year total)

Summary: Develop technology and systems addressing fundamental limitations in current microsurgical practice, using vitreoretinal surgery as the initial focus. This includes development of a "surgical workstation" that is interfaced to a stereo visualization subsystem and a family of novel sensors, instruments, and robotic devices.

Role: co-Investigator

Title: Development of Infrastructure for Integrated Sensing, Modeling, and Manipulation with Robotic and Human-Machine Systems.

Dates: 9/1/07 – 8/31/10 (extended to 8/31/12)

Grantor: National Science Foundation

Award Number: MRI 0722943

Amount: \$1,994,355 (3 year total)

Summary: This is a Major Research Instrumentation (MRI) development grant, where we propose to develop a broadly applicable software, mechatronic interface, and hardware infrastructure that will facilitate research on sensor-based robotic systems.

Role: co-Investigator

Title: Wearable Intelligent Navigation System for Surgery

Dates: 8/15/10 – 2/29/12

Grantor: National Science Foundation

Award Number: IIP-0646587

Amount: \$90,000 (JHU subcontract)

Summary: This supplement was awarded to Juxtopia, LLC to collaborate with the CISST ERC at JHU to apply Juxtopia's context-aware augmented reality system (CAARS) to create a "wearable intelligent navigation system for surgery (WINSS)" that enables a surgeon, wearing the CAARS goggles, to perform image-guided surgery while keeping hands and eyes focused on the patient.

Role: co-Investigator

Title: Systems Approach to the Design and Integration of Hospital Intensive Care Units

Dates: 1/5/12 – 8/31/12

Grantor: JHU Applied Physics Lab (APL)

Award Number: WA-105263

Amount: \$30,000 (JHU subcontract)

Summary: The goal of this project is to develop an architecture, and prototype implementation, for an integrated clinical environment, consisting of networked medical devices, a central server/database, and client terminals. The prototype system will include a ventilator and an infusion pump.

Role: Principal Investigator (of JHU subcontract)

Title: Development of Human Torso Models and Analyzing Target Data for Injury Assessment in a Blast Environment

Dates: 1/1/10 – 12/31/10

Grantor: JHU Applied Physics Lab (APL)

Award Number: N00024-03-D-6606

Amount: \$80,000

Summary: The goal is to develop semi-automated segmentation methods and a statistical atlas of the lung, and to support finite element analysis of the lung response to a blast environment.

Role: co- Investigator

Title: Methods and Apparatus for Irradiation Experiments with SARRP

Dates: 4/1/10 – 2/29/11

Grantor: Gulmay Medical

Award Number: N/A

Amount: \$192,896

Summary: This grant supports the continued development and maintenance of the Small Animal Radiation Research Platform (SARRP) developed at JHU and commercialized by Gulmay Medical.

Role: co-Principal Investigator

Title: **A robotically-assisted surgical workstation for osteoporotic bone augmentation.**

Dates: 8/1/07 – 7/31/10 (extended to 7/31/11)

Grantor: National Institutes of Health

Award Number: EB007747-01

Amount: \$344,269 (3 year total)

Summary: The goal is to develop an image-guided workstation with biomechanical planning and intraoperative updates for surgical interventions applied to osteoporotic bone augmentation, when the risk of bone fracture becomes imminent.

Role: co-Investigator

Title: **Real-Time Control Software for a Surgical Robot**

Dates: 5/15/09 – 7/31/10

Grantor: Curexo Technology Corporation

Award Number: N/A

Amount: \$120,028

Summary: The goal of this research is to assist the company in the development of real-time control software for the Robodoc system.

Role: Principal Investigator

Title: **Engineering Research Center for Computer-Integrated Surgical Systems and Technology.**

Dates: 9/1/1997-8/31/2008

Grantor: National Science Foundation

Award Number: EEC 9731748

Amount: \$30,000,000 (for 10 years)

Summary: The CISST ERC is a multi-institutional, multidisciplinary center whose focus is of basic science, computer-based technology, and engineered systems working cooperatively with surgeons to significantly change the way surgical procedures are carried out in the 21st century. Significant research focuses include modeling and analysis for treatment planning and control, robotics and human interfaces and systems for minimally-invasive, image-guided percutaneous therapy and microsurgery.

Role: Thrust Leader

Title: **Development of a Surgical Assistant Workstation for Teleoperated Surgical Robots.**

Dates: 9/12/06 – 9/11/08

Grantor: National Science Foundation

Award Number: EEC 0646678 (ERC Supplement)

Amount: \$691,454

Summary: This is a collaborative project between the CISST ERC and Intuitive Surgical, Inc. to develop a prototype Surgical Assistant Workstation by combining open source, modular CISST software components with the daVinci-specific ISI API. The goal is to provide a uniform interface enabling more rapid research and technology transfer.

Role: co-Investigator

Title: **Intelligent Management and Dissemination of Research Information.**

Dates: 9/12/07 – 9/11/08

Grantor: National Science Foundation

Award Number: EEC 0751230 (ERC Supplement)

Amount: \$147,271

Summary: This is a collaborative project between the CISST ERC and Morgan State University to improve the data management capability of the ERCs. The project involves the creation of a searchable, object-oriented database of site visit posters and associated multimedia.

Role: co-Investigator

Title: **An Image Guided Small Animal Radiation Research Platform**

Grantor: National Institutes of Health

Dates: 4/1/05 – 3/31/08

Award number: 1 RO1 CA108449-01

Award amount: \$253,553 (3 year total)

Summary: The goal of this project is to develop and test an image guided small animal radiation research platform (SARRP) that will accurately deliver complex ionizing radiation dose distributions in small animal tumor model systems (mice, rats and rabbits).

Role: co-Investigator

Title: **Dexterous, Compact Telesurgical Robot for Throat & Airways**

Dates: 03/01/05-02/28/07

Grantor: National Institutes of Health

Award number: 1 R21 EB0045457-01

Award amount: \$274,999 direct; \$440,500 total

Summary: The goal of this proposal is development and initial evaluation on phantoms of a very compact, high-dexterity telesurgical robot system suitable for minimally invasive surgery of the throat & airways.

Role: co-Investigator

Title: **Intelligent Management and Dissemination of Research Information**

Dates: 9/1/05 - 8/31/06

Grantor: National Science Foundation

Award number: EEC-0540753

Award amount: \$12,264 (direct, JHU portion)

Summary: This is a collaborative project between JHU and Morgan State University. The primary objective of this research is to address the Engineering Research Center (ERC) information overload and provide a general design solution that enables better dissemination of research results.

Role: Principal Investigator of JHU portion

Title: **Needle Placement and Injection in Rodents**

Dates: 9/10/03 – 08/31/05

Grantor: National Institutes of Health

Award number: R01 CA84596

Award amount: \$167,000 (JHU portion)

Summary: This is a subcontract from Memorial Sloan Kettering Cancer Center (MSKCC) to develop an image-guided robot system for small animal research. Specifically, the robot is used to insert a measurement probe into anatomic targets that are identified in a preoperative PET image.

Role: co-Investigator

Title: **A Flexible "Human-in-the-loop" Microsystem Assembly Platform**

Grantor: National Science Foundation

Dates: 1/1/2004-6/30/2004

Award number: DMI-0339761

Award amount: \$ 99,700

Summary: This is a cooperative venture with Invenios, Inc., to build a versatile microassembly platform and evaluate its performance for optical alignment, mechanical assembly and microsurgery tasks.

Role: co-Investigator

Title: **Robotic Revision Hip Replacement Surgery**
Grantor: National Institute of Science and Technology
Dates: 4/15/1995-1/31/2000
Award number: NIST ATP Cooperative Agreement No. 94-01-0228.
Award amount: \$2,051,000
Summary: Development of x-ray registration and guidance methods for robotically-assisted revision hip replacement. This was a joint venture between Integrated Surgical Systems, IBM, and Johns Hopkins University.
Role: Principal Investigator for ISS component