

Ankur Kapoor

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Education

Ph.D. in Computer Science

August 2007

Motion Constrained Control of Robot for Dexterous Surgical Tasks
Johns Hopkins University, Baltimore, USA
Advisor: Prof. Russell H. Taylor

M.S in Computer Science

August 2003

Johns Hopkins University, Baltimore, USA
Project 1: *Preliminary Experiments in Robot/Human Cooperative Micromanipulation*
Advisor: Prof. Russell H. Taylor
Project 2: *Real-Time support for CISST Libraries*
Advisor: Dr. Peter Kazanzides

B.E. in Mechanical

B.E. in Electrical and Electronics

With Highest Honors (CGPA: 9.55/10.00)

Spring 2000

Birla Institute of Technology and Sciences, India
Thesis 1: *Direct Drive Articulated Robot Arm using Fiber Reinforced Composites*
Advisor: Prof. Ravi Prakash, Center for Robotics, India
Thesis 2: *Visual Servo Control using Inexpensive Custom Hardware*
Advisor: Sartaj Singh, Center for Artificial Intelligence and Robotics, India

Experience

Visiting Scientist

Radiology and Imaging Sciences,
Clinical Center
National Institute of Health

October 2007 – Present

Robotic Assistance for Heart Valve Repair

Developed a pneumatic actuated robotic assistant system for transapical aortic valve replacement under MRI guidance in a beating heart. The system integrates an interactive real-time MRI system, a robotic arm with a newly developed robotic valve delivery module, as well as user interfaces for physician to plan the procedure and manipulate the robot. A dexterous handheld module for beating-heart mitral valve repair under image guidance (CT and US) is under design review.

Cost-Effective Devices for Image guided Needle Procedures

Lead the development of a prototype for a semi-automated device for assisting in angle selection during needle-based procedures. The device is designed to integrate with CT or Cone Beam CT and requires minimal disruption in existing procedural workflow. Clinical trials to evaluate efficacy of the device are ongoing.

Biopsy and Laser Ablation in Lung

Lead the development of a prototype system for a bronchial device for biopsy and ablation of regions in lung under CBCT guidance. This electromagnetically tracked device is currently being tested pre-clinically in phantoms.

Translational Research

Designed clinical protocols to evaluate experimental image guided therapies developed with industry collaborators for open, laparoscopic and percutaneous settings. This allows intramurally developed algorithms and systems to be translated to the industry while providing a direct feedback of clinical problems and workflow.

Research Assistant

ERC-CISST, Johns Hopkins University

Summer 2002 – October 2007

Human-Machine Interaction

Developed a generic method to implement task specific virtual fixtures (VF) for surgical assistant robots. Formulated a library of task primitives and a way to assemble primitives as constraints of a multi-objective optimization (linear or nonlinear) problem. The methods are based on instantaneous kinematics of the task and are independent of manipulator characteristic: teleoperative or cooperative controlled; admittance or impedance type. Multiple user trials for realistic surgical tasks such as suture passing and *Bimanual* knot positioning were performed using the VF library.

Cooperative Control of Robot

Developed a prototype for an augmented manipulation system to provide a flexible and intuitive means to perform micrometer scale laboratory bio-manipulation tasks. The efficacy and accuracy of the system was tested using pronuclear injections on 50-100 μ m mouse embryos.

Developed a prototype for 5-DoF "Eye robot" workstation for retinal microsurgery. The prototype has been evaluated by clinicians in animal models using chicken embryos as eye phantoms. Successfully injections in veins of diameter 80-100 μ m were performed.

Tele-Robot Control

Developed a two-arm integrated system comprising of dexterous snake-like robots, Davinci Master Tele-Manipulators and a stereo visualization display for tele-surgery of throat and upper airway. Evaluation of the system by clinicians and residents is under progress. Restructured telerobotic control as two constrained least squares optimization problems; one each for master and slave, enabling previously developed virtual fixtures to be incorporated into control of dexterous snake-like devices.

Software Architecture Design and Implementation

Conceived and implemented an open source common programming interface to multiple types of surgical robots. Designed application frameworks to implement different architectures ranging from complete control over components including low-level servo to simple API for integrating commercial off-the-shelf robot hardware. These designs are implemented in open source software package *CISST*. The "core components" of the package are being used in *Surgical Assistant Workstation* – a joint collaboration with Intuitive Surgical, Inc. Key design features include an extensive application of "Command Pattern" as well as a dynamic interface query mechanism.

Electronic Hardware Design

Developed custom hardware using FPGAs that can selectively be operated in speed or torque control mode for control of small motors of snake-mechanisms. This hardware has also been used for controllers in other collaborating laboratories (SPL – Harvard/BWH, ARMA – Columbia and HEL – Hopkins).

Software Engineer

Veritas Software, India

July 2000– August 2001

Designed and developed *Volume Manager* on Linux that involved patches to the Linux kernel. The volume manager is the flagship product of Veritas that provides easy-to-use storage management for large scale computing and data enterprises (Google, Yahoo!, etc.). Provided supported to *Volume Manager* on other Unix Platforms.

Inexpensive Hardware for Robots

Center for Artificial Intelligence and Robotics, India

May 1999– December 1999

Designed and implemented a frame grabber card. Tested performance of frame grabber on a visual servo control. Designed and implemented two custom multi-axis controllers. The hardware now serves as standard components for high power robots at the center.

Publications

Book Chapters

1. M. Li, D. Mazilu, A. Kapoor and K. A. Horvath, *MRI Compatible Robot Systems for Medical Interventions*, Advances in Robot Manipulators, Eds. Ernest Hall, IN-TECH, pp. 443-458, 2010.
2. M. Li, A. Kapoor and R. H. Taylor, *Telerobot Control by Virtual Fixtures for Surgical Applications*, in Advances in Telerobotics Human Interfaces, Bilateral Control and Applications, Eds. Manuel Ferre et al, Springer, pp. 381-402, 2006.

Journal Articles

3. M. Li, A. Kapoor, D. Mazilu and K. A. Horvath. *Pneumatic Actuated Robotic Assistant System for Aortic Valve Replacement under MRI Guidance*. IEEE Transactions on Biomedical Engineering, pp. 443-451, 58(2), 2010.
4. G. Jones, F. Hunter, H. A. Hancock, A. Kapoor, M. J. Stone, B. J. Wood, J. Xie, M. R. Dreher, and V. Frenkel. *In Vitro Investigations Into Enhancement of tPA Bioavailability in Whole Blood Clots Using Pulsed-High Intensity Focused Ultrasound Exposures*. IEEE Transactions on Biomedical Engineering, pp. 33-36, 57(1), 2010.
5. B. J. Wood, J. Kruecker, N. Abi-Jaoudeh, J. K. Locklin, E. Levy, S. Xu, L. Solbiati, A. Kapoor, H. Amalou, A. M. Venkatesan. *Navigation systems for ablation*. Journal of Vascular and Interventional Radiology, 21 (SUPPL. 8), pp. S257-S263.
6. N. Simaan, K. Xu, A. Kapoor, W. Wei, P. Kazanzides and R. H. Taylor. *Design and Integration of a Telerobotic System for Minimally Invasive Surgery of the Throat*. International Journal of Robotics Research, pp. 1134-1153, 28(9), 2009.
7. A. T. Hillel, A. Kapoor, N. Simaan, R. H. Taylor and P. Flint. Applications of robotics for laryngeal surgery. Otolaryngologic Clinics of North America, pp. 781-991, 41(4), 2008.
8. A. Kapoor, S. Shah, P. Guion, B. J. Wood, J. Ding, D. Petrisor, D. Stoianovici, J. Karanian, W. F. Pritchard, and K. Cleary. *Robotically assisted needle driver: evaluation of safety release, force profiles, and needle spin in a swine model*. International Journal of Computer Assisted Radiology and Surgery, pp. 173-179, 3(1-2), 2008.

Refereed Conference Papers

9. M. Li, A. Kapoor, D. Mazilu, B. J. Wood and K. A. Horvath. *Cardiac Interventions under MRI Guidance using Robotic Assistance*. In Proceedings, IEEE International Conference on Robotics and Automation, pp. 2574-2579, 2010.

10. A. Kapoor, B. Wood, D. Mazilu, K. Horvath and M. Li. *MRI-compatible Hands-on Cooperative Control of a Pneumatically Actuated Robot*. In Proceedings, IEEE International Conference on Robotics and Automation, pp. 2681-2686, 2009.
11. A. Kapoor and R. H. Taylor. *A Constrained Optimization Approach to Virtual Fixtures for Multi-Handed Tasks*. In Proceedings, IEEE International Conference on Robotics and Automation, pp. 3401-3406, 2007.
12. B. Mitchell, J. Koo, I. Iordachita, P. Kazanzides, A. Kapoor, J. Handa, G. Hager and R. H. Taylor. *Development and Application of a New Steady-Hand Manipulator for Retinal Surgery*. In Proceedings, IEEE International Conference Robotics and Automation, pp. 623-629, 2007.
13. A. Kapoor, M. Li, and R. H. Taylor. *Constrained Control for Surgical Assistant Robots*. Presented at IEEE International Conference on Robotics and Automation, pp. 231-236, 2006.
14. A. Kapoor, A. Deguet, and P. Kazanzides. *Software components and frameworks for medical robot control*. Presented at IEEE International Conference Robotics and Automation, pp. 3813-3818, 2006.
15. A. Kapoor, K. Xu, W. Wei, N. Simaan, and R. H. Taylor. *Telemanipulation of Snake-Like Robots for Minimally Invasive Surgery of the Upper Airway*. In Proceedings, MICCAI Medical Robotics Workshop, 2006.
16. I. Iordachita, A. Kapoor, B. Mitchell, P. Kazanzides, G. Hager, J. Handa, and R. H. Taylor. *Steady-Hand Manipulator for Retinal Surgery*. In Proceedings, MICCAI Medical Robotics Workshop, 2006.
17. M. Li, A. Kapoor, and R. H. Taylor. *A Constrained Optimization Approach to Virtual Fixtures*. Presented at IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 1408-1413, 2005.
18. P. Kazanzides, A. Deguet, A. Kapoor, O. Sadowsky, A. LaMora, and R. H. Taylor. *Development of open source software for computer-assisted intervention systems*. In Proceedings, The Insight Journal - MICCAI Open-Source Workshop, 2005.
19. A. Kapoor, N. Simaan, and R. H. Taylor. *Suturing in Confined Spaces: Constrained Motion Control of a Hybrid 8-DoF Robot*. Presented at International Conference on Advanced Robotics, pp. 452-459, 2005.
20. A. Kapoor, M. Li, and R. H. Taylor. *Spatial Motion Constraints for Robot Assisted Suturing using Virtual Fixtures*. In Proceedings, International Conference on Medical Image Computing and Computer Assisted Intervention, 2005.
21. A. Kapoor, N. Simaan, and P. Kazanzides. *A System for Speed and Torque Control of DC Motors with Application to Small Snake Robots*. Presented at IEEE/APS Mechatronics and Robotics, 2004.
22. R. Kumar, A. Kapoor, and R. H. Taylor. *Preliminary Experiments in Robot/Human Cooperative Microinjection*. In Proceedings, IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 3186-3191, 2003.
23. A. Kapoor, R. Kumar, and R. H. Taylor. *Simple Biomanipulation Tasks With "Steady Hand" Cooperative Manipulator*. Presented at International Conference on Medical Image Computing and Computer Assisted Intervention, 2003.

Selected Abstracts

24. A. Kapoor, M. Li, and B. J. Wood. *Mixed variable optimization for radio frequency ablation planning*. SPIE Medical Imaging, 2011.
25. S. Billings, A. Kapoor, B. J. Wood, and E. Boctor. *A Hybrid Surface/Image Based Approach to Enabling Ultrasound/CT Registration*. SPIE Medical Imaging, 2011.
26. M. Li, D. Mazilu, B. J. Wood, K. Horvath, and A. Kapoor. *A robotic assistant system for cardiac interventions under MRI guidance*. SPIE Medical Imaging, 2010.

27. V. Saxena, A. Beck, A. Kapoor and B. J. Wood. *Accuracy of RFA Probe Insertion Using Camera-on-Needle versus Electromagnetic Tracking*. Annual Meeting of Society of Interventional Radiologists, 2010.
28. R. Faezeh, A. Kapoor, N. Glossop, J. Kruecker, S. Xu, A. Viswanathan, O. A. Chiesa, J. W. Karanian, W. Pritchard, E. Levy, A. Venkatesan, L. Solbiati and B. J. Wood. *A comparison of methods for tracking RFA probes and sensitivity to RF field and temperature*. Annual Meeting of Society of Interventional Radiologists, 2010.
29. D. Mazilu, M. Li, A. Kapoor, and K. Horvath. *Robotically assisted minimally invasive aortic valve replacement under MRI guidance*. Conference of International Society of Computer Aided Surgery, 2009.
30. S. Shah, A. Kapoor, K. Sharma, P. Guion, D. Mazilu and B. J. Wood. *Semi-Automated Laser Guidance for Needle Alignment during CT guided Interventional Procedures*. Annual Meeting of Society of Interventional Radiologists, 2008.

Invited Talks and Presentations

1. *Registration Methods in Multi-Modality Imaging* invited talk at 52nd Annual Meeting of American Association of Medical Physicists, Philadelphia, July 2010.
2. *Computer-Assisted Treatments at National Institutes of Health* invited talk at McMaster School of Biomedical Engineering, Hamilton, December 2008.
3. *Image Guided Therapies for Minimally Invasive Robotic-Assisted Surgery* invited talk at International Institute of Information Technology, Hyderabad, February 2008.
4. *Collaborative Assistance and Manipulation Enhancement for Computer-Assisted Treatments* invited talk at Dayalbagh University, Agra, January 2008.
5. *Haptic Feedback in Robot-Assisted Surgical Systems* at 14th Annual Symposium on Haptic Interfaces, Arlington, March 2006. (A demo and presentation of the Custom Research DaVinci Platform)
6. *The "Steady-Hand" Robot Exhibit with Simple Virtual Fixtures* at 11th Annual CNSF Exhibit for U. S. Congress, Washington, D.C., June 2005.
7. *The "Steady-Hand" Robot Exhibit with Simple Virtual Fixtures* at WTEC Robotics Event, National Science Foundation (NSF), Arlington, September 2005.
8. *The "Steady-Hand" Robot*, as part of *OR of the Future* at the 53rd annual meeting of the Congress of Neurological Surgeons, October 2003.

Research Grant Support

NIH Bench to Bedside Program

B. J. Wood (PI)

Optical guidance for improved prostate cancer surgery

The goal is to develop and test imaging devices that can provide real-time quantitative guidance to enhance visualization of neurovascular bundle using near infrared sensing during open, laparoscopic or robotic assisted surgery.

Role: Associate Investigator.

Ongoing

Clinical Protocols

- A comparison of methods for assisting needle angle selection during image-guided tissue biopsy
The goal is to compare the accuracy outcomes of low-cost assisting devices such as semi-automated laser guide in CT guided needle biopsies.
Role: Associate Investigator. *Ongoing*
- Feasibility of an open and minimally invasive image-guided surgery system for abdominal procedures
The goal of this study is to evaluate registration and tracking methods for open and laparoscopic abdominal surgery procedures.
Role: Associate Investigator. *Under review*

Teaching and Mentoring

PhD Co-Advisor

Graduate Partnership Program with Johns Hopkins University
Seth Billings Spring 2010-Present

Student Mentor

Clinical Research Training Program: Hari Trivedi 2011-
Advised in prototype development and pre-clinical study design for biopsy and ablation in lung under CBCT guidance.

Clinical Research Training Program: Bobbak Mansouri 2009-2010
Advised in pre-clinical and clinical study design and processes including institutional review board for semi-automated laser guidance method for needle procedures.

Howard Hughes Student: Vishal Saxena 2009-2010
Supervised pre-clinical evaluation of a camera-on-a-stick based navigational aid for needle based procedures.

Intramural Research Training Award: Faezeh Razjouyan 2009-2010
Advised on pre-clinical and clinical comparison of different techniques for tracking of radiofrequency ablation devices.

Intramural Research Training Award: Sapna Shah 2008-2009
Advised on pre-clinical testing of image-guided robots for automatic and semi-automatic needle guidance.

Research Experience for Undergraduates Program Summer 2005
Undergraduate Student: Tian Xia
Supervised the implementation of a real-time interface to custom daVinci wrist controller using a dedicated microcontroller servo control and RTAI Linux high-level control.

Computer Integrated Surgery Class Project Spring 2003
Undergrad Students: Brandon Devries and Greg Stock
Guided the redesign of a 3 DoF robotic arm and the calibration of analog sensors for a digitizer. The overall objective was to create teaching aids for K-12 students to learn concepts such as registration, calibration, and error analysis.

Research Experience for Undergraduate Program Summer 2002
Undergrad Student: Daniel Olson
Supervised the designing of the first prototype and implementation of a PIC microcontroller based interface of a low cost 3DoF digitizer. The objective was to develop teaching aids for K-12 education program to learn basic concepts of programming, sensor interface.

Teaching Assistant

Computer System Fundamentals Spring 2001
Taught by: Prof. Gerald Masson

Computer System Architectures Fall 2001
Taught by: Dr.-Ing. D. Burschka

Professional Skills

Languages: C++/C, MATLAB

Environments: Linux, Real-Time OS (RTAI, RTLinux), Windows, Mac OS X

Tools: VTK, OpenCV, CVS, CMake

Design: Pro-Engineer (Mechanical Design), Altium (Board Level Design), Quartus (FPGA Design)

Open Source Software

The CISST Libraries: A collection of libraries designed to ease the development of computer assisted intervention systems. The package contains components such as basic types (vectors, matrices, etc.), thread safe numerical routines (based on LAPACK), OS abstraction layers for portability across platforms and real time support for robots. First released in September 2005 with P. Kazanzides, A. Deguet and O. Sadowsky as coauthors. Available at <http://www.cisst.org/cisst/>

Honors and Awards

- Popular press ([website](#)) 2007
Research (Snake like robots) featured in New York Times
- Popular press ([website](#)) 2007
Research listed in L'Internaute as "*10 promesses technologiques pour 2007*"
- Best Graduating Student for Class of 2000 2000
Electrical and Electronics Department
- Institutes Merit Scholarship 1995—2000
Birla Institute of Technology and Science

Professional Activities

Journal Reviewer

- Transactions on Robotics
- The International Journal of Robotics Research
- International Journal of Medical Robotics and Computer Assisted Surgery
- Transactions on Information Technology in BioMedicine
- Robotica
- Robotics and Automation Magazine

Conference Reviewer

- IEEE Conference on Robotics and Automation (ICRA)
- IEEE/RSJ Conference on Intelligent Robots and Systems (IROS)
- Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI).
- Robotics: Science and Systems Conference