Deepak Raina

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Current Position

- **Purdue University** — Indiana, USA
  SERB - Overseas Visiting Doctoral Fellow (OVDF) — *January 2022 – Present*
- **Indian Institute of Technology** — Delhi, India
  Prime Minister's Research Fellow (PMRF); Ph.D. in Robotics; GPA: 9/10 — *July 2019 – Present*

Education

- **Indian Institute of Technology** — Jodhpur, India
  Master of Technology in Mechanical Engineering (Robotics); GPA: 9.24/10 — *July 2015 – June 2017*
- **Maharishi Markandeshwar Engg. College** — Ambala, India
  Bachelor of Technology in Mechanical Engineering; GPA:9/10 — *June 2011 – May 2015*

Research Interests

Medical Robotics, Physical Human-Robot Interaction, Tele-robotics, Medical Image Analysis, Robot Learning from Demonstration, Space Robotics, Vision-guided Robotics, Motion-planning, Vehicle Design and Dynamics

Skills

- **Programming Languages**: Python, C++, HTML
- **Tools**: ROS, Gazebo, MoveIt!, pyTorch, Pybullet, OpenCV, ADAMS; MATLAB, Qt-creator; Solidworks, ANSYS
- **Hardware**: Sawyer robots, Universal robots (UR10, UR5), RG2 gripper, Intel RealSense camera, Haptic devices

Academic Experience

- **Doctoral Research Fellow** — July 2020 - Present
  Indian Institute of Technology, Delhi and Purdue University, USA
  - **Autonomous robotic manipulation of ultrasound probe**:
    - Formulated a Bayesian Optimization (BO)-based search strategy, utilizing domain expertise, to efficiently locate high-quality images within the scanning region, eliminating the need for thorough scanning.
    - Proposed incorporating expert prior knowledge in Bayesian Optimization, obtained through expert demonstrations of high-quality probing poses for high image quality.
    - A novel expert's image quality metric model is developed, trained using a dataset of ultrasound images labelled for diagnostic quality by expert radiologists, which provides image feedback of the region to the BO.
    - Formulated a new kernel metric, Deep Kernel, which is lower dimensional when compared to standard kernels, which leads to a sample-efficient BO framework for substantially optimizing the high-dimensional controller, including probe position, orientation, and force adjustment.
    - Achieved over 50% increase in sample efficiency in comparison to standard BO, with a probe pose and force accuracy of 98.7% and 97.8%, respectively
  - **Ultrasound image quality assessment**:
    - Developed a supervised CNN model for analyzing the inter- and intra-patient ultrasound images, using a dataset of highly variable urinary bladder images, labelled for quality by expert radiologists.
    - Using deep variational clustering, developed an unsupervised CNN model to classify the ultrasound image quality, to overcome annotation noise in the supervised CNN model.
    - Achieved remarkable accuracy of 93%, surpassing the state-of-the art networks for image quality assessment
  - **Development of robotic ultrasound probe gripper with jelly dispenser**:
    - Designed a gripper that can accommodate various types of probes with varying cross-sections at the point of grip. The operator can easily attach and detach different probes using this gripper.
    - The gripper features an ultrasound gel dispenser that dispenses the gel automatically onto the patient's skin, using a camera image to detect the presence of gel between the probe and the body.
  - **Telerobotic Ultrasound (TR-US) for safety of doctors during COVID-19 (Video)**:
    - Developed the control architecture to teleoperate the ultrasound probe attached to the robotic arm

    - System performance analysis through 21 human trials at All India Institute of Medical Sciences (AIIMS), Delhi
    - Results demonstrated < 0.05 P-value on comparing tele-robotic and manual ultrasound images, gradual improvement of NASA-TLX test parameters, and 0.95 value of reliability index for questionnaire survey.

- **Masters Research Fellow** June 2016 - May 2017
  Indian Institute of Technology, Jodhpur
  - **Impact modeling and control of multi-arm space robot for capturing orbiting objects**:
    - Proposed unified framework for impact modeling and post-impact control of orbiting objects.
    - Post-impact reactionless control for stabilization of the multi-arm robot is proposed.
    - Numerical studies of different impact scenarios are analyzed in case multi-arm open and closed-loop impacts.
    - An adaptive reactionless control algorithm is proposed to capture unknown targets.

- **Graduate Teaching Assistant**
  Indian Institute of Technology, Jodhpur and Delhi; Purdue University, USA
  - MFET 442: Programming Robots with ROS Jan-May 2023
  - MCP100: Engineering Visualization and Communication Jan-May 2020, Jan-Dec 2021
  - MCL211: Design of Machines Aug-Dec 2019
  - ME311: Dynamics of Machines and Mechanisms Jan-May 2017, Aug-Dec 2016
  - ME222: Kinematics of Machines and Mechanisms Jan-May 2016
    - Designed and graded questions for homework assignments and quizzes
    - Conducted weekly office hours and attended classes to assist students during in-class doubts.

- **Graduate Mentor**
  Indian Institute of Technology, Jodhpur and Delhi; Purdue University, USA
  - Mentored 1 undergraduate, 1 graduate and 5 intern students in Robotics, AI and Medical imaging analysis
  - Facilitated weekly meetings to track project progress and provide guidance on hardware, software, and tools.
  - The research outcomes were published in international academic journals, conferences and patents.

- **Student Volunteer**
  I-Hub Foundation for Cobotics (IHFC) at IIT Delhi *Dec 2019 - Present*
  - Lead editor of half yearly newsletters.
  - Promoting hub activities in social media, writing proposals for new initiatives

- **Vice President**
  SAE INDIA Collegiate Club at MMEC Mullana *Mar 2014 - 2015*
  - Organized and oversaw activities bringing together automobile enthusiasts, popularizing automobile engineering.
  - Initiated participation of college in various automotive competitions organized by SAE, ASME etc.

- **Team Captain**
  ASME-Human Powered Vehicle Challenge (HPVC) Team *Sep 2014 - Feb 2015*
  - Led a team of 15 students having 5 departmental heads for designing and fabricating a racing tricycle.
  - Managed budget of USD 2000 allocating it to material procurement, transport and others.

Industrial Experience

- **TCS Robotics Research and Innovation Lab** Delhi, India
  Researcher - Robotics group *Dec. 2017 - July 2019*
  - **Robotic packing of Long Distance Carriers (LDCs) (Video)**:
    - Designed new industrial level system to automatically and optimally load parcels in LDC's.
    - Developed collision-free motion planning module for picking parcels from conveyor and placing in LDC's.
    - Helped achieve target filling rate of 12 seconds per LDC.
  - **Palletizer - Automated Truck Loading System (ATLS)**:
    - Designed GUI-based system having a UR-10 manipulator that can load heterogeneous boxes on a pallet.
    - Increased system throughput by directly planning motions using UR-driver by surpassing ROS-MoveIt library.
    - Successfully achieved target output of 12 seconds per pick and place of the box.
  - **Vision-based Control of Redundant Robotic Manipulators (Video)**:

    - Path planning is done in image space using RRT-planner, which helps in satisfying multiple task constraints like FoV limits, joint limits, obstacles, singularities, occlusions etc. in the planning stage itself.
    - A unique mapping between the feature space and the joint space is established by task-priority method, which uses some DoFs for visual servoing whereas redundant DoFs are used for secondary tasks.
  - **Calibration: Robot and Camera**:
    - Developed a package for autonomous calibration of stereo camera with Universal Robots
    - Automated transformation detection that helps with both *eye-to-hand* and *eye-in-hand* setup of the robot.
    - Added testing support feature to verify the generated robot to camera transformation matrix.
    - Dropped calibration time from 20 minutes to 9 minutes, and resource requirement from 2 person to a 1 person.
  - **Chitrakar: Robot Artist (Video)**:
    - Developed a robotic arm to draw a human face as a recognizable non-self-intersecting loop (Jordan curve).
    - Designed motion planning module and novel gripper to complete the drawing within 30 minutes.
    - This work demonstrates the use of robotics to augment humans in executing difficult craft-work.

- **Tata Automation Limited** Pune, India
  Trainee *Jun. 2016 - Jul. 2016*
  - **BRABO**: This is first made-in-India industrial articulated robot. Designed and performed experiments for design evaluation, validation and testing of this robot.
  - **PID Tunning**: Reduced the vibration of robot joints by tuning the PID values for motor-controller setup.

Relevant Course-Work

Robotics, AI for Cognitive Robot Intelligence, Reinforcement Learning [Coursera], Computer Vision, Machine Learning [NPTEL], Linear-Systems Theory, Linear Algebra, Multibody Dynamics, Computer-Aided Design, Finite Element Method, Vehicle Dynamics

Achievements

- **SERB - Overseas Visiting Doctoral Fellowship (2022-2023)**: Among 25 Ph.D. students to be selected across country to spend 1.5 years at Purdue University, USA.
- **Runner-up International Robot Design Competition Award (2021)**: Awarded to our Telerobotic Ultrasound system at ICSR 2021 Robot Design Competition for the COVID-19 innovative response.
- **Director's Honorarium (2021)**: Awarded by Director of IIT Delhi for my efforts in establishing the Technology Innovation Hub (TIH) on Collaborative robotics (Cobotics) at IIT Delhi.
- **Prime Minister's Research Fellowship (2019-2023)**: Among 10 students to be selected across country in Mechanical Engineering. This fellowship is awarded by Ministry of Education (MoE) for persuing Ph.D. at IITs
- **Dassault Systèmes Design Award (2014)**: Awarded 2^{nd} prize in design of human-powered vehicle competition organized by ASME at IIT Delhi.
- **Indira Gandhi Merit Scholarship (2011-2015)**: Awarded by Director of Higher Education for securing 7^{th} rank in 12^{th} state board exams.
- **Letter of Appreciation (2011)**: Awarded by Union Minister of India Mr. Anurag Thakur for excellent performance in 12^{th} state board exams

Publications

- **Conference**
  - **Robotic Sonographer: Autonomous Robotic Ultrasound using Domain Expertise in Bayesian Optimization**, [Accepted]
    Deepak Raina, SH Chandrashekhara, Richard Voyles, Juan Wachs, Subir Kumar Saha
    IEEE International Conference on Robotics and Automation (**ICRA**) 2023.
  - **Deep Kernel and Image Quality Estimators for Optimizing Robotic Ultrasound Controller using Bayesian Optimization**, [Accepted]
    Deepak Raina, SH Chandrashekhara, Richard Voyles, Juan Wachs, Subir Kumar Saha
    IEEE International Symposium on Medical Robotics (**ISMR**) 2023.
  - **Expert-Agnostic Ultrasound Image Quality Assessment using Deep Variational Clustering**, [Accepted]
    Deepak Raina, Dimitrios Ntentia, SH Chandrashekhara, Richard Voyles, Subir Kumar Saha
    IEEE International Conference on Robotics and Automation (**ICRA**) 2023.

- **Slim U-Net: Efficient Anatomical Feature Preserving U-net Architecture for Ultrasound Image Segmentation**, [Accepted]
  Deepak Raina, Kashish Verma, Chandrashekhara SH, Subir Kumar Saha
  ACM International Conference on Biomedical and Bioinformatics Engineering (**ICBBE**) 2022
- **Comprehensive Telerobotic Ultrasound System for Abdominal Imaging: Development and in-vivo Feasibility Study**, [Paper]
  Deepak Raina, Hardeep Singh, Subir Kumar Saha, Chetan Arora, Ayushi Agarwal, Chandrashekhara Sh, Krithika Rangarajan, Suvayan Nandi
  IEEE International Symposium on Medical Robotics (**ISMR**) 2021.
- **AI-based Modeling and Control of Robotic Systems: A Brief Tutorial**, [Paper]
  Deepak Raina, S.K. Saha
  IEEE International Conference on Robotics and Computer Vision (ICRCV) 2021.
- **A Novel Image-based Path Planning Algorithm for Eye-in-Hand Visual Servoing of a Redundant Manipulator in a Human Centered Environment**, [Paper]
  Deepak Raina, P. Mithun, Suril V. Shah, Swagat Kumar
  IEEE International Conference on Robot and Human Interactive Communication (**Ro-Man**), 2019.
- **Impact Modeling and Estimation for Multi-Arm Space Robot while Capturing Tumbling Orbiting Objects**, [Paper]
  Deepak Raina, Suril V. Shah
  ACM Proceedings of Advances in Robotics (**AIR**), 2017.

Journal

- **USQNet: Deep Learning Model for Enhancing Quality Assessment of Ultrasound Images using Multi-scale and Fine-grained processing**, [Under Review]
  Deepak Raina, SH Chandrashekhara, Richard Voyles, Juan Wachs, Subir Kumar Saha
  IEEE Transactions on Biomedical Engineering (TBME) 2023.
- **Tele-robotic ultrasound: an initial feasibility study**, [Paper]
  SH Chandrashekhara, K. Rangarajan, A. Agrawal, S. Thulkar, S. Gamanagatti, Deepak Raina, S.K. Saha and Chetan Arora,
  World Journal of Methodology 2022.
- **Comprehensive Impact Modeling and Reactionless Control for post-capturing and manoeuvring of orbiting objects using a Multi-arm space robot**, [Paper]
  Deepak Raina, Sunil Gora, Dheeraj Maheshwari, Suril V. Shah,
  Acta Astronautica 2021.
- **Design and Development for Roll Cage of All-Terrain Vehicle**, [Paper]
  Deepak Raina, Rahul Dev Gupta, Rakesh Kumar Phanden
  International Journal for Technological Research in Engineering (IJTRE), 2015.

Workshop

- **Local and global feature fusion for ultrasound image quality assessment: Towards autonomous ultrasound**,
  Deepak Raina, Mythra V. Balakuntala, Richard Voyles, Subir Kumar Saha,
  Workshop on Human-centered Autonomy in Medical Robotics,
  IEEE International Conference on Robotics and Automation (**ICRA**) 2022 [Link]
- **Telerobotic Ultrasound: Towards safer, precise and remote diagnosis of COVID-19 patients**,
  Deepak Raina, Suvayan Nandi, Subir Kumar Saha, Chetan Arora, Krithika Rangarajan and Chandrashekhara Sh,
  Workshop on Autonomous System in Medicine,
  IEEE International Conference on Intelligent Robots and Systems (**IROS**) 2020 [Link]
- **Chitrakar: Robotic System for Drawing Jordan Curve of Facial Portrait**, [Paper]
  Aniruddha Singhal, Ayush Kumar, Shivam Thukral, Deepak Raina, Swagat Kumar,
  Workshop on Creativity and Robotics,
  International Conference on Social Robotics (**ICSR**), 2020 [Link]
- **Reactionless control and target manoeuvring of orbiting object in post-capture phase using a multi-arm space robot**,
  Deepak Raina, Sunil Gora, Suril V. Shah
  Workshop on Space Robotics,
  IEEE International Conference on Robotics and Automation (**ICRA**) 2020 [Link]

Book Chapters

- **Modeling and Estimation of Closed-Loop Impact for Multi-arm Space Robot While Capturing a Tumbling Orbiting Object**, [Paper]
  Deepak Raina, Sunil Gora, Suril V. Shah
  Machines, Mechanism and Robotics, Lecture Notes in Mechanical Engineering, Springer, 2019

Patents

- **Modular Robotic Ultrasound Probe Gripper with Autonomous Gel Dispenser** [Submitted],
  Deepak Raina, Ziming Zhao, Richard Voyles, Juan Wachs, Subir Kumar Saha, SH Chadrashekhara
  App. No. 202311002219

- **Autonomous multi-bin parcel loading system**,
  Aniruddha Singhal, Harshad Kahdilkar, Venkat Raju, Deepak Raina, Venkatesh S. Prasad, Sivam Thukral, Rajesh Sinha,
  Filed on July 14, 2019

- **Theses**
  - **Impact Modeling and Estimation for Multi-Arm Space Robot while Capturing Tumbling Orbiting Objects**,
    Supervisor: Prof. Suril V. Shah,
    Department of Mechanical Engineering, IIT Jodhpur

- **News**
  - **IIT Delhi, AIIMS New Delhi and Addverb Co-develop Telerobotic Ultrasound System During COVID Times**
    NDTV, Hindu, Dainik Jagran, News18, IIT Delhi, Times of India
  - **Chitrakar: A system that can transform images of human faces into drawings**
    TechXplore, AtomsTalk

Academic Projects

- **Course Projects**
  Masters and Doctorate (Reports and Codes)
  - Symbolic motion planning of mobile manipulator in a room environment
  - Bayesian state estimation of underwater robot using acoustic observations
  - Hand gesture-based control of Music Player using Convolutional Neural Network (CNN)
  - Potential field-based motion planning of a serial robot among obstacles
  - Image-based visual servoing (IBVS) controller for the UR5 robotic arm
  - Solidworks API for triangulation of solid models using Delaunay Triangulation
  - Adaptive slicing procedure for layered manufacturing and generate G-Codes
  - Acceleration, braking, ride and steering dynamics calculation of Mahindra XUV500 and simulation in AdamsCar

- **Design and fabrication of Off-Road Vehicle** SAE BAJA 2015
  Lead Designer, Vice-captain *March 2014 - 15*
  - Designed a roll-cage for this vehicle using design optimization techniques
  - The roll-cage, suspension arms, hub and knuckle was tested against all modes of failure with ANSYS
  - Worked on braking system design and dynamics
  - Prepared DFMEA for the vehicle. Ranked 36^{th} out of 120 teams

- **Design and fabrication of Human-Powered Vehicle** ASME HPVC 2014
  Captain, Lead Designer *Sep 2013-Feb 2014*
  - Designed a lightweight and stable HPV using tadpole configuration with Rollover Protection System
  - Performed ergonomics study so that human can apply its peak power with less fatigue
  - The fairing is designed and validated to reduce drag forces. Won 2^{nd} prize in Design

References

- **Ph.D. Advisor:** Prof. Subir Kumar Saha, Indian Institute of Technology, Delhi, India; Email: saha@mech.iitd.ac.in
- **Ph.D. Advisor:** Prof. Richard Voyles - Purdue University, West Lafayette, USA; Email: rvoyles@purdue.edu
- **Collaborator:** Prof. Juan Wachs - Purdue University, West Lafayette, USA; Email: jpwachs@purdue.edu
- **Collaborator:** Prof. S.H. Chandrashekhara - All India Institute of Medical Sciences, Delhi, India; Email: drchandruradioaiims@gmail.com
- **Collaborator:** Prof. Chetan Arora - Indian Institute of Technology, Delhi, India; Email: chetan@cse.iitd.ac.in