

# Deepak Raina

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## CURRENT POSITION

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- **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

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- **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

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

## SKILLS

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- **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

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- **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 quality of 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** *Dec 2019 - Present*  
*I-Hub Foundation for Cobotics (IHFC) at IIT Delhi*
  - Lead editor of half yearly newsletters.
  - Promoting hub activities in social media, writing proposals for new initiatives
- **Vice President** *Mar 2014 - 2015*  
*SAE INDIA Collegiate Club at MMEC Mullana*
  - 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** *Sep 2014 - Feb 2015*  
*ASME-Human Powered Vehicle Challenge (HPVC) Team*
  - 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

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- **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

- **DST - AWSAR 2022 Award:** Distinguished as one of the nation's top 100 scientific research stories for my doctoral research story on Tele-robotic Ultrasound.
- **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 pursuing Ph.D. at IITs
- **Dassault Systèmes Design Award (2014):** Awarded 2<sup>nd</sup> 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<sup>th</sup> rank in 12<sup>th</sup> state board exams.
- **Letter of Appreciation (2011):** Awarded by Union Minister of India Mr. Anurag Thakur for excellent performance in 12<sup>th</sup> 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 Chandrashekhara  
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

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### • 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<sup>th</sup> 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<sup>nd</sup> prize in Design

## EXTRA CO-CURRICULAR ACTIVITIES

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- Represented M.M. University as a player in All India Inter University Badminton Championship
- Volunteering under National Service Scheme (NSS) for 2 years including 7 days' special camp every 6 months
- Green Belt in Martial Arts

## REFERENCES

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