

# Preface

*Introduction to Robotics* is a book which aims to understand the underlying concepts used in designing and building a robot, and to make it work. There are a number of books available in the market which typically cater to either researchers working mainly on the analyses aspects of robots, e.g., kinematics, dynamics, control, etc., or practicing engineers interested in the feasibility study of using robots for particular applications, procurement of robots, their programming, economics, etc. In an undergraduate curriculum of Robotics, it is important that the students are exposed to both the aspects of analyses and applications. Hence, the need was felt for a book which would cover both the aspects in a lucid manner.

Since the first edition of this book *Introduction to Robotics* published in 2008, it has received several praises, mainly from students and faculty in India and abroad. The book has been widely used in Singapore, Mexico (translated in Spanish by Prof. Jorge Eduardo Aguirre Aquilar and Prof. Francisco Javier Standoval Palafox), and the People's Republic of China. I have received comments from several senior well-reputed professors who felt the book to be of very high quality.

## **Need for a Revised Edition**

I have used the book in teaching several courses at IIT Delhi, namely, *Robotics Engineering* to the undergraduate (UG) students, and *Robotics, Mechatronics Product Design* and *Multibody Systems and Vibration Design* to the postgraduate (PG) students. I am sure the book has been used by many in their universities and institutes either as a part of a core or elective course. During my interactions with professors and students of other institutions, it was clear that many of them do not cover the mathematical content, i.e., transformations, forward and inverse kinematics, dynamics, etc., of the book in great detail due to relative difficulty in understanding those contents. In fact, these topics are extremely important from the programming, control, and design point of view. That was the time when the need of a software like RoboAnalyzer for three-dimensional visualization of robot motion was felt. It was developed over the past five years and became popular for its ability to teach robotics in a fun way. It teaches a student the physics of robots first before he or she gets into the mathematical aspects. For example, in Inverse Kinematics, one can learn the concept of multiple solutions by clicking several buttons on the window interface of the software. The software is made available not only through the online portal of this book but also through a dedicated website [www.roboanalyzer.com](http://www.roboanalyzer.com), which gets updated whenever a new module is developed.

Besides, it was noticed that in many institutions, in courses like *Robotics and Automation* or *Applications of Robotics*, etc., there is a need of wider coverage of topics on industrial applications of robots, types of grippers, robot programming, and the like, which are missing in the first edition. Hence, those aspects are included in the present edition. These additions, however, do not majorly change the prescribed roadmap of the first edition to the teachers of UG- and PG-level students belonging to various disciplines.

## Suggested Roadmap

A suggested roadmap for this edition is given below:

### For UG-level Courses

- At junior level (typically, 2nd and 3rd year students)
  - ♦ Mechanical discipline: Chapters 1–5, 13
  - ♦ Electrical and Computer Science disciplines: Chapters 1–5, 10
- At senior level (typically, 3rd and 4th year students) with above background
  - ♦ Mechanical discipline: Chapters 2, 6–9, 12
  - ♦ Electrical and Computer Science disciplines: Chapters 2, 5–6, 8, 11–12

### For PG-level (Master's and Ph. D students) Courses

- With no exposure to a UG-level Robotics course
  - ♦ Mechanical discipline: Chapters 1–5, 8
  - ♦ Electrical discipline: Chapters 1–5, 12
- With exposure to a UG-level Robotics course
  - ♦ Mechanical discipline: Chapters 5–9, 12
  - ♦ Electrical and Computer Science disciplines: Chapters 5–8, 11–12

Besides, the book can be used in courses like “Mechatronics and Automation” (MA), “Multi Body Dynamics” (MBD), and others. For example, Chapters 3–4, 8, 10, and 13–14 would constitute about 90% of MA, whereas Chapters 5–6, 8–9 can cover upto 80% of MBD.

The book can also be used by practicing engineers, as each chapter contains many figures, tables, examples, references, web-based exercises, and on-line support materials.

## New to this Edition

The new topics and the features of this second edition are highlighted chapter-wise.

**Chapter 1: Introduction** Eight new application areas (e.g., Medical, Underwater, etc.) with photos of the robots. The statistics of robots and other dynamic information are updated.

**Chapter 2: Serial Robots and Their Applications** The title is changed to reflect the addition of new topics on five industrial applications of robots.

**Chapter 3: Actuators and Grippers** The topic of grippers is added and accordingly, the title of the chapter is changed.

**Chapter 4: Sensors, Vision and Signal Processing** Vision is expanded to help the students of robotics and/or automation courses, and the industry users of robot systems. Since each sensor signal needs some kind of conditioning before they are displayed or used by the robots for feedback control, etc., they are included in this edition.

**Chapter 5: Transformations** To understand this topic in a fun way, numerical examples using RoboAnalyzer (RA) software are included. Examples were also solved using MATLAB software and its module MuPAD. An important correlation between the definitions of the Denavit and Hartenberg (DH) parameters presented in this book and some other popular books is drawn which will enable readers of those books to use the RA software and compare their results with this book.

**Chapter 6: Kinematics** Many RoboAnalyzer (RA)-based examples are included. The inverse kinematics of a spatial six-degrees-of-freedom wrist-partitioned robot adopted from the book on *Fundamentals of Robotic Mechanical Systems* by J Angeles, Springer-Verlag, New York, 2003, are also included because of its implementation in the RA software.

**Chapter 7: Statics and Manipulator Design** An important aspect of robotics, i.e., its design, was missing in the first edition. The same is now included which will be of immense benefit to practicing engineers working in the area of robotics and robot designs.

**Chapters 8 (Dynamics) and 9 (Recursive Robot Dynamics)** No major change, except that many more examples including those using RoboAnalyzer, MATLAB, etc., are added.

**Chapter 10: Linear Control** This chapter is mainly the first part of the earlier Control chapter. It is completely re-written bringing almost all aspects of Linear Control Theory using simple examples of a moving block and a robotic joint.

**Chapter 11: Non-linear Control** It is a new chapter covering the remaining part of the earlier Control chapter but in a much more expanded form.

**Chapter 12: Motion Planning** Spline trajectory is re-written, and cycloidal trajectory is added which was used throughout the book to generate numerical results for kinematics and dynamics. It is also the default trajectory in RoboAnalyzer software.

**Chapter 13: Control Hardware and Robot Programming** This chapter is renamed from “Computers for Robots” (Chapter 12 of the first edition) to justify the new topics, mainly, the expanded descriptions of Robot Programming languages. Examples and illustrations using a real industrial KUKA KR-5 robot available in the Programme for Autonomous Robotics (PAR) Laboratory of IIT Delhi are also included.

**Chapter 14: Student Projects** It is a new chapter added in this edition, based on the contents of Appendix C in the first edition. New projects, both by the students and those possible using commercially available robots, are included for the benefit of applying the knowledge covered throughout this book into practice.

**Appendices** “Appendix B: Use of MATLAB and RIDIM” of the first edition is separated into two appendices, namely, “Appendix B: MATLAB and Allied Toolbox and Software” and “Appendix C: Use of RoboAnalyzer.” In the allied toolbox, how to use a freely available **Robotics Toolbox** developed by Prof. Peter Corke of Queensland University of Technology, Australia, is included for the general awareness of students and readers of this book.

**References** Since the present edition mentions many useful online resource materials, e.g., videos, software, etc., their references are listed separately under the category ‘Web References’ (WR) at the end of the list of references.

Besides, this second edition has been enriched with more figures (310 from 190, i.e., up by ~43%), tables (37 from 23, i.e., up by ~60%), examples (176 from 98, i.e., up by ~80%) and exercises (263 from 195, i.e., up by ~35%) to help the readers grasp the subject in a lucid manner, and practice for better understanding of the concepts explained in the book.

## Online Learning Center

The comprehensive OLC can be accessed at <http://www.mhhe.com/saha/ir2> and contains the following material:

### For Students

- *RoboAnalyzer Software*
- List of Abbreviations, List of Symbols, author’s website link, Web links for further reading
- Chapter Summary, Web-Based Exercises, Student Projects, Case Studies, Use of MATLAB, Allied Toolbox and Software, and RoboAnalyzer

### For Faculty

- *RoboAnalyzer Software*
- Solution Manual
- Chapterwise PowerPoint slides

## Acknowledgements

It is my moral responsibility to acknowledge those without whose support the completion of this second edition of the book would not have been possible within a short span of one and a half years. First, the Department of Mechanical Engineering at IIT Delhi and my colleagues are thanked who allowed me to take the sabbatical leave during 2013 by sharing my academic and administrative responsibilities. The book grant from the Quality Improvement Programme of IIT Delhi was a welcome offer to cover the incidental costs of writing the book. While proofreading the typed version of this edition, I must thank my following students who, almost on a war footing, read the manuscripts, corrected/drew figures, created examples whenever required, and typed the equations:

1. Mr Rajeevlochana G Chittawadigi (Graduated as MS student in 2013, and presently working with the 3D PLM Software, Bangalore)
2. Mr Abdullah Aamir Hayat (Presently, a PhD student)
3. Mr Arun Dayal Udai (Presently, a PhD student at IIT Delhi, and a faculty in BIT, Mesra)
4. Mr Riby Abraham Bobby (Presently, a PhD student)

The name of Mr Mangal Sharma (a project staff) must be mentioned here, as he took off all the burden of printing the chapters from me while I was concentrating on writing the chapters.

The names of Mr Dharmendra Jaitly (Technical Staff in the Mechatronics Laboratory), and my other contemporary PhD and MTech students (Mr Paramanand Nandihal, Mr Majid Hameed Koul, Mr Vinay Gupta, Mr Anil Sharma, Mr Vikas

Kharolia) needed special mention due to their time-to-time praise, motivation, and feedback, particularly, during our tea sessions in the laboratory. I wanted to mention the name of my ex-PhD student and presently a faculty member of IIIT Hyderabad (Dr Suril V Shah) who was instrumental in preparing the PowerPoint presentations of the lecture slides in 2010 after the publication of the first edition in 2008. The untold names of the students of various courses taught by me at IIT Delhi or during my lecturing of selected topics on Robotics at IITDM, Jabalpur; IIITM, Gwalior; NIT and CMERI, Durgapur; IISc, Bangalore; IIT Madras; and Waseda-IPS, Japan, who gave important feedback are also acknowledged.

At his stage, I must also thank the reviewers for their valuable comments which have truly raised the standard of this book. Their names are mentioned below:

<b>S Sanyal</b>	<i>National Institute of Technology (NIT) Raipur, Chhattisgarh</i>
<b>Vikas Rastogi</b>	<i>Delhi Technological University, New Delhi</i>
<b>Ashish Dutta</b>	<i>Indian Institute of Technology (IIT) Kanpur, Uttar Pradesh</i>
<b>Arun Dayal Udai</b>	<i>Birla Institute Technology (BIT), Mesra, Jharkhand</i>
<b>S S Roy</b>	<i>National Institute of Technology (NIT) Durgapur, West Bengal</i>
<b>U S Dixit</b>	<i>Indian Institute of Technology (IIT) Guwahati, Assam</i>
<b>Sanjiv Arul</b>	<i>Amrita School of Engineering, Coimbatore, Tamil Nadu</i>
<b>Ajith R R</b>	<i>College of Engineering, Thiruvananthapuram, Kerala</i>
<b>Ramesh S</b>	<i>R V College of Engineering, Bangalore, Karnataka</i>

It will remain incomplete if I do not mention the McGraw Hill Education (India) staff for readily agreeing to bring out the second edition, especially Ms Vibha Mahajan, Ms Harsha Singh, Ms Sohini Mukherjee, Mr Suhaib Ali, and many others in the background, for their persuasion and help.

Finally, I should not forget my family (wife *Bulu* and daughter *Esha*) for their support and patience for not getting my attention while I was engrossed with the book writing.

## **Feedback Request**

At the end, I am quite confident that the readers will find the improved second edition much more reader-friendly and value-added for its detailed content and lucid presentation, particularly, due to the use of RoboAnalyzer software. Even though all efforts were made to minimize typos or any other mistakes, the readers are requested to point out any mistake, if still left, and give their feedback to me directly at [saha@mech.iitd.ac.in](mailto:saha@mech.iitd.ac.in) or [sahaiitd@gmail.com](mailto:sahaiitd@gmail.com).

*Happy Reading!*

**SUBIR KUMAR SAHA**

## **Publisher's Note**

Remember to write to us! We look forward to receiving your feedback, comments and ideas to enhance the quality of this book. You can reach us at [info.india@mheducation.com](mailto:info.india@mheducation.com). Kindly mention the title and author's name as the subject. In case you spot piracy of this book, please do let us know.