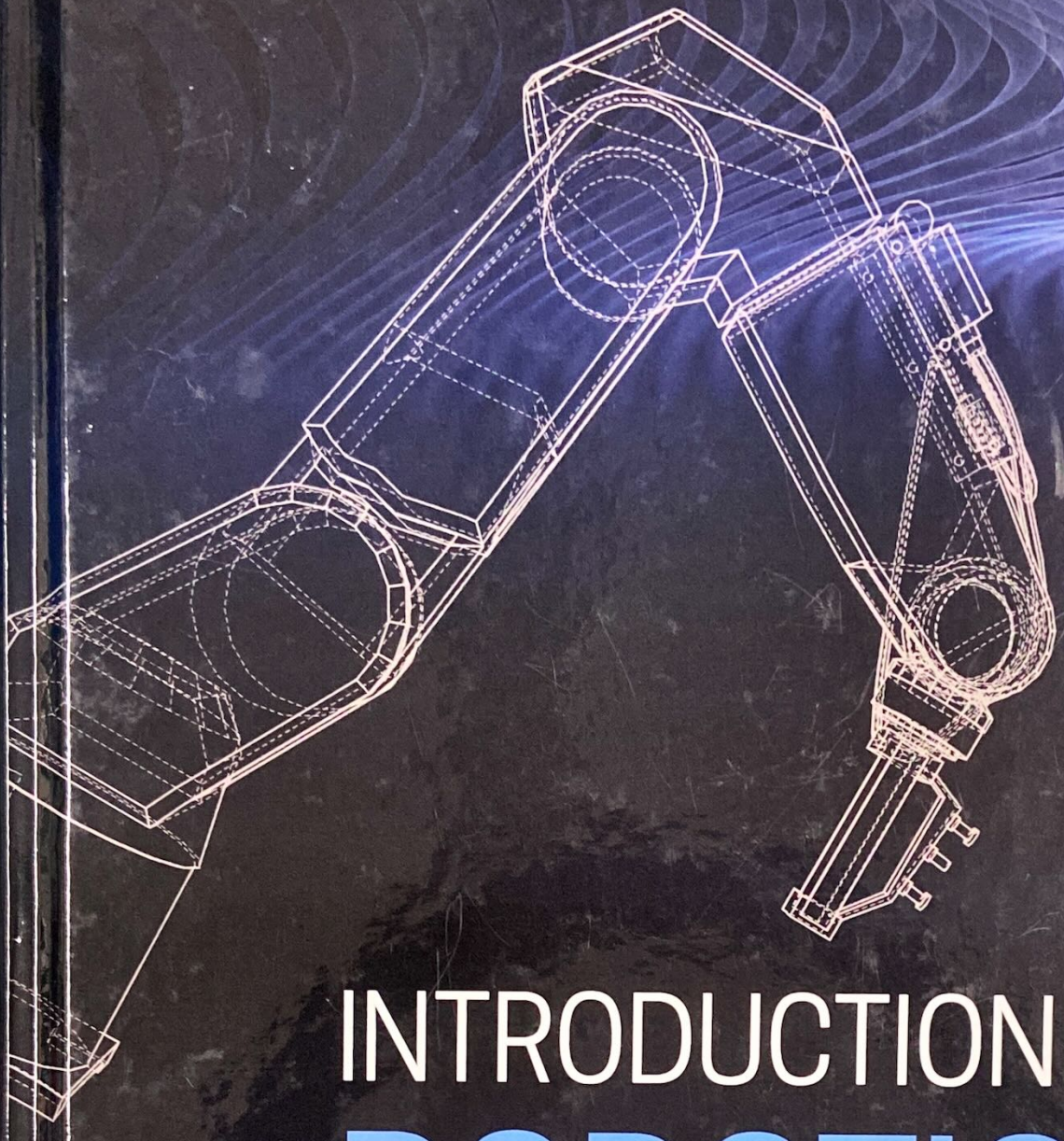
SAEED B. NIKU



INTRODUCTION TO ROBOTICS

ANALYSIS, CONTROL, APPLICATIONS

THIRD EDITION

with website

WILEY

Introduction to Robotics

Analysis, Control, Applications

Third Edition

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Contents

Preface

This new third edition of the *Introduction to Robotics* textbook is the culmination of over a year of intense work. If judging the previous edition by the number of instructors who adopted it, the number of countries in which it was popularly sold, and the number of languages into which it was translated indicates that it was a good book, I hope that this new edition is even better. It has two completely new chapters on screw-based mechanics and parallel robots, it has many new examples and homework problems, it has many new subjects in most chapters, and the writing has been edited and streamlined throughout.

And still the old adage from one of my former students whose name I have long forgotten applies: in the life of any product there comes a time when you have to shoot the designer and go into production. For a book, there comes a time that you have to shoot the author and go into publication.

The intention behind writing this book was, and still is, to cover most subjects that an engineering student or a practicing engineer who intends to learn about robotics may need to know, whether to design a robot, to integrate a robot in appropriate applications, or to analyze a robot. As such, it covers all necessary fundamentals of robotics, robot components and subsystems, and applications.

The book is intended for senior or introductory graduate courses in robotics as well as for practicing engineers who would like to learn about robotics. Although the book covers a fair amount of mechanics and kinematics of both serial and parallel robots, both with the Denavit-Hartenberg approach as well as screw-based mechanics, it also covers microprocessor applications, control systems, vision systems, sensors, and actuators. Therefore, it can easily be used by mechanical engineers, electronic and electrical engineers, computer engineers, and engineering technologists. With the chapter about control theory, even if the student has not had a controls course, he or she can learn enough material to be able to understand robotic control and design.

The book consists of 12 chapters. Chapter 1 covers introductory subjects that familiarize the reader with the necessary background information. This includes some historical information, robot components, robot characteristics, robot languages, and robotic applications. Chapter 2 explores the forward and inverse kinematics of serial robots, including frame representations, transformations, position and orientation analysis, as well as the Denavit-Hartenberg representation of robot kinematics. Chapter 3 covers the kinematics of serial robots with screw-based mechanics. Chapter 4 discusses parallel robots of many different types. Chapter 5 continues with differential motions and velocity analysis of robots and frames. Chapter 6 presents an analysis of robot dynamics and forces. Lagrangian mechanics is used as the primary method of analysis and development for this chapter. Chapter 7 discusses methods of path and trajectory planning, both in joint space and in Cartesian space. Chapter 8 covers fundamentals of control engineering, including analysis and design tools. Among other things, it discusses the root locus; proportional, derivative, and integral control; as well as electromechanical system modeling. It also includes an introduction to multiple input, multiple output (MIMO) systems, digital systems, and nonlinear systems. However, the assumption is that students will need additional instruction to be proficient in actually designing systems. One chapter on this subject cannot be adequate, but can nicely serve as an introduction for majors in which a separate course in control engineering is not offered. Chapter 9 covers actuators, including hydraulic devices, electric motors such as DC servo motors and stepper motors, pneumatic devices, as well as many other novel actuators. It also covers microprocessor control of

these actuators. Although this is not a complete mechatronics book, it does cover a fair amount of mechatronics. Except for the design of a microprocessor, many aspects of mechatronic applications are covered in this chapter. Chapter 10 is a discussion of sensors used in robotics and robotic applications. Chapter 11 covers vision systems, including many different techniques for image processing and image analysis. Chapter 12 discusses the basic principles of fuzzy logic and its applications in microprocessor control and robotics. This coverage is not intended to be a complete and thorough analysis of fuzzy logic, but an introduction. It is believed that students and engineers who find it interesting will continue on their own. Appendix A is a quick review of matrix algebra and some other mathematical facts that are needed throughout this book. Appendix B discusses digital image acquisition.

With the additional new chapters on screw-based mechanics and parallel robots, it is almost impossible to cover everything in the book in a quarter-based class with 30 lectures in 10 weeks. Therefore, for quarter-based classes, the instructor must make some choices as to which subjects should be included. Depending on other classes the student takes, certain material may be skipped. For example, students at Cal Poly, San Luis Obispo all take a required controls class, and most have a mechatronics class. Therefore, we can skip chapters on these subjects. However, for a semester-based 14-week class with 3 lectures per week, there is ample material and time to cover the entirety of the book.

The following breakdown can be used as a model for setting up a course in robotics in a quarter system. In this case, certain subjects must be eliminated or shortened, as shown:

Introductory material and review: 1 lecture
Kinematics of position: 6 lectures
Screw-based mechanics: 2 lectures
Parallel robots: 3 lectures
Differential motions: 4 lectures
Robot dynamics and force control: 2 lectures
Path and trajectory planning: 1 lecture
Actuators: 2 lectures
Sensors: 2 lectures
Vision systems: 5 lectures
Fuzzy logic: 1 lecture
Exam: 1 lecture

Alternately, for a 14-week long semester course with 3 lectures per week, the course may be set up as follows:

Introductory material and review: 2 lectures
Kinematics of position: 7 lectures
Screw-based mechanics: 2 lectures
Parallel robots: 3 lectures
Differential motions: 5 lectures
Robot dynamics and force control: 4 lectures
Path and trajectory planning: 3 lectures
Robot control and modeling: 4 lectures
Actuators: 2 lectures
Sensors: 2 lectures
Vision systems: 5 lectures
Fuzzy logic: 1 lecture
Exam: 1 lecture

The book also features design projects that start in Chapter 2 and continue throughout the book. At the end of each chapter, the student is directed to continue with the design projects in reference to the present subject. Therefore, by the end of the book, they may complete their project.

I would like to thank all the people who, in one way or another, have helped me. This includes my colleagues, including Drs. Bill Murray, Charles Birdsong, Lynne Slivovsky, and John Ridgely; all the countless individuals who did the research, development, and hard work that came before my time and that enabled me to learn the subject myself; all the users and students and anonymous reviewers who made countless suggestions to improve each edition; Dr. Thomas Cavicchi, Dr. Norali Pernalete, Dr. Fernando Gonzalez, as well as my students Tomy Tran, Jonathon Sather, Jonathon Stearns, and Trent Peterson; and the students who helped with the design and development of projects at Cal Poly, including the Robotics Club. I also thank Sandra Grayson, the acquisition editor at Wiley; Louis Manoharan, my project editor; Sathishwaran Pathbanabhan, my production editor; Tiffany Taylor, my copyeditor; and the editors and the artists who made the book look as it does. Finally, I thank my family, Shohreh, Adam, and Alan, who always inspire me in everything I do. Their patience is much appreciated. To all of you, my sincere thanks.

I hope that you will enjoy reading the book, and more importantly, that you will learn the subject. The joy of robotics comes from learning it.

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