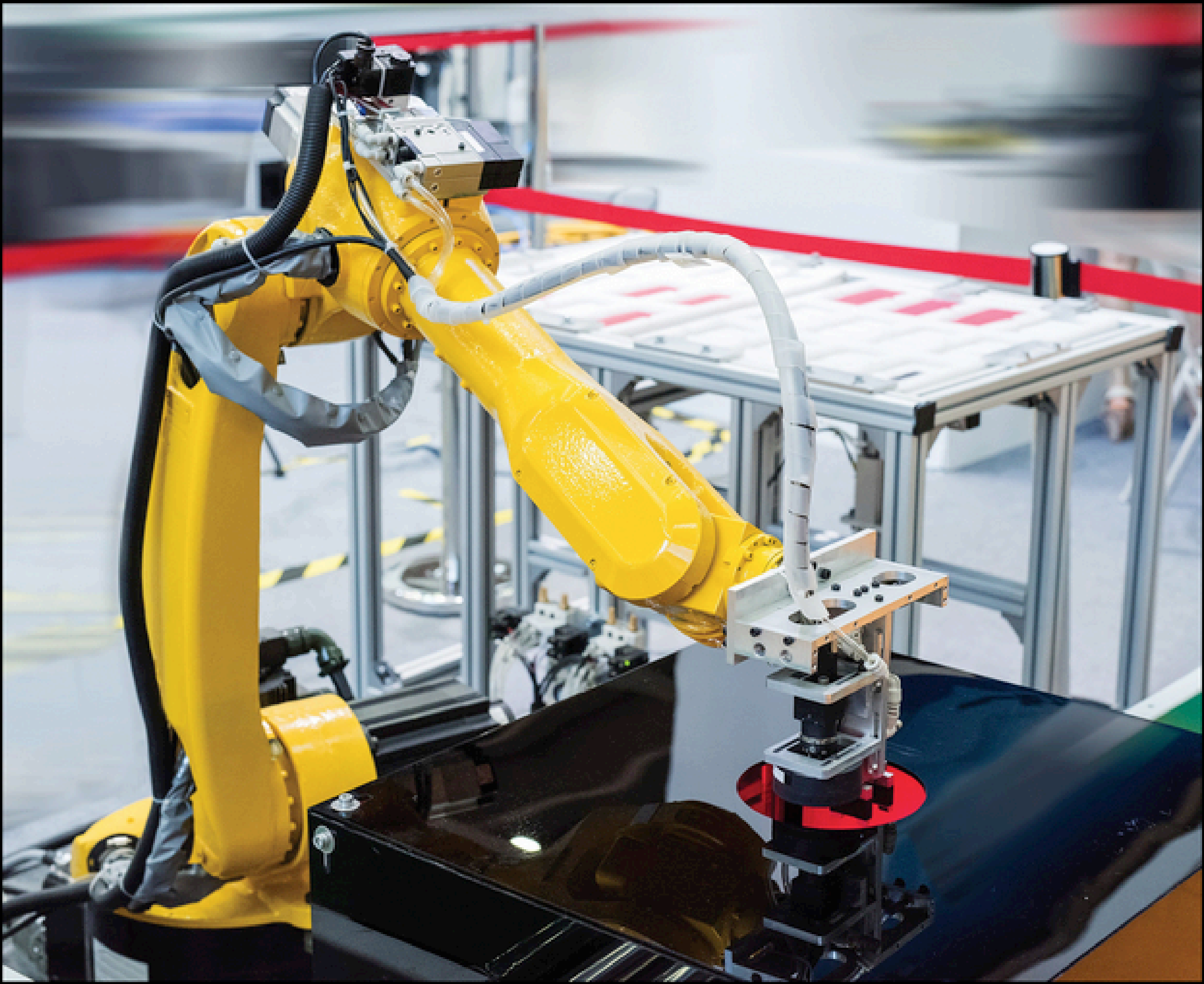

Robot Manipulator Redundancy Resolution

Yunong Zhang and Long Jin

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To our parents and ancestors, as always

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Preface

In recent decades, robotics has attracted considerable attention in scientific research and engineering applications. Much effort has been contributed to robotics and different types of robots have thus been developed and investigated. Among these robots, redundant robot manipulators have played a more and more important role in numerous fields of engineering applications, and they have been widely applied in industrial automation for performing repetitive dull work, such as welding, painting, and assembly. For a redundant robot manipulator, it possesses more degrees-of-freedom (DOF) than the minimum number required to perform a given end-effector primary task. One important issue in operating such robotic systems, redundancy resolution, has been widely studied, which is related to the motion planning and control of redundant manipulators. That is, given the desired Cartesian paths of the end effector, the corresponding joint trajectories need to be obtained online or in real-time t. Various redundancy-resolution schemes have thus been developed and investigated for the motion planning and control of redundant robot manipulators. By resolving the redundancy properly (or say, by using a specific redundancy-resolution scheme), redundant robot manipulators can avoid joint physical limits, while conducting the given end-effector primary path-tracking task.

In general, the redundancy-resolution problem can be solved at the joint-velocity level or at the joint-acceleration level, resulting in the corresponding velocity-level and acceleration-level redundancy-resolution schemes. In this book, focusing on redundancy resolution, we present and investigate different methods and schemes for the motion planning and control of redundant robot manipulators. Specifically, in view of the fact that the Jacobian matrix of a robot manipulator is actually varying with time during the motion-task execution, the problem of time-varying matrix pseudoinversion, as a new issue, is involved in the pseudoinverse-based scheme formulation. By computing the time-varying pseudoinverse of the Jacobian matrix (of the robot manipulator), discrete-time zeroing dynamics (ZD) models, as a new approach to the time-varying Jacobian matrix pseudoinversion, are applied to the redundant-manipulator kinematic control. Then, considering that calculating the inverse of Jacobian matrix is less efficient, three types of inverse-free simple solution based on the gradient dynamics (GD) method and ZD method, are thus presented and investigated to avoid the Jacobian inversion. Recent progress in our 16-year study shows the advantages of unifying the treatment of various schemes of manipulators' redundancy resolution. We recall some fundamental techniques for such a unification and then specify it in full details based on quadratic programming (QP) and its online solutions. Such a QP formulation is general in the sense that it incorporates equality, inequality, and bound constraints, simultaneously. This QP formulation covers the online avoidance of joint physical limits and environmental obstacles, as well as the optimization of various performance indices. Every term is endowed with clear physical meaning and utility. Computer-simulation results based on various robotic models show the effectiveness of the presented methods and schemes. For substantiating the physical realizability, some of these methods and schemes are applied to an actual six-DOF planar robot manipulator.

The idea for this book was conceived during the research discussion in the laboratory and at international scientific meetings. Most of the materials of this book are derived from the authors' papers published in journals and proceedings of international conferences. In fact, in recent decades, the field of robotics has undergone the phases of exponential growth, generating many new theoretical concepts and applications (including the authors' ones). Our first priority is thus to cover each central topic in enough details to make the material clear and coherent; in other words, each part (and even each chapter) is written in a relatively self-contained manner.

This book contains 15 chapters that are classified into the following seven parts.

Part I: Pseudoinverse-Based ZD Approach (Chapter 1);
Part II: Inverse-Free Simple Approach (Chapter 2 through Chapter 4);
Part III: QP Approach and Unification (Chapter 5);
Part IV: Illustrative Velocity-Level QP Schemes and Performances (Chapter 6 through Chapter 8);
Part V: Self-Motion Planning (Chapter 9 through Chapter 11);
Part VI: Manipulability Maximization (Chapter 12 and Chapter 13);
Part VII: Encoder Feedback and Joystick Control (Chapter 14 and Chapter 15).

Chapter 1 – This chapter presents and investigates the applications of discrete-time ZD models to the kinematic control of redundant robot manipulators via time-varying matrix pseudoinversion. That is, by computing the time-varying pseudoinverse of the Jacobian matrix (of the robot manipulator), the resultant ZD models are applied to the redundant-manipulator kinematic control. Computer-simulation results based on two robot manipulators further illustrate the effectiveness of the presented ZD models for time-varying matrix pseudoinversion applied to the redundancy resolution of robot manipulators.

Chapter 2 – In this chapter, base on GD method, an inverse-free scheme is presented at the joint-velocity level to avoid calculating the inverse of Jacobian matrix. The scheme is called a G1 type as it uses GD once. In addition, two path tracking simulations based on five-link and six-DOF redundant robot manipulators illustrate the efficiency and the accuracy of the presented scheme. What is more, the physical realizability of G1 type scheme is also verified by the physical experiments based on the six-DOF planar redundant robot manipulator hardware system.

Chapter 3 – In this chapter, another inverse-free simple solution based on GD method, named the D1G1 scheme, is presented at the joint-acceleration level for solving the inverse kinematics problem of redundant robot manipulators. Furthermore, simulation results based on a three-link redundant robot manipulator substantiate the effectiveness and accuracy of the presented inverse-free D1G1 scheme.