Preface

Robots have changed the life of human beings in the twenty-first century. In industrial automation, the use of robots is vital to preserve the quantity and quality of production by introducing flexibility to the production line. Industrial robots usually have an articulated structure in which a series of links are connected to each other to provide a large workspace. The motion of the robot is controlled through the disjointed actuators that manipulate individual motion of each link. Although, in such structures, characteristics such as a large workspace and flexibility may be obtained, the accuracy of the last manipulating element is significantly threatened by the serial structure.

For applications in which high precision and low compliance are required or a relatively high load capacity per robot weight is essential, parallel structures are the absolute alternative. A parallel robot has an inherent closed-loop kinematic structure, and its moving platform is linked to the base by several independent kinematic chains. Many industrial applications have adopted parallel structure for their design; however, only a very few text-books have been published to introduce the analysis of such robots in terms of kinematics, dynamics, and control. This book is intended to give some analysis and design tools for the increasing number of engineers and researchers who are interested in the design and implementation of such robots in industries. In this book, a systematic approach is presented to analyze the kinematics, dynamics, and control of parallel robots.

In order to define the motion characteristics of such robots, it is necessary to represent 3D motion of the robots' moving platform with respect to a fixed-coordinate frame. This naturally leads to the need for a systematic representation of the position, orientation, and location of bodies in space. In Chapter 2, such representations are introduced with an emphasis on screw coordinates, which makes the representation of general motion of the robot much easier to follow. It should be noted that the ideas developed for position and orientation representation will form a basis for linear and angular velocity and acceleration representations, and this is also adopted to represent forces and torques applied in a robotic manipulator.

Kinematic analysis refers to the study of the geometry of motion in a robot without considering the forces and torques that cause the motion. In this analysis, the relation between the geometrical parameters of the manipulator and the final motion of the moving platform is derived and analyzed. A complete treatment of such an analysis is given in Chapter 3, and elaborative case studies are provided for three parallel robots, including a planar cable-driven parallel robot. The analysis of cable-driven parallel robots is formally treated in this book as the promising new generation of parallel structures that provide a very large workspace.

In Chapter 4, kinematic analysis of robot manipulators is further examined beyond static positioning. Differential kinematic analysis plays a vital role in the singular free design of robotic manipulators. Jacobian analysis not only reveals the relation between the joint variable velocities and the moving platform linear and angular velocities, but it also constructs the transformation needed to find the actuator forces from the task space forces and moments acting on the moving platform. A systematic approach to performing Jacobian analysis of parallel manipulators is given in this chapter and the proposed method is examined through the same case studies analyzed in Chapter 3.

The dynamic analysis of parallel manipulators presents an inherent complexity due to the closed-loop structure and kinematic constraints. Nevertheless, the dynamic modeling is quite important for the control, particularly because parallel manipulators are preferred in applications where precise positioning and suitable dynamic performance under high loads are the prime requirements. Although a great deal of research has been presented on the kinematics of parallel manipulators, works on the dynamics and control of parallel manipulators are relatively few, and almost no books cover these issues in detail. These issues are addressed well in this book in Chapter 5, in which dynamic analysis of such robots is examined by three methods, namely the Newton–Euler principle of virtual work and Lagrange formulations. Furthermore, a method is presented in this chapter to formulate the dynamic equation of parallel robots into a closed form, by which the dynamic matrices are more tractable and dynamics verification becomes possible.

The control of a parallel robot is elaborated in the last two chapters of the book, in which both motion and force control schemes are covered. Different model-free and model-based controllers are introduced and robust and adaptive control schemes are elaborated in Chapter 6. The control techniques are applied to two case studies, in which both cable-driven redundant parallel manipulator and fully parallel manipulators are examined through the proposed control schemes. Finally, Chapter 7 covers the force control of parallel robots in detail. In this chapter, stiffness control, direct force control, and impedance control schemes are elaborated and implemented on the same case studies followed in the book.

A key to verify the analysis and the controller performance is computer simulation. Computer simulations are being used for the case studies followed in all chapters throughout the text. Simulations are usually performed by commercially available packages such as MATLAB®, which provides a suitable means to simulate the robot's kinematic or dynamic characteristics and to verify the performance of the control systems. The manuscript was typeset using LaTeX, and the artworks were generated by Smart Draw and Inkscape software.

I am indebted to many people who have supported me either technically or spiritually during the writing of this book. As it involves the knowledge about many disciplines, numerous people have contributed to this work, but a list of the names could not be presented here; however, all of them are acknowledged. I would like to dedicate this book to the late Professor G. Zames and Professor P. R. Bélanger, not just for many things I have learned from them in control theory, but also for the deep influence they have induced in my soul *to make a difference*. I am also indebted to Professors J. Angeles and C. Gosselin who encouraged me to pursue this work. Many of the results presented in this book are mainly the contributions of J. Angeles, C. Gosselin, J.-P. Merlet, L-W. Tsai, and many other prominent researchers in this field. I had the pleasure to organize and further elaborate on these contributions. Any error in the presentation of their work is solely mine.

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Hamid D. Taghirad
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