Preface

The first robots, as they are understood today, were developed in the sixties of the previous century. Their mechanisms were almost without exceptions simple serial mechanical arms possessing six or preferably fewer degrees of freedom, and used almost exclusively in different industrial applications. Fifty years later, robot mechanisms are still extensively being investigated for a variety of robot applications in everyday life. A significant impulse to the development of robot mechanisms was given in the nineties by a dramatic appearance of parallel mechanisms and later by human-like or animal-like mechanisms. New designs are mainly due to many new discoveries and better understanding of human or animal motion. They also result from new technological advancements such as new materials, more efficient or conceptually different actuators and even artificial muscles.

Although the theory of robot mechanisms largely relies on methods of classical mechanics, in recent decades it has made huge steps forward. Authors, such as B. Roth, K. Hunt and J. Duffy and L.-W. Tsai, J. Angeles, J.M. McCarthy and many others, have contributed to genuine advances in science and in industrial practice. Today, for instance, all major manufacturers of industrial robots offer robots with high precision parallel kinematic structures and all major research laboratories develop humanoid robots or body parts possessing the morphology and other characteristics of humans.

The book consists of ten chapters. In the first chapter we introduce the mathematical tools which are used throughout the book, making the presentation self-contained. Translation and rotation of the body are treated as a transformation between vector spaces. Special attention is focused on the rotation matrix and its characteristic properties, as well as on the homogeneous transformation matrix which describes the position and orientation of a body, together with its velocities and accelerations. In the second chapter, we review the basic characteristics of robot mechanisms, calculate the number of degrees of freedom and present some typical arrangements of links and joints used in robot mechanisms. We present the parameters and variables of a kinematic pair and then develop a step by step procedure which enables us to model an entire mechanism.

In the third chapter we develop equations for the kinematic analysis of serial mechanisms. These equations represent the position and orientation, the linear and angular velocity and the linear and angular acceleration. We introduce the Jacobian matrix and the Hessian matrix of the mechanism. Both are of crucial importance in the kinematic analysis of robots. In the second part of the chapter we define the direct and the inverse kinematics problem. The inverse kinematics problem for serial mechanisms of general geometry is difficult to solve. In general, a closed-form solution does not exist and special-purpose numerical iterative methods are to be applied. Their main drawbacks are associated with the convergence and with multiple solutions which are pertinent to the inverse kinematics problem. Difficulties are also due to the fact that the existence of a real solution is not always guaranteed. In the fourth chapter, we define the criteria to examine different functional properties of robot mechanisms from a perspective of a user or a designer robots. Among these we study the reachable and the dexterous workspace, the kinematic flexibility and singularity, as well as the manipulability and the kinematic index. The fifth chapter deals with describing kinematic singularities in industrial robots. The description is in terms of singular planes. The singular planes show that the origin of kinematic singularities in industrial robots are pointing singularities. This leads to a discussion singularity free pointing systems and how they can be incorporated into singularity free robots.

A redundant mechanism is referred to as a mechanism which contains more degrees of freedom than is needed to perform a given task. Redundant mechanisms can solve a given primary task in an infinite number of ways. This feature allows to the robot to simultaneously solve additional secondary tasks. The kinematic redundancy of mechanisms is the theme of the sixth chapter of this book. Mathematically speaking, the system of differential equations defining the kinematics of a redundant mechanism is underdetermined and the related Jacobian matrix is rectangular. This requires special mathematical approaches to solve the inverse kinematics problem. Humans or animals are using kinematic redundancy as a tool to optimize their motion. Some simplified examples are described in the end of the section. The seventh chapter is devoted to parallel mechanisms. These mechanisms contain one or more closed kinematic chains. Different types of parallel mechanisms are described and the computation of direct and inverse kinematics of parallel mechanisms is discussed. Attention is given also to the difficulties that arise when a parallel mechanism enters in a singular position.

In the eight and the ninth chapter we describe the mathematical basis and learn about the effects of robotic touch and grip. Robotic grip is understood as a set of contacts between the fingers and the object. The problem is how to determine the conditions to restrict an object's movement. In the tenth and the last chapter of the book we present the direct and the inverse kinematic model of the thumb and fingers of the human hand. The introduced kinematic models were obtained based on a series of optical measurements of the human hand. The introduced models enable us to analyze the motion of the human hand depending on the length and width of the palm.

The book deals primarily with the analytical study of kinematics of robot mechanisms which includes the geometry of motion of mechanisms without regards to the forces and moments that cause or result from the motion. In addition to recognized areas, this book also presents examples of recent advances in emerging areas such as the design and control of humanoids and humanoid subsystems, and the analysis, modeling and simulation of human body motions.