Preface

A robot may not injure a human being or, through inaction, allow a human being to come to harm.

– Isaac Asimov

Humanoid robots are the most universal machines designed so far. Their human-like appearance presumes that one day humanoid robots will become the ubiquitous helpers of mankind as an embodiment of artificial intelligence (AI). Although still in its initial phase, research in the field of humanoid robotics is advancing at a fast pace, covering thereby a diverse set of problems. The research is benefiting from but is also contributing to technological achievements in such areas as self-driving transportation means in a complex environment (e.g. in relation to sensing, perception, and motion planning), natural language communication (e.g. in relation to personal assistance), and AI in general. This is also true for the areas in the field of the mechanical sciences and control.

Characterized as universal, a humanoid robot is also an inherently complex machine. Its control architecture comprises a hierarchical structure. At the middle levels of the hierarchy, kinematic, kinetostatic, and dynamic models have to be employed to ensure appropriate control of the motion and the flow of forces. This is a challenging problem since the models have to account for the relatively large number of actuated joints and the best way to simultaneously control them while performing a varying number of tasks, with a kinematic structure that varies frequently by forming closed kinematic chains and unforming them while the robot establishes new contacts and breaks old ones. The models also have to account for the "floating base" and its "underactuation," as well as for the varying environment conditions.

The aim of this book is the in-depth covering of a core set of problems related to the modeling and the model-based control of humanoid robots. A large body of research exists in the robotics field that can support this goal. Kinematically redundant manipulators and the related problem of multi-degree-of-freedom (DoF) resource allocation to manage a number of robot tasks have been studied from the mid-1970s. A number of studies exist on robots with closed kinematic chains, referred to as parallel-link manipulators. Studies on structure-varying robotic mechanisms, such as multifingered hands, multilegged robots, and dual-/multiarm manipulators, are also abundant. Underactuated, articulated multibody systems on a floating base, such as free-floating space robots, manipulators on flexible bases, and macro-mini manipulators (i.e. a small manipulator attached to the end of a larger arm) have been studied from the mid-1980s. There are a number of studies in the closely related field of constrained multibody systems. Contact modeling is also a well-established area of research.

The ultimate goal is to design a humanoid robot controller that can guarantee the performance of a broad variety of motion and force control tasks. This can only be done when a whole-body model of the robot is employed. With a whole-body model, the structure of the controller becomes quite complex, though, as already noted. The control inputs then have to be derived with the help of an optimization approach. A number of humanoid robot controllers that appeared recently in the literature have been based on this approach, while taking advantage of the existing general optimization software packages. Because of the complexity, however, real-time control may not be feasible with this approach. On the other hand, with a simplified model it is possible to derive the optimal control solution analytically. Analytical solutions yield the advantage of shorter computational cycles. The simplest possible model is the (linear) inverted pendulum model. It was proposed some time ago to deal with the task of balance stabilization on a flat ground. Later it was shown that the model can be enhanced by adding a reaction wheel assembly component. A centroidal moment can then be generated that plays an important role when dealing with unknown disturbances applied to the body of the robot or that appear while the robot steps over irregular terrain, for example. Analytical optimal solutions for a whole-body model are quite rare, though. At present, the analytical approach is indispensable for motion generation and control in real-time.

It is quite exciting that the research in the field of humanoid robotics can contribute to other areas as well. Such areas include the biomechanics and motor control of human movement, physical therapy, the sport sciences, and physics-based animation of articulated figures. Researchers in these fields could benefit from the results described in this book as well.

The authors of this work have been involved for decades in the areas of research that constitute the foundation of humanoid robotics. It was a challenging task to draw on the past results, to organize and reinterpret them in an attempt to exemplify their role when applied to humanoid robots. This work also includes many important and up-to-date results reported by other researchers. From this point of view, the style resembles somewhat that of a reference. What makes it different from a handbook, though, is the revealing of some important interrelations between the results in the different areas of research and their contribution to the main goal of this work.

Tokyo, July 2018 The authors