Part B Robot Structures

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The chapters contained in Part B, Robot Structures, are concerned with the design, modeling, motion planning, and control of the actual physical realizations of a robot. Some of the more obvious mechanical structures that come to mind are arms, legs, and hands; to this list we can add wheeled vehicles and platforms, and robot structures at the micro- and nanoscales. Even for that most basic robotic device, the arm, an incredibly diverse set of structures is possible, depending on the number and types of joints and actuators, and the presence of closed loops in the kinematic structure, or flexibility in the joints and links. Constructing models, and planning and control algorithms for these diverse structures represents an even greater set of challenges.

The topics addressed in these chapters are essential to creating not only the physical robot itself, but also to creating and controlling movements, and manipulating objects in desired ways. As such the connections with the chapters on Robot Foundations (Part A) — particularly the chapters on Kinematics (Chap. 1), Dynamics (Chap. 2), and Mechanisms and Actuation (Chap. 3) — are self-evident. What ultimately distinguishes robotics from other disciplines that study intelligence is that, by definition, robots require a physical manifestation, and by extension must physically interact with the environment. In this regard the topics addressed in these chapters can be said to constitute the most basic layer of this endeavor.

Just as it is difficult to examine human intelligence from a purely abstract perspective, remotely detached from the physical body, so it is difficult to separate the contents of the remaining parts without including in the discussion the actual medium of interaction with the physical world, the (physical) robots themselves. For example, the question of how to coordinate sensing and perception with action (Part C), how to grasp and manipulate objects (Part D), and how to teach multiple robots to cooperate (Part E), must inevitably consider the physical structure of the robot. Robots specialized to various applications and environments (Part F), particularly those intended for direct interaction with humans (Part G), naturally must also consider the robot's physical structure.

With this overview of Part B, we now provide a brief synopsis of each chapter.

Chapter 10, Performance Evaluation and Design Criteria, provides a concise overview of the robot design process, and surveys some of the criteria and tools used in the mechanical design and performance evaluation of robots. Criteria such as workspace volume, local and global dexterity, and elastostatic and elastodynamic performance are not only applicable to determining the topological structure and physical dimensions of the robot, but can also be useful for, e.g., workpiece placement and kinematic redundancy resolution.

Chapter 11, Kinematically Redundant Manipulators, addresses the motion generation and control of manipulators with redundant kinematic degrees of freedom. Kinematic redundancy affords a robot with an increased level of dexterity that may be used to, e.g., avoid singularities, joint limits and workspace obstacles, and also to minimize joint torques, energy, or other suitable performance criteria. The chapter discusses inverse kinematic redundancy resolution schemes for manipulators ranging from those with just a few degrees of kinematic redundancy, to hyperredundant manipulators that can be kinematically modeled as continuous curves.

Chapter 12, Parallel Mechanisms and Robots, presents an introduction to the kinematics and dynamics of parallel mechanisms such as the well-known Stewart–Gough platform. Parallel mechanisms contain closed loops in their kinematic structure, and as such methods for their analysis differ considerably from those for their serial counterparts. This chapter discusses topics ranging from type synthesis and forward and inverse kinematic solutions of parallel mechanisms, to an investigation of their singularity behavior, workspace characterization, static and dynamic analysis, and practical issues in their design.

Chapter 13, Robots with Flexible Elements, addresses the dynamic modeling and control of robots with flexibility in the joints and links. Because the control methods developed to compensate for joint versus link flexibility are structurally different, the chapter is organized such that these two types of flexibility are examined independently. The methods, however, can be extended to the case when both joint and link flexibilities are present, possibly even dynamically interacting at the same time. The chapter also examines the typical sources of flexibility in industrial robots.

Chapter 14, Model Identification, discusses methods for determining the kinematic and inertial parameters of robot manipulators. For kinematic calibration, the primary aim is to identify the geometric Denavit–Hartenberg parameters or equivalent, typically by sensing a combination of joint and endpoint positions. Inertial parameters in turn are estimated through the execution of a trajectory while additionally sensing one or more components of joint forces or torques. The chapter is organized such that both kinematic and inertial parameter identification are cast into a common framework of least-squares parameter estimation: common features relating to the identifiability of the parameters, adequacy of the measurement sets, and numerical robustness are identified and emphasized for both the kinematic and inertial parameters.

Chapter 15, Robot Hands, investigates the principal issues behind the design, modeling, and control of robot hands. Beginning with a discussion of levels of anthropomorphism, and the characterization of robot hand dexterity, the chapter investigates the relevant design issues for robot hands, actuation and transmission architectures, and available sensing technologies. The dynamic modeling and control of robot hands are made challenging not only by the complex kinematic structure, but also by the flexible transmission elements, and the chapter devotes particular attention to these issues.

Chapter 16, Legged Robots, discusses the myriad issues involved in the design, analysis, and control of legged robots. Beginning with a history of legged robot research, the chapter provides an analysis of cyclic walking, and the control of biped robots based on the forward dynamics and the zero-moment point (ZMP). Multilegged robots, such as dynamic quadrupeds inspired by mammals and behavior-based multilegged robots, are also discussed, as are hybrid leg–wheel–arm robots, tethered walking robots, and even legged robots capable of climbing walls.

Chapter 17, Wheeled Robots, provides a general and comprehensive description of wheeled mobile robots. The chapter begins with a discussion of robot mobility based on the types of wheels and the nature of the kinematic constraints, followed by a discussion of kinematic and dynamic state space models, and structural properties of wheeled robot models such as controllability, nonholonomy, and stabilizability. The chapter also discusses feedback linearizability in the context of nonlinear control, and concludes with a detailed classification of the possible robot structures based on the number and types of wheels.

Chapter 18, Micro/Nanorobots, provides an overview of the state of the art in micro- and nanorobotics. The former entails robotic manipulation of objects with dimensions in the millimeter to micron range, as well as the design and fabrication of autonomous robotic agents within this size range (nanorobotics is defined in the same way, but for dimensions smaller than a micron). The chapter outlines scaling effects, actuation, and sensing and fabrication at these scales, and also applications to microassembly, biotechnology, and the construction and characterization of micro- and nano-electromechanical systems.