Multimedia Contents

Part B Design

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The chapters contained in Part B, Design, are concerned with the design and modeling 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; snake-like and continuum robots; robots capable of swimming and flying; 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 robots to move in the world (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 16, 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 17, Limbed Systems, discusses the myriad issues involved in the design, analysis, and control of robots with limbs. Defining a limbed system as a robot consisting of a body and at least one limb such that it is able to support and propel itself, the chapter begins with an overview of the design process for limbed systems, from conceptual to detailed, and the basic dynamics of passive and controlled walking. The chapter also examines numerous case studies illustrating the diversity of limbed robot designs, and schemes for their actuation and locomotion. Multi-legged 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 18, 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 19, 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 20, Snake-Like and Continuum Robots, begins with a history of snake robots, starting with the pioneering work of Shigeo Hirosein in the early 1970s. While snake-like and continuum robots have very similar exterior appearances, there is considerable diversity in their mechanical design, and the ways in which they are actuated. This chapter describes the mechanical design, actuation, modeling, motion planning, and control of such robots. The chapter also provides case studies of a wide range of existing snake-like and continuum

robots that illustrate the diversity of designs as well as applications.

Chapter 21, Soft Robots, begins with the premise that robots of the future will not resemble the bulky rigid machines found in today's factory floors, but will be compliant and adaptable, and able to safely interact with humans – in other words, soft. This chapter discusses the design, modeling, and control of actuators for this new generation of soft robots.The chapter surveys the different principles and technologies that can be used to design and implement actuators for soft robotics. Many of the concepts are organized so as to allow a direct analogy with natural muscles. Variable impedance actuators are examined in some detail, from their mathematical modeling to motion and force planning and control.

Chapter 22, Modular Robots, provides an overview of the design of modular robots. The chapter begins with a discussion of the concept of modularity, and a definition and classification of modular robots. The chapter then examines reconfigurable modular manipulators, from the earliest designs that were conceived in an industrial automation setting, to more recent self-reconfigurable modular robots. Issues related to the design of modules and the interfaces between them, and the determination of optimal configurations, are also discussed in this chapter.

Chapter 23, Biomimetic Robots, broadly examines the ways in which biological principles can be applied to the design of robotic mechanisms. The challenges of biomimetic design include developing a deep understanding of the relevant natural system, and translating this understanding into a set of engineering design rules; this often entails the development of novel fabrication and actuation to realize the biomimetic design. This chapter discusses the basic design principles underlying biomimetic robots and their contrast with bio-inspired robots, and the fundamental components for developing a biomimetic robot. The chapter also provides detailed reviews of biomimetic designs that have been developed for flapping-wing flight, jumping, crawling, wall climbing, and swimming, as well as the enabling material and fabrication technologies for these biomimetic designs.

Chapter 24, 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 classification of wheeled robot structures according to the number and type of wheels and how they are arranged. Omnimobile robots and articulated robot realizations are described, and wheel–terrain interaction models for computing contact forces are also presented. The chapter concludes with a classification of wheel–terrain interaction cases depending on the relative stiffnesses of the wheel and terrain, and the structure and dyamics of suspension systems that enable movement of wheeled robots over uneven surfaces.

Chapter 25, Underwater Robots, examines the design issues for underwater robots, with a focus on remotely operated vehicles and autonomous underwater vehicles. The major components of an underwater robot – from the mechanical elements and subsystems including any attached manipulators, to power sources, actuators and sensors, and architectures for computing and communications and control, are discussed in this chapter. Aspects of the mathematical modeling and control of underwater robots is covered in a separate chapter later in this handbook.

Chapter 26, Flying Robots, provides an overview of the core elements of flying robots. The reader will be guided through the design process of aerial robots, beginning with a qualitative characterization of the different types of flying robot. Design and modeling are particularly closely intertwined in flying robots, and the chapter provides an overview of the underlying aerodynamics and tools for their analysis. The chapter then shows how these tools can be applied to the design and analysis of various types of flying robots, including fixed-wing, rotary-wing, and flapping wing systems, with case studies illustrating these design principles.

Chapter 27, 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 micrometer 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 micrometer). 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.