Part E

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Part E Mobile and Distributed Robotics

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Part E. Mobile Robotics started as a research domain in its own right in the late 1960s with the *Shakey* project at SRI. The seminal paper by N.J. Nilsson "A Mobile Automaton: An Application of Artificial Intelligence Techniques" at IJCAI 1969, already addressed perception, mapping, motion planning, and the notion of control architecture. Those issues would indeed be at the core of mobile robotics research for the following decades. The 1980s boomed with mobile robot projects, and as soon as it was necessary to cope with the reality of the physical world, problems appeared that fostered novel research directions, actually moving away from the original concept in which the robot was just an application of AI techniques. This part addresses all the issues that, put together, are necessary to build and control a mobile robot, except for the mechanical design itself.

Sensing as such is the subject of Part C but the use of sensing for environment mapping and robot localization, central to mobile robot navigation, are developed in this part in Chaps. 36 and 37, with very close links to estimation theory (Part A, Chap. 4). Several issues presented in the foundations (Part A) are revisited in this part and placed in the context and specificities of mobile robots, such as motion control (Chap. 6, Part A and Chap. 34 in this part). Motion planning is addressed in Part A, Chap. 5, whereas the specific problems of motion planning and obstacle avoidance are the subject of Chap. 35. A mobile robot is a system integrating sensing, decision making, and action. Therefore control architecture issues were very much developed in robotics through mobile robotics, often raising controversy. Chapter 38, focusing on behavior-based systems, should probably be read bearing in mind Chap. 8 (Part A) on robotic systems architectures and programming, and Chap. 9 (Part A) on AI reasoning and learning methods for robotics.

What happens when several mobile robots meet together? How does collective behavior emerge and how can it be controlled? These questions arose very early. Answers are developed in Chaps. 39, 40, and 41

With the development of mobile robots, control issues became a major concern when it appeared necessary to achieve smooth and efficient motion and to follow determined trajectories. In addition, the design of the locomotion structure of wheeled robots was often similar to that of a car, i. e., nonholonomic. Kinematics and control, which were essentially studied in manipulators, entered the field of mobile robotics. The techniques for steering control using mainly feedback control and linear control theory are presented in Chapter 34 .

Chapter 35 addresses motion planning from the viewpoint of mobile robotics. In this context, nonholonomic kinematic constraints appeared as a major difficulty and differential geometry as a major tool for achieving the motions computed by classical motion planners. Another difference from classical motion planning addressed here is negotiating unknown or mobile obstacles in uncertain environments, which led to the development of approaches using sensor-based motion.

Mobile robot navigation requires building maps of the environment. The first question addressed in Chapter 36 is therefore: what representations are the most adequate, considering for example that on uneven terrain, the very notion of *obstacle* has a different meaning than indoors? And another question is: how should sensing uncertainties be processed? Furthermore, mobile robots need to map their environment incrementally, while moving in it. Hence partial representations, built from different positions, need to be fused together to construct a consistent map. This requires the robot to know those positions, which are only defined with respect to the environment map itself. Hence localization and mapping must be achieved simultaneously, and Chapter 37 overviews the techniques for solving this SLAM problem.

The mid 1980s was a very rich period for mobile robotics. It is then that three main topics were first addressed: SLAM, nonholonomy, and control architectures. Probably one of the most exciting controversies in the field was raised by Rodney Brooks' subsumption architecture which, by eliminating deliberative components from the architecture, became the paradigm for behavior-based robots. Chapter 38 discusses those architectural concepts.

This part includes three chapters on distributed robotics. Interaction among multiple mobile robots for achieving a common mission or for coordination, through direct or indirect communication, or even no communication at all, robot systems composed of a few machines or large swarms with emerging behaviors, and the underlying algorithms are described in Chapter 40 . In that chapter, each robot has its own capacity and individual behavior. Can we design robots from other robots? Can robots reconfigure their own body? Can robots replicate? Chapter 39 overviews modular robots, i. e., robots built from interchangeable parts, that can reconfigure themselves according to the task, to the motion or situation.

Finally, with the development of miniaturization and wireless communication, the notion of distributed robots itself has taken another dimension. Robots can be scattered everywhere and become pervasive. These new problems are the subject of Chapter 41, which concludes this part.

As soon as technology enabled the design at an affordable cost of robots integrating sensing decision and motion and as research results became available, potential applications in all domains became a serious investigation issue in numerous projects, as will be described in Part F.