1 Introduction

1.1 Introduction

Robotics has achieved its greatest success to date in the world of industrial manufacturing. Robot arms, or *manipulators*, comprise a 2 billion dollar industry. Bolted at its shoulder to a specific position in the assembly line, the robot arm can move with great speed and accuracy to perform repetitive tasks such as spot welding and painting (figure 1.1). In the electronics industry, manipulators place surface-mounted components with superhuman precision, making the portable telephone and laptop computer possible.

Yet, for all of their successes, these commercial robots suffer from a fundamental disadvantage: lack of mobility. A fixed manipulator has a limited range of motion that depends

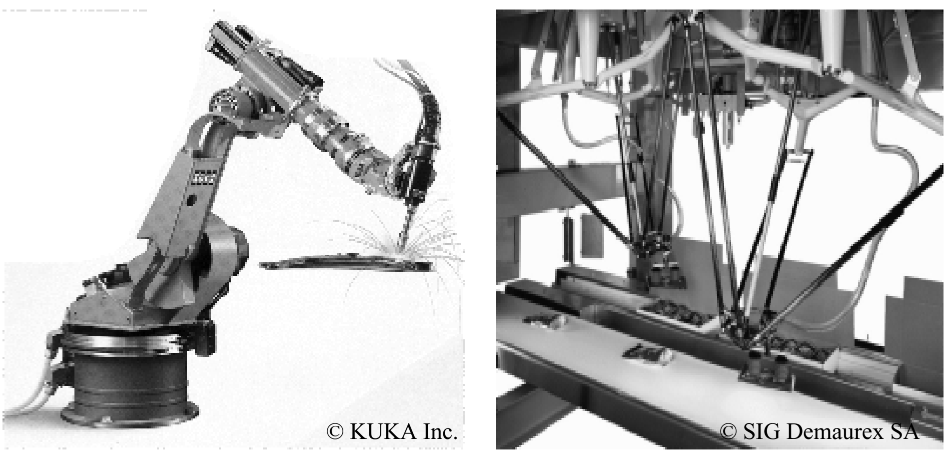

Figure 1.1
Picture of auto assembly plant-spot welding robot of KUKA and a parallel robot Delta of SIG Demaurex SA (invented at EPFL [140]) during packaging of chocolates.

on where it is bolted down. In contrast, a mobile robot would be able to travel throughout the manufacturing plant, flexibly applying its talents wherever it is most effective.

This book focuses on the technology of mobility: how can a mobile robot move unsupervised through real-world environments to fulfill its tasks? The first challenge is locomotion itself. How should a mobile robot move, and what is it about a particular locomotion mechanism that makes it superior to alternative locomotion mechanisms?

Hostile environments such as Mars trigger even more unusual locomotion mechanisms (figure 1.2). In dangerous and inhospitable environments, even on Earth, such *teleoperated* systems have gained popularity (figures 1.3, 1.4, 1.5, 1.6). In these cases, the low-level complexities of the robot often make it impossible for a human operator to directly control its motions. The human performs localization and cognition activities, but relies on the robot's control scheme to provide motion control.

For example, Plustech's walking robot provides automatic leg coordination while the human operator chooses an overall direction of travel (figure 1.3). Figure 1.6 depicts an underwater vehicle that controls six propellers to autonomously stabilize the robot submarine in spite of underwater turbulence and water currents while the operator chooses position goals for the submarine to achieve.

Other commercial robots operate not where humans *cannot* go but rather share space with humans in human environments (figure 1.7). These robots are compelling not for reasons of mobility but because of their *autonomy*, and so their ability to maintain a sense of position and to navigate without human intervention is paramount.

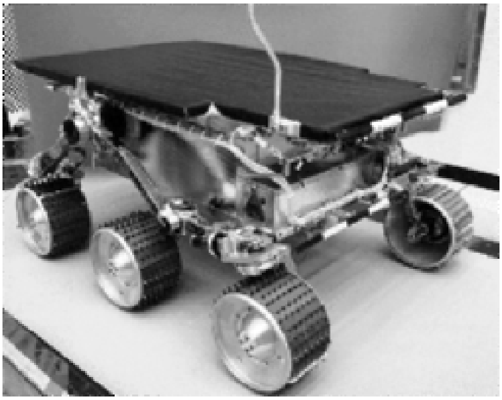

Figure 1.2
The mobile robot Sojourner was used during the Pathfinder mission to explore Mars in summer 1997. It was almost completely teleoperated from Earth. However, some on-board sensors allowed for obstacle detection. (http://ranier.oact.hq.nasa.gov/telerobotics_page/telerobotics.shtm).

Figure 1.3
Plustech developed the first application-driven walking robot. It is designed to move wood out of the forest. The leg coordination is automated, but navigation is still done by the human operator on the robot. (http://www.plustech.fi). © Plustech.

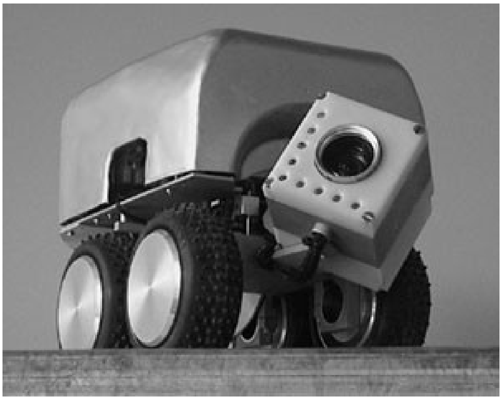

Figure 1.4
Airduct inspection robot featuring a pan-tilt camera with zoom and sensors for automatic inclination control, wall following, and intersection detection (http://asl.epfl.ch). © Sedirep / EPFL.

Figure 1.5
Picture of Pioneer, a robot designed to explore the Sarcophagus at Chernobyl. © Wide World Photos.

Figure 1.6
Picture of recovering MBARI's ALTEX AUV (autonomous underwater vehicle) onto the Icebreaker Healy following a dive beneath the Arctic ice. Todd Walsh © 2001 MBARI.

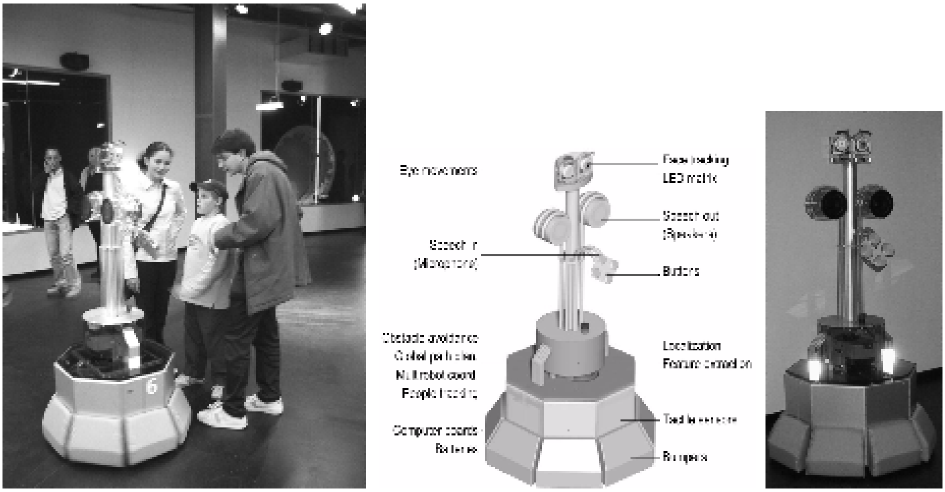

Figure 1.7
Tour-guide robots are able to interact and present exhibitions in an educational way [48, 118, 132, 143,]. Ten Roboxes have operated during 5 months at the Swiss exhibition EXPO.02, meeting hundreds of thousands of visitors. They were developed by EPFL [132] (http://robotics.epfl.ch) and commercialized by BlueBotics (http://www.bluebotics.ch).

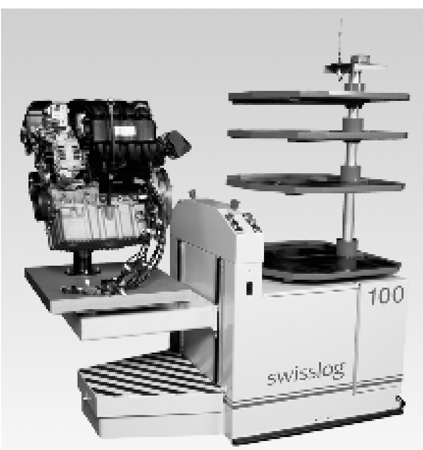

Figure 1.8
Newest generation of the autonomous guided vehicle (AGV) of SWISSLOG used to transport motor blocks from one assembly station to another. It is guided by an electrical wire installed in the floor. There are thousands of AGVs transporting products in industry, warehouses, and even hospitals. © Swisslog.

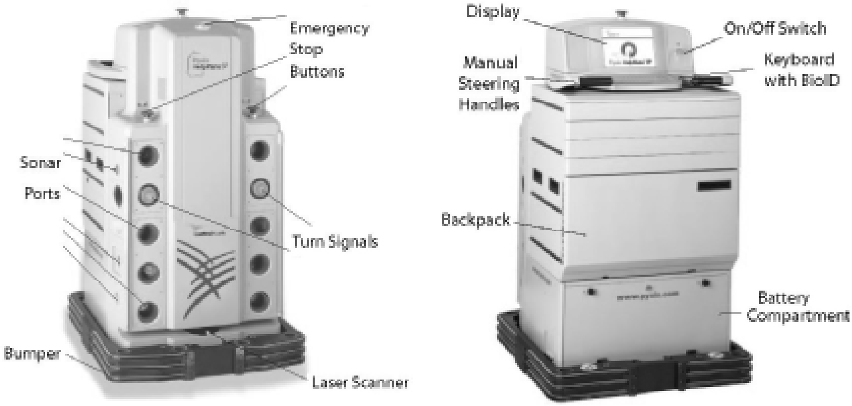

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Figure 1.9
HELPMATE is a mobile robot used in hospitals for transportation tasks. It has various on-board sensors for autonomous navigation in the corridors. The main sensor for localization is a camera looking to the ceiling. It can detect the lamps on the ceiling as references, or landmarks (http://www.pyxis.com). © Pyxis Corp.

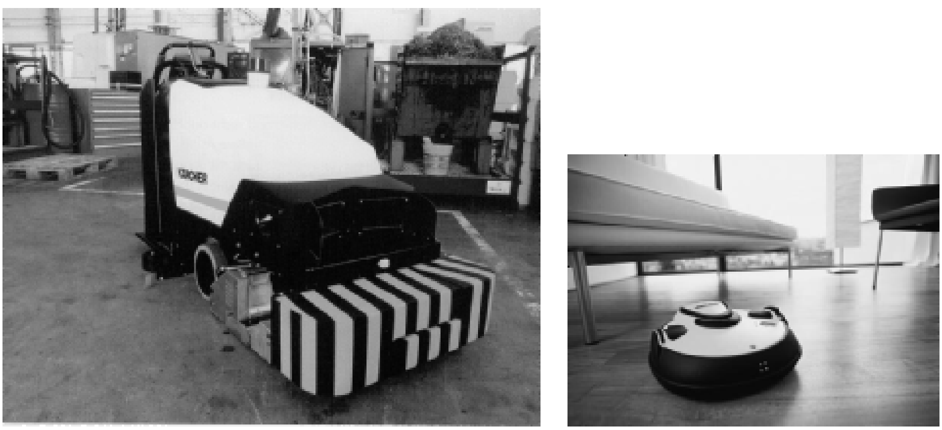

Figure 1.10
BR 700 industrial cleaning robot (left) and the RoboCleaner RC 3000 consumer robot developed and sold by Alfred Kärcher GmbH & Co., Germany. The navigation system of BR 700 is based on a very sophisticated sonar system and a gyro. The RoboCleaner RC 3000 covers badly soiled areas with a special driving strategy until it is really clean. Optical sensors measure the degree of pollution of the aspirated air (http://www.karcher.de). © Alfred Kärcher GmbH & Co.

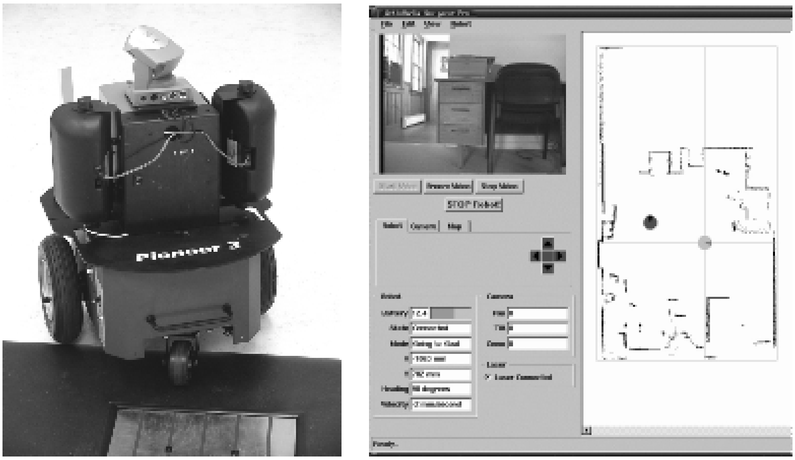

Figure 1.11
PIONEER is a modular mobile robot offering various options like a gripper or an on-board camera. It is equipped with a sophisticated navigation library developed at SRI, Stanford, CA (Reprinted with permission from ActivMedia Robotics, http://www.MobileRobots.com).

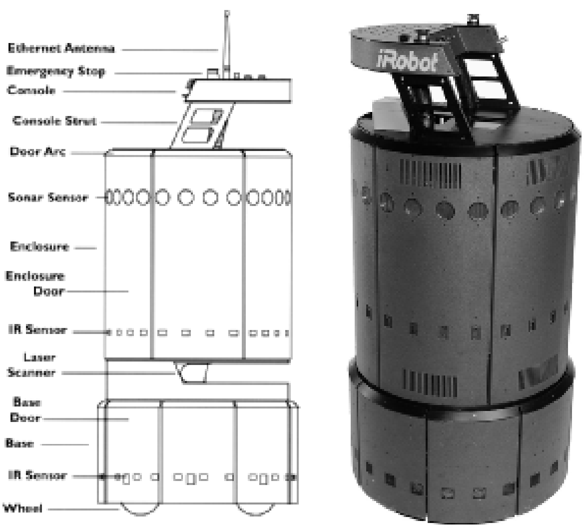

Figure 1.12
B21 of iRobot is a sophisticated mobile robot with up to three Intel Pentium processors on board. It has a large variety of sensors for high-performance navigation tasks (http://www.irobot.com/rwi/).
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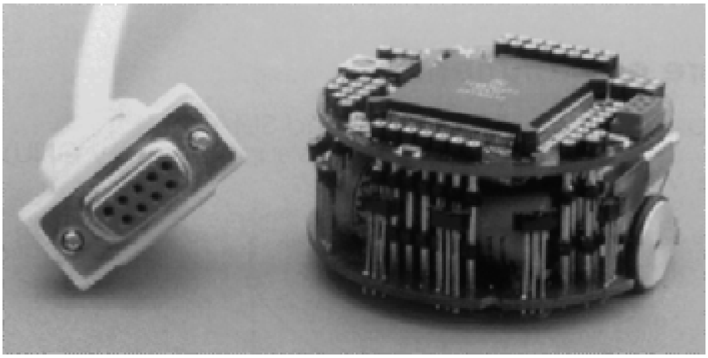

Figure 1.13
KHEPERA is a small mobile robot for research and education. It is only about 60 mm in diameter. Various additional modules such as cameras and grippers are available. More then 700 units had already been sold by the end of 1998. KHEPERA is manufactured and distributed by K-Team SA, Switzerland (http://www.k-team.com). © K-Team SA.

For example, AGV (autonomous guided vehicle) robots (figure 1.8) autonomously deliver parts between various assembly stations by following special electrical guidewires using a custom sensor. The Helpmate service robot transports food and medication throughout hospitals by tracking the position of ceiling lights, which are manually specified to the robot beforehand (figure 1.9). Several companies have developed autonomous cleaning robots, mainly for large buildings (figure 1.10). One such cleaning robot is in use at the Paris Metro. Other specialized cleaning robots take advantage of the regular geometric pattern of aisles in supermarkets to facilitate the localization and navigation tasks.

Research into high-level questions of cognition, localization, and navigation can be performed using standard research robot platforms that are tuned to the laboratory environment. This is one of the largest current markets for mobile robots. Various mobile robot platforms are available for programming, ranging in terms of size and terrain capability. The most popular research robots are those of ActivMedia Robotics, K-Team SA, and I-Robot (figures 1.11, 1.12, 1.13) and also very small robots like the Alice from EPFL (Swiss Federal Institute of Technology at Lausanne) (figure 1.14).

Although mobile robots have a broad set of applications and markets as summarized above, there is one fact that is true of virtually every successful mobile robot: its design involves the integration of many different bodies of knowledge. No mean feat, this makes mobile robotics as interdisciplinary a field as there can be. To solve locomotion problems, the mobile roboticist must understand mechanism and kinematics; dynamics and control theory. To create robust perceptual systems, the mobile roboticist must leverage the fields of signal analysis and specialized bodies of knowledge such as computer vision to properly employ a multitude of sensor technologies. Localization and navigation demand knowledge of computer algorithms, information theory, artificial intelligence, and probability theory.

Figure 1.15 depicts an abstract control scheme for mobile robot systems that we will use throughout this text. This figure identifies many of the main bodies of knowledge associated with mobile robotics.

This book provides an introduction to all aspects of mobile robotics, including software and hardware design considerations, related technologies, and algorithmic techniques. The intended audience is broad, including both undergraduate and graduate students in introductory mobile robotics courses, as well as individuals fascinated by the field. While not absolutely required, a familiarity with matrix algebra, calculus, probability theory, and computer programming will significantly enhance the reader's experience.

Mobile robotics is a large field, and this book focuses not on robotics in general, nor on mobile robot applications, but rather on mobility itself. From mechanism and perception to localization and navigation, this book focuses on the techniques and technologies that enable robust *mobility*.

Clearly, a useful, commercially viable mobile robot does more than just move. It polishes the supermarket floor, keeps guard in a factory, mows the golf course, provides tours in a museum, or provides guidance in a supermarket. The aspiring mobile roboticist will start with this book, but quickly graduate to course work and research specific to the desired application, integrating techniques from fields as disparate as human-robot interaction, computer vision, and speech understanding.

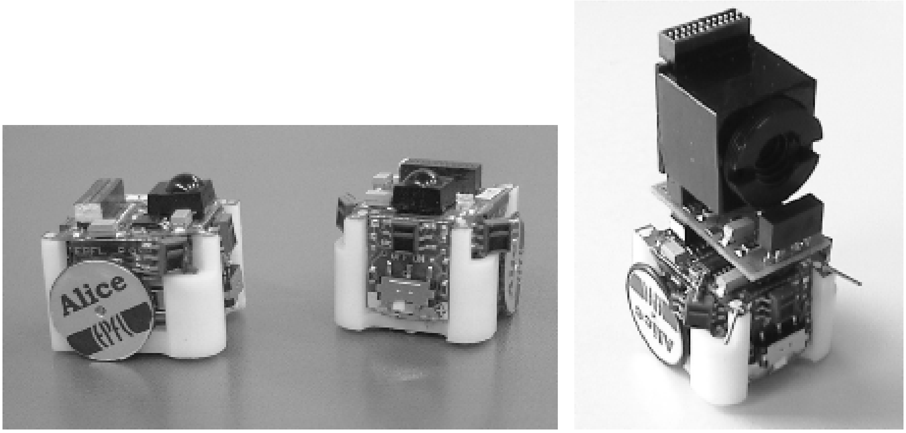

Figure 1.14
Alice is one of the smallest fully autonomous robots. It is approximately 2 x 2 x 2 cm, it has an autonomy of about 8 hours and uses infrared distance sensors, tactile whiskers, or even a small camera for navigation [54].

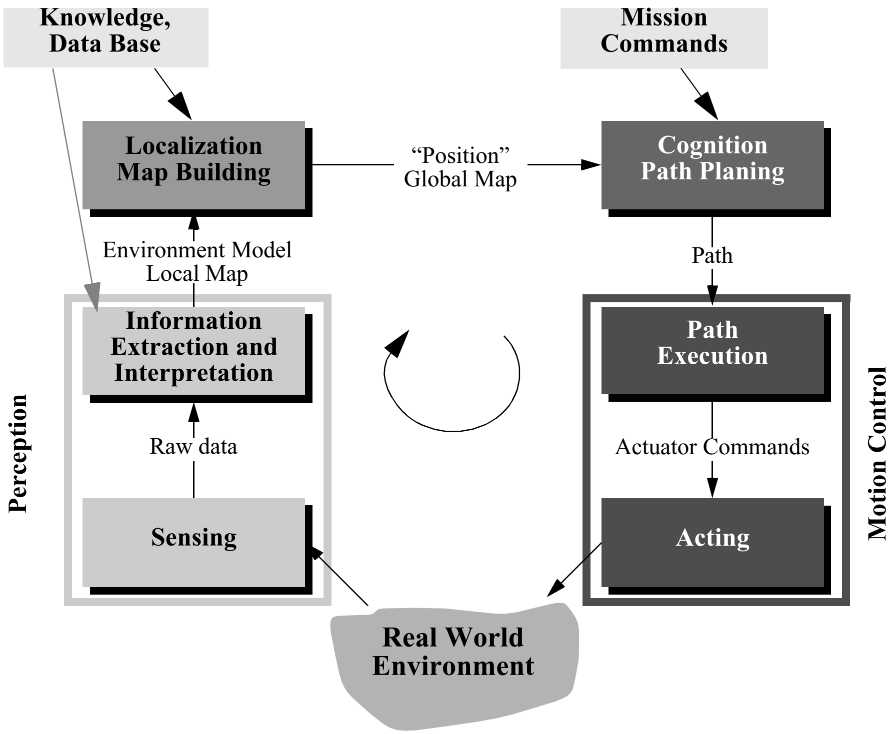

Figure 1.15
Reference control scheme for mobile robot systems used throughout this book.

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