Preface

Autonomous robots are intelligent machines capable of performing tasks in the world *by themselves*, without explicit human control over their movements. This book is an introduction to these remarkable systems, which have proliferated in recent years and promise to play a major role in our lives in the future. The book has several objectives:

- to provide a "guided tour" of the field of autonomous robots, in two ways: first, by reviewing the hardware implementations of several hundred current systems and some of their application areas (such as entertainment, industry, the military, and personal service); and second, by introducing some of the technology underlying these robots and their uses (including control, architectures, learning, manipulation, grasping, navigation, and mapping);
- to review the biological inspiration that forms the basis of many current and recent developments in robotics;
- to discuss some of the fundamental issues associated with robot control.

The breadth of the field can be seen from the fact that the book includes discussions of wheeled robots, legged robots (with two, four, six, and eight legs), flying robots, underwater robots, snakelike robots, climbing robots, jumping robots, and other kinds of robots.

We frequently define a robot as a machine that senses, thinks, and acts. In artificial intelligence such systems are known as "agents." Robots are distinguished from software agents in that they are *embodied* and situated in the real world. They receive information from the world through their sensors. They can be touched and seen and heard (sometimes even smelled!), they have physical dimensions, and they can exert forces on other objects. These objects can be balls to be kicked, parts to be assembled, airplanes to be washed, carpets to be vacuumed, terrain to be traversed, or cameras to be aimed. Robots are also subject to the world's physical laws, they have mass and inertia, their moving parts encounter friction and hence produce

heat, no two parts are precisely alike, measurements are corrupted by noise, and, alas, parts break. Robots also contain computers, which provide them with ever-increasing speed and power for both signal processing and cognitive functions. The world into which we place these robots keeps changing; it is nonstationary and unstructured, so we cannot predict their behavior accurately in advance.

These are some of the features of autonomous robots. They suffer from all the limitations of the real world, but because they are physical, they also fascinate us. This is particularly true of humanoid robots, but there is some intrigue in all moving robots. They are an imitation of life, and we are drawn to watching them. It is not only the fact that they move that beguiles us, since many things move in the world, but that they appear to move intelligently, they avoid obstacles, they interact with one another, and they accomplish tasks. For those of us who design and build them, enabling them to perform these and other actions is precisely our goal.

This book is an introduction to both the science and practice of autonomous robots. It can be used as a textbook in senior-level or first-year graduate courses. It is also a book of reference readings for practitioners in industry. Although there is some mathematics in the book, it appears primarily in connection with issues of control and localization. The book does not, however, offer a rigorous treatment of robot control. Rather, it attempts to stimulate, to pose questions, to review the way in which robots are designed, constructed, and used, and to provide some perspective on a rapidly changing field. Some chapters, like those providing overviews of mobile robots (chapter 7), legged locomotion (chapters 8 and 9), and humanoid robots (chapter 13) should be accessible to anyone with some engineering or computer science background, or even an intelligent layperson with no formal technical training.

Autonomous robots are increasingly evident in many aspects of industry and everyday life. As Rodney Brooks of MIT stated in a recent article, ''The robots are here!'' They are accepted by military organizations, since they are capable of reconnaissance and other missions. They are very evident in the entertainment industry, where they appear as pets or even as soccer players. In the service industries, robots are being used or considered for use in such tasks as vacuuming carpets, washing airplanes, filling gasoline tanks of automobiles, and delivering meals in hospitals and mail to offices.

I believe that during the next twenty years we will see autonomous robots appear in many aspects of our personal and professional lives. We may not recognize some of them, since they may be embedded in our cars or kitchen appliances or innumerable other objects with which we interact. Mobile autonomous robots will also become increasingly evident, not only in the exploration of distant planets or undersea environments, but also in the performance of numerous services for people, in

health care, industry, the environment, and our homes. These will indeed be exciting years for roboticists.

There are several hundred pictures of robots from many laboratories throughout the world in this book. Even so, the field is growing so rapidly that it was impossible to include all of the robots that have been developed. So I apologize to all my colleagues whose robots are not mentioned in the book and whose articles are not cited. I am grateful to all of you for helping to create this dynamic field.

This book would not have been possible without the help of numerous colleagues and friends. I would like to acknowledge my intellectual debt of gratitude to Rodney Brooks of MIT (from whose work I learned to look at the intelligence and control of robots in a totally new way), to my USC colleague Michael Arbib (whose astounding breadth of knowledge about both the brain and robotics continues to be a source of inspiration for me), and to my late colleague Rajko Tomović from the former Yugoslavia (from whom I learned many analogies between human control and robot control). I am also immensely grateful to my other USC colleagues, particularly Maja Matarić and Gaurav Sukhatme, for their support, for sharing some of their deep knowledge of the field with me, and for continuing and vastly enhancing the robotics program I started many years earlier. I also want to thank all my former doctoral students, particularly those who worked in robotics and related areas, including Andrew Frank, John Coggshall, Jim Chang, Fred Hadaegh, Dan Antonelli, Howard Olsen, Tasos Chassiakos, Huan Liu, Dit-Yan Yeung, Danilo Bassi, Gerard Kim, Patti Koenig, Arvin Agah, Tony Lewis, John Kim, Gaurav Sukhatme, Alberto Behar, Michael McHenry, Ayanna Howard, Jim Montgomery, and Stergios Roumeliotis. Over the years it has become clear that I have learned more from them than they have from me.

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