Preface

Purpose

The word "Robot" comes from the Czech word "Robota" which means "labor doing compulsory manual works without receiving any remuneration" or "to make things manually". Oxford dictionary defines "Robot" as "a machine resembling a human being and able to replicate certain human movements and functions automatically." These days, more and more robot is living up to its name. Gone is the time when robots are merely mechanisms attached to controls. Today's robots are a combination of manipulative, perceptive, communicative, and cognitive abilities. They can be seen welding heavy machinery or repairing nuclear power plants; they can be seen crawling through debris underwater or crawling across the craters on Mars; they can be seen de-mining military zones or cleaning windows on high buildings. Today's robots are capable of so many tasks. Yet, there is so much more on the horizon.

Tomorrow's robots, which includes the humanoid robot, will tutor children, work as tour guides, drive humans to and from work, do the family shopping. Tomorrow's robots will enhance lives in ways we never dreamed possible – Do not have time to attend the decisive meeting on Asian strategy? Let your robot go for you and make the decisions. Are not feeling well enough to go to the clinic? Let Dr. Robot come to you, make a diagnosis, and get you the necessary medicines for treatment. Do not have time to coach the soccer team this week? Let the robot do it for you.

Tomorrow's robots will be the most exciting and revolutionary thing to happen to the world since the invention of the automobile. It will change the way we work, play, think, and live. Because of this, nowadays robotics is one of the most dynamic fields of scientific research. These days, robotics is offered in almost every university in the world. Most mechanical engineering departments offer a similar course at both the undergraduate and graduate levels. And increasingly, many computer and electrical engineering departments are also offering it.

This book will guide you, the curious beginner, from yesterday to tomorrow. I will cover practical knowledge in understanding, developing, and using robots as versatile equipment to automate a variety of industrial processes or tasks. But, I will also discuss the possibilities we can look forward to when we are capable of creating a vision-guided, learning machine.

Contents

I have arranged the book, according to the following concerns:

- Focus:
  I focus a great deal on analysis, and control of today's robots. I also delve into the more recent developments being made with the humanoid robot.
- Educational:
  Whenever possible, I describe the philosophy and physics behind a certain topic, before discussing the concise mathematical descriptions.
- Systems Approach:
  The robot is a tightly-integrated entity of various engineering systems, ranging from mechanics, control, and information to perception and decision-making. Therefore, I use the systems approach to clearly organize and present the multiple facets of robotics.

I follow the motion-centric theme of robotics, because motion is a visible form of action which is intrinsically linked to perception. On the other hand, I intend to stick to the original meaning of robotics, namely: the study of the robot which is shaped like a human. It is my aim that this book provides a balanced coverage of various topics related to the development of robots. Whenever possible, I relate our discussion to the humanoid robot.

I have designed the flow of the chapters to be clear and logical, in order to ease the understanding of the motion-centric topics in robotics. I embrace both traditional and non-traditional fundamental concepts and principles of robotics, and the book is organized as follows:

In Chapter 1, I introduce the robot, from a philosophical point of view, as well as the theme of robotics, from the perspective of manufacturing and automation. Additionally, I illustrate the motion-centric topics in robotics. I link the directing concept of task-action-motion to perception in our discussion on artificial intelligence, and propose a new definition.

In Chapter 2, I review the mathematical description of a rigid body's motion. Motion is the unifying concept in robotics which links various topics together, such as generation of motion, modelling and analysis of motion, control of motion, and visual perception of motion. Here, I unify the mathematical notations related to geometrical entities under consideration in both kinematic analysis and visual perception of motion.

In Chapter 3, we study the pure mechanical aspect of a robot. We also cover, in detail, fundamental topics on mechanism and kinematics. I introduce a simple illustration on D-H parameters, as well as a new term, called the *simple open kinematic-chain*. This new term is useful for the kinematic modelling of the humanoid robot. Finally, I include a new scheme for solving inverse kinematics, called *discrete kinematic mapping*, which complements the classical solutions.

In Chapter 4, we study the electromechanical aspect of a robot. After I discuss the origin of the rigid body's motion, I introduce actuation elements at a conceptual level. I also introduce a new concept of the dynamic pair and discuss the solutions of kineto-dynamic couplings. I propose a new scheme on one-to-many coupling (i.e. a single actuator for all the degrees of freedom) in comparison with the traditional scheme of one-to-one coupling (i.e. one actuator per degree of freedom). In the latter part of the chapter, I focus on the fundamentals of establishing equations of motion, which relate force/torque to motion. I also mention the study of robot statics.

In Chapter 5, we study the control system of a robot. First, I introduce the basics of the control system. Then, I focus on the control and sensing elements of the system, especially on how to alter the direction of motion, how to regulate the electrical energy applied to the electric motors, and how to sense motion and force/torque variables. I discuss at an appropriate level the aspects of designing robot control algorithms in joint space, task space and image space.

In Chapter 6, we study the information system of a robot. Traditionally, this system aspect of the robot has been overlooked in robotics textbooks. Although an information system is not too important to an industrial robot, it is an indispensable subsystem of the humanoid robot. Here, we emphasize the basics of the information system, in terms of data processing, storage and communication. We study the fundamentals of computing platforms, micro-controllers and programming together with a conceptual description of multi-tasking. I also include discussions on various interfacing systems typically used by a micro-controller (i.e. I/O).

In Chapter 7, we study the visual sensory system of a robot. It is a common fallacy among novices that it is simple to form a vision system by putting optical lenses, cameras and computers together. However, the flow of information from the light rays to the digital images goes through various signal conversions. Thus, a primary concern of the robot's visual-sensory system is whether or not the loss of information undermines the image and vision computing by the robot's visual-perception system. I start this chapter with a study of the basic properties of light and human vision. Then, I focus on the detailed working principles underlying optical image-formation, electronic image-formation, and the mathematical modelling of the robot's visual sensory system. I also cover the important topics of CMOS-imaging sensors, CCD-imaging sensors, TV/Video standards, and image-processing hardware.

In Chapter 8, we study the visual-perception system of a robot. I keep to the motion-centric theme of robotics while focusing on the fundamentals underlying the process of inferring three-dimensional geometry (including posture and motion) from two-dimensional digital images. This process includes image processing, feature extraction, feature description and geometry measurement with monocular & binocular vision. When discussing image processing, I introduce the principle of dynamics resonance. It serves as the basis for explaining various edge-detection algorithms. I discuss in detail a probabilistic RCE neural network which addresses the issue of uniformity detection in images. In our study of binocular vision, I present two new solutions which cope with the difficult problem of binocular correspondence. Finally, I provide a theoretical foundation for further study of a robot's image-space control.

In Chapter 9, we study the decision-making system of a robot. Decision-making is indispensable in the development of autonomous robots. After I introduce the basics of decision-making, I discuss the fundamentals of task and action planning, at a conceptual level. However, I emphasize motion planning. We first study motion planning in task space, and introduce a new strategy, known as *backward-motion planning.* Then, we study image-guided motion planning in task space, discussing in detail, a unified approach, called *qualitative binocular vision.* I cover three important examples of image-guided autonomous behavior: a) hand-eye coordination,

b) head-eye coordination, and c) leg-eye coordination.

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