Robot Force Control

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During the last decades, robotics applications have emerged in environments that are increasingly unstructured. Consequently, the control systems needed for managing the automated tasks are becoming more reliant on external, sensory data, e.g. force, tactile, or long-range information from sensors such as sonars or image-based sensors. In *Robot Force Control*, which is one of many strong installations in Kluwer's Robotics: Vision, Manipulation, and Sensors Series, Siciliano and Villani provide a long-needed overview over one particular aspect of sensor based robotics, namely force control of robot manipulators. In most robotics textbooks, force control is treated somewhat cursory, if at all, with focus on single degree-of-freedom manipulation tasks. In contrast to this, *Robot Force Control* delivers a thorough treatment of both theoretical and experimental aspects of the subject. This contribution exceeds the previous surveys on force control [3, 5, 6], and provides more of a control theoretic flavor than what is given in the monograph [4]. *Robot Force Control* is structured as follows:

Chapter 1. Introduction: This chapter sets the stage for the book, and the authors argue convincingly for the use of force feedback when controlling robot manipulators. It is shown how careful interactions with the environment are crucial for the successful execution of a number of robotic tasks. Since the motion of the end-effector is constrained by the environment, motion control, i.e. tracking of preplanned trajectories, is doomed to fail unless highly accurate models of the environment are available. Two different categories of force feedback are identified, namely direct and indirect methods. Direct methods explicitly incorporate force terms in the feedback law, while indirect methods, such as compliance or stiffness based methods, lack such terms. In this chapter, the experimental apparatus, used at the University of Naples, is also presented, even though the treatment is somewhat cursory and merely provides a hint of real-world applications. Moreover, this coupling between experiments and theory is a tread that runs throughout the book, and it makes it highly enjoyable and states a convincing case for force control as a mature and applicable control methodology, and in this light the book can be thought of as a reply to the classic work on motion control, e.g. [1, 2].

Chapter 2. Motion Control: In this chapter, the basic kinematic and dynamic models of robot manipulators are introduced, and classic motion control (representations, redundancy resolution, etc.) is described in some detail. This chapter is probably the least satisfying chapter in the book for two reasons. Firstly, in Chapter 1 it is argued rather convincingly that motion control is not a viable option in many robotics applications. The topic of Chapter 2 thus makes the flow of the book somewhat awkward. Secondly, the development of the manipulator models is presented in a manner that is too sketchy for someone not familiar with the topic. Some of the variables are furthermore undefined and the reader is forced to use Appendix A in parallel with this chapter in order to understand what is being presented. However, for readers who have some familiarity with inverse Jacobians, Christoffel symbols, and generalized forces, the chapter should pose no problem.

Chapter 3. Indirect Force Control: The concepts of compliance and impedance control are introduced as the basis for indirect force control. Experimental results are given for a six degree of freedom manipulator, and a nice discussion is provided about the trade-offs between contact forces and end-effector position errors. The question concerning how to choose appropriate force/torque sensors is also discussed, even though this fascinating topic of hardware/control co-design could have been given a more central role.

Chapter 4. Direct Force Control: In this chapter it is investigated how to design a direct force control, driven by the error between the desired and measured forces. The idea of parallel control is also introduced as a way of decoupling the control action into one force (or torque) component and one position (or orientation) component. Illustrative experimental results are provided and impact phenomena are discussed, making this chapter a fairly complete treatment of the state-of-the-art of a highly active area of research.

Chapter 5. Advanced Force and Position Control: This chapter adds to the previous chapters by introducing further possible routes in which force control can be taken. The authors focus on the important topics of passivity-based control, adaptive control, and output-feedback control. The one topic that is missing here is hybrid force control, i.e. to use position control along unconstrained directions and use force control along environmentally constrained directions. Even though the authors explicitly state that this topic falls outside the scope of the book due to potential problems associated with modeling the environment, it can be argued that a chapter on advanced topics in force control should contain some discussions about this important area of research.

In *Bagombo Snuff Box* (Berkley Books, NY, 1999) Kurt Vonnegut presents a list of advise for aspiring authors, including "Every sentence must do one of two things - reveal character or advance the action." This is good advise in the scientific domain as well, and Siciliano and Villani certainly manages to satisfy this condition. They write in a very precise manner, avoiding unnecessary excursions into tangential areas of research, which makes the book both compact and easy to read. An additional strong point with the book is that computational issues are made explicit. Any one who has ever implemented advanced control strategies knows that computational considerations must be made. In *Robot Force Control* each chapter furthermore ends with suggested further readings, which helps steering the curious reader in the right directions.

When it comes to a potential target audience, *Robot Force Control* is not particularly suitable as a textbook since very few proofs, theorems, or even derivations are given. Neither does it contain problems at the end of the chapters, and the explicit purpose of the book is rather to collect some of the key results in the area of force control, and in particular to report on the extensive research done in this area at the University of Naples over the last ten years. Nonetheless, the book is fairly easy to digest, which in combination with the fact that it covers some highly active areas of research in robotics, makes it a book that many graduate students in robotics, as well as researchers new to the area, would benefit from having a copy of in their bookcase.

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