Preface

The field of control engineering has provided valuable theoretical contributions to advancements in Robotics. Aspects of control engineering which have been utilized include: linear systems theory, multivariable control, adaptive control and nonlinear control. The need for further development and research in these and related areas is apparent when new applications and more stringent performance criteria are encountered. In fact, some fundamental and somewhat rudimentary issues have not yet been resolved.

The simplest and most common compensation technique for industrial robots is the PID type controller. In general, this controller is designed with the assumption of independent manipulator joint dynamics, thus its performance is limited because manipulators are n degree-of-freedom coupled nonlinear dynamic systems. The PID controllers, however, are generally designed and easily implemented for single-input/single-output plants. Although the overall system's performance using these controllers may not be acceptable, this method has been proven to guarantee global stability of robot manipulators and can lead to acceptable performance in some cases. To improve the performance, feedforward compensation has been introduced to effectively correct for tracking errors. This approach works reasonably well when the plant parameters have been identified correctly. In order to maintain acceptable responses in the face of changing parameters or loads, adaptive control schemes have been used to re-tune the controller gains continuously. Also, several other schemes have been proposed for the control of robot manipulators.

The performance of a system, however, does not depend on the control system design alone. An appropriate match between system hardware design and controller design is a key issue, particularly when high performance is required. Thus, in the design of machines for advanced applications, fundamental physical understanding should reflect all aspects of the control system including those relevant to mechanical design. The unification of theoretical work with mechanical design is necessary to improve system hardware and ultimately to permit "exact" execution of the control actions. These considerations are of great importance in the development of precision positioning robots for submicron assembly operations, and high speed high accuracy manipulators for trajectory control. For example, in certain laser cutting applications the end effector speed, acceleration and tracking tolerance are on the order of 3 m/s, 3 to 5 G and 0.05 mm respectively. Thus, the hardware for such applications must be properly engineered to meet these severe control specifications.

The gap between mechanical design and control is gradually closing. Advancements in control engineering have contributed strongly to the merging of these fundamental issues, and the development of a unified approach to robot design and control. The goal of this book is to present such a unified approach to design and control in the development of high performance robot manipulators -- this text is intended to provide not only theoretical fundamentals needed for analysis and synthesis but also practical hardware implementations in direct-drive robot technology.

This book is organized into four parts: Direct-Drive Technologies, Arm Design Theory, Development of M.I.T. Direct-Drive Manipulators, and Supporting Articles.

Chapter 1 of this book starts with a historical perspective in robot design, then presents the direct-drive concept. Description of several direct-drive robots is given as an overview for the state-of-the-art in this technology. This includes a few models that were designed at the M.I.T. Laboratory for Manufacturing and Productivity, Carnegie-Mellon University and industrial companies that have produced products which use this concept.

The robot components; such as motors, drive amplifiers, sensors and arm linkages; are covered in Chapter 2. More importantly, the issues in arm design and control are also discussed in this chapter.

Chapters 3, 4, 5 and 6 deal with arm design theory. They introduce analytical tools for evaluation of the static characteristics of manipulators and new approaches in the design of manipulators with simplified dynamics.

The development of the M.I.T. direct-drive robot for high speed trajectory control is presented in chapters 7 and 8. These chapters cover not only the design of the mechanism but also the control system design.

The last part of this book presents some supporting articles relevant to the design and control of direct-drive manipulators.

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