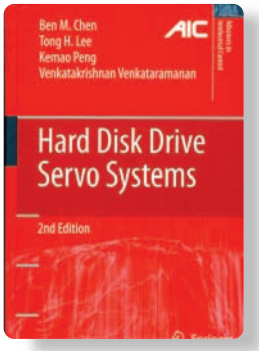
IEEE Control Systems Magazine welcomes suggestions for books to be reviewed in this column. Please contact either Michael Polis or Zongli Lin, associate editors for book reviews.



Springer: Advances in Industrial Control, 2006
ISBN 1-84628-304-3,
US$139, 310 pp.

Hard Disk Drive Servo Systems, 2nd edition

by B.M. CHEN, T.H. LEE, K. PENG, and V. VENKATARAMANAN

I was first introduced to disk drive servo systems as a graduate student under William Messner at Carnegie Mellon University. While my graduate work focused on control for distributed manipulation systems, most of my colleagues worked on projects for the Data Storage Systems Center. Our group meetings invariably focused on disk-drive-relevant topics, such as dual-stage control, windage disturbances, and servo patterns and demodulation. With this background, I was able to obtain a summer internship at Seagate Research working on spinstand microactuator integration, and I continued to work at Seagate part time while I finished my Ph.D. What drew me to disk drive control as a career was the wide range of control problems inherent in the industry. Robust control must be used to overcome manufacturing variability, but adaptation is also needed to maintain performance. Iterative learning control is needed to correct for repetitive disturbances due to eccentric mounting of the disk to the spindle. Nonlinearities arise due to actuator saturation during seeks, bearing hysteresis in the voicecoil motor (VCM), and position-error signal (PES) demodulation. Dual-stage actuators move the control problem from single-input, single-output (SISO) to double-input-single-output (DISO), or double-input, double-output (DIDO), and bring additional saturation nonlinearities. All of these problems must be solved while pushing performance at approximately a 40% cumulative annual growth rate. The scale of the problem, with track density quickly approaching 200,000 tracks per inch (200 kTPI) and track-following errors constrained to be within 15% of track pitch 3 σ, leads to fundamental challenges in position detection, while pushing bandwidths ever higher as higher frequency disturbances become relevant.

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THE BOOK

Hard Disk Drive Servo Systems arrives as one of the few books dedicated to this interesting and important control problem. Part I of *Hard Disk Drive Servo Systems* briefly discusses the history of hard drive control and the disk drive servo loop before delving in-depth into system identification and then linear and nonlinear control theory. Part II then applies the concepts of Part I to solve track-seeking, track-following, and dual-stage control problems. A specific example is given for a microdrive system, with concepts from all prior chapters being applied to a small form factor drive. The next chapter discusses a piezoelectric bimorph actuator for use as a second-stage actuator. Finally, the book closes with a benchmark problem through which various control approaches are compared.

I found the organization of the book somewhat confusing overall. Chapter 1, which contains the hard drive overview material, seems overly short and does not properly motivate the problem, in my opinion. Chapter 2, which describes system identification methods, does not seem to be necessary for the development, and the space might be better served in expanding on the introduction. Likewise, Chapter 10, which describes control of a piezoelectric actuator, does not seem relevant in the book's context and would better fit as an appendix. In general I prefer the structure presented by [1], which presents control concepts in the same sections as the disk drive examples. In chapters 2–5 of *Hard Disk Drive Servo Systems* it is easy to forget that one is reading a book about disk drive control rather than a book on general control theory.

Hard Disk Drive Servo Systems focuses almost exclusively on feedback controllers for track-following and track-seeking control. I was surprised to find nearly no coverage of PES generation and demodulation, disturbance sources and their relative magnitudes, or repetitive control techniques for repeatable runout compensation. As such, this book is not very useful as an introduction or general reference for disk drive control. The authors, like most university researchers, do not have access to the drive PES signals and therefore use laser doppler vibrometers (LDVs) to measure head position. However, in practice, PES generation and associated noise are critical in the design and analysis of disk drive systems, and at least brief coverage of servo patterns and demodulation approaches would be useful. Likewise, short sections on disturbances, repetitive control, and nonlinearities could greatly enhance the book's general interest.

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However, while the book is somewhat restricted in its coverage, what it does cover it covers in great depth. I would consider this book to be must-read material for those directly involved in track-following or track-seeking controller design. The structural decomposition approach employed for linear systems provides an effective development framework for the authors' robust and perfect tracking (RPT) controller. The coverage of composite nonlinear feedback, which consists of a linear controller in parallel with a nonlinear controller, is excellent, and the authors make a compelling case for its use in practice. While the Preface comments that a senior or first-year graduate course on control would be appropriate background, I found the mathematical treatment to be quite dense, and would recommend this book only to those who have had graduate courses in both linear and nonlinear control. Thankfully, all of the control approaches presented in the book have convenient Matlab implementations in the authors' downloadable toolbox.

CONCLUSIONS

As a whole, *Hard Disk Drive Servo Systems* is an invaluable addition to the practicing servo engineer's library. Its theoretical focus means that the book may find an audience outside of the disk drive industry, but its mathematical rigor may be too much for an engineer without graduate education. The book should not be misconstrued as an introductory or comprehensive book on disk drive servo control problems. Perhaps the most valuable contributions are the Matlab control toolbox and the benchmark problem. With these tools, the authors' claims can be tested and their results expanded upon.

REFERENCE

[1] A. Al Mamun, G.X. Gao, and C. Bi, *Hard Disk Drive: Mechatronics and Control*. Boca Raton, FL: CRC, 2006.

REVIEWER INFORMATION

Mark Bedillion (Mark.D.Bedillion@seagate.com) is a research engineering manager at Seagate Technology in Servo-Mechanical Systems. He received the B.S. degree in 1998, the M.S. degree in 2001, and the Ph.D. degree in 2005, all from Carnegie Mellon University's Department of Mechanical Engineering. He joined Seagate Research in 2003, where his research focuses on the impact of alternative storage technologies to the drive's servomechanical subsystem.

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