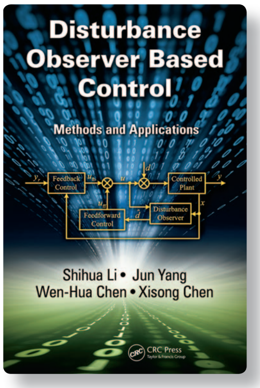
IEEE Control Systems Magazine welcomes suggestions for books to be reviewed in this column. Please contact either Scott R. Ploen or Hong Yue, associate editors for book reviews.



CRC Press (Taylor and Francis Group), 2014, ISBN: 9781466515796, 340 pages, US$67.65.

Disturbance Observer-Based Control: Methods and Applications

by SHIHUA LI, JUN YANG, WEN-HUA CHEN, and XISONG CHEN

Reviewed by ARGYRIOS ZOLOTAS

This 340-page book is primarily based on the authors' extensive ten-year research effort on disturbance-observer-based control (DOBC) theory and applications. The book covers the theoretical analysis of both basic and advanced concepts in DOBC, as well as engineering applications in process control, mechatronics, and flight control systems. The target audience is both researchers working on advanced control methods and related engineering fields and practicing engineers interested in disturbance estimation and compensation. This book attempts to fill the absence of an academic reference book on DOBC methods and applications, and, in this context, the authors provide a systematic perspective on the underlying philosophy of DOBC, its distinct features relative to other methodologies and design tools, and its major theoretical developments and application-related contributions.

An ever-increasing demand for higher-precision control performance has been observed in the modern control systems community, such as in mechatronics and robotics, electrical machines and drives, power electronics, energy conversion, and the aerospace and automotive sectors. Two key factors impeding further improvement of precision control are the disturbances and uncertainties affecting the systems. These include external, undesired inputs and a wide range of uncertainties including parametric perturbations, unmodeled dynamics and variations of system dynamics due to changes in the controlled system, as well as changes in the systems' operational conditions. The existence of such disturbances and uncertainties leads to significant challenges for feasible and effective control solutions because there are intrinsic conflicts or restrictions in performance specifications, such as the tradeoff between setpoint tracking and disturbance rejection or between nominal performance and robustness.

It is the importance of disturbance attenuation or rejection that led to the development of many notable control approaches such as H_∞ robust control [1], adaptive control [2], sliding model control [3], internal model control [4], and DOBC, to name but a few.

DOBC stems from feedforward control, which was originally developed in the process control domain and then gained popularity in other domains. In feedforward control, a sensor typically monitors a disturbance in a physical process, and the measurement is used by the feedforward controller to generate a compensating action to counteract the disturbance. However, most disturbances in practical processes are not easy, or perhaps even possible, to monitor by physical sensors, which motivated the development of the disturbance observation approach (also referred to as disturbance soft-sensing in the literature). In this context, DOBC is usually perceived as a composite controller comprising a feedforward compensation controller, based on disturbance observations, and a feedback control law to stabilize/regulate the nominal dynamics of the physical system. In addition, DOBC provides an alternative way to improve disturbance rejection and robustness against uncertainties without sacrificing nominal control performance because the disturbance-observer-based compensation loop activates only in the presence of detected disturbances and uncertainty.

This book introduces most of the existing disturbance estimator techniques and elaborates on some typical examples. The disturbance observer was first presented in the frequency domain [5] for mechatronics systems. The extended state observer was proposed in the time domain about ten years later. Since 2000, several nonlinear disturbance-observer design methods have been developed to enhance disturbance estimation performance as well as closed-loop control precision for nonlinear systems. These types of nonlinear methodologies also form the main body of the theoretical advances presented in the book.

As readers proceed through the chapters, they will learn that DOBC is a two-stage design process, that is, a baseline

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controller is designed first followed by a feedforward compensator incorporating the estimate from a disturbance observer. Studies also illustrate that DOBC potentially offers advantages for systems with unmatched uncertainties, meaning uncertainty that affects the system through channels other than the control input. This issue is illustrated through practical control applications (some with experimental results), which is a noteworthy feature of the book.

CONTENTS

The book consists of six sections on disturbance observation in the sequence of Overview (I), Estimator Design (II), Control Design (III), and Application (IV–VI). It is divided into 16 chapters with most of the theoretical advances in DOBC design in chapters 5–9 and practical applications in chapters 10–16. The book deals with methods based on physical models rather than data- or knowledge-based disturbance-estimation techniques.

Section I is a single-chapter section and includes an overview of disturbances in systems and disturbance attenuation methods ultimately leading to a motivation of disturbance estimation and DOBC. A large number of references dealing with these topics are cited, which both researchers and practicing engineers will find of particular interest. The authors skillfully avoid comparing disturbance-attenuation methods (such as adaptive control, robust control, sliding mode control, and internal model control) but rather motivate disturbance-observer-based approaches to complement and enhance disturbance attenuation. Another interesting feature of this section is the historical overview of disturbance-observer techniques, which lists major aspects in the analysis and design of such techniques, such as robustness and stability, hierarchy in the design, and matched and mismatched uncertainties.

Section II, which consists of chapters 2–4, introduces disturbance-estimation techniques. Chapter 2 deals with linear approaches, namely, frequency-domain-based approaches (that is to say, transfer-function-based approaches) and time-domain-based approaches (that is, state-space-based approaches). In particular, the frequency-domain approach is presented for both minimum and nonminimum-phase transfer-function systems with the help of a few numerical examples. In the state-space domain, the authors list the typical extended state-observer approach, which emphasizes the use of state information via augmentation with appropriately chosen disturbance states. Chapters 3 and 4 consider nonlinear approaches. The former introduces two basic types of nonlinear disturbance observers, specifically for constant disturbances and for harmonic disturbances with known frequencies but unknown amplitudes, and briefly discusses error convergence for the aforementioned types. Chapter 4 deals with more advanced nonlinear disturbance observer approaches, which are mainly based on recent work [6]–[8]. This chapter presents a higher-order disturbance observer for both constant and ramp-type disturbance profiles, then moves on to the extended high-gain design, and ultimately presents a finite-time convergence-rate approach. Sections I and II could easily be considered as part of a control-related graduate course since they provide a useful introductory tutorial on disturbance observers.

While the previous sections concentrate on disturbance-observer approaches, Section III covers various DBOC design methods. This section strongly mirrors the research efforts and experience of the authors in this field. Chapter 5 introduces a nonlinear DOBC framework, with the design taking place in two stages. First, design a nonlinear controller assuming the disturbance is measurable. Second, design the disturbance observer and integrate it with the overall system. The authors take a rigorous approach in establishing the foundation for the proposed method and illustrate the effectiveness of the method with a robotic manipulator example.

Chapters 6 and 7 address the problem of systems with mismatched uncertainties. In particular, Chapter 6 presents the extended state observer (ESO) approaches to estimating disturbances while listing many papers from the control literature. The authors introduce a recently proposed generalized (GESO)-based control approach. GESO-based control extends the applicability of ESO-based methods and successfully deals with control design of generic systems under mismatched uncertainties for both the single-input, single-output and multi-input, multi-output cases. Chapter 7 presents an advanced nonlinear DOBC approach for nonlinear systems under mismatched uncertainty. The important aspects of this chapter are the comparison of the proposed method with nonlinear dynamic inversion control and an extended discussion on robustness against model uncertainties. Chapter 8 gives a design methodology for systems with an arbitrary disturbance relative degree. The design method deals with the issue of disturbance relative degree being lower than the input relative degree in a system. The presented methodology retains the DOBC property of nominal performance recovery. Section III ends with Chapter 9, which blends DOBC design with sliding mode while still addressing systems under mismatched uncertainty. While it is widely known that sliding mode control handles matched uncertainty very well [3], the authors present novel sliding-mode control methods to counteract mismatched uncertainties in the system via a nonlinear disturbance observer. In fact, the disturbance observer is seen as complementary in the overall approach and hence does not affect the design in a negative way when disturbances or uncertainties are absent. This chapter is very useful to researchers since it provides both a reference and a basis for further advances.

Sections IV–VI present application studies of DOBC, also emphasizing the importance of different application aspects when it comes to applied control. Although DOBC stems from mechanical engineering examples, it is becoming more popular in other application domains. In particular, Section IV discusses DOBC applications in the process control industry including a typical level tank system in Chapter 10 and a ball mill grinding circuit study in Chapter 11. Section V presents DOBC applications in the area of mechatronics, for example, a maglev vehicle study and a permanent magnet synchronous motor study in Chapter 13. The final section consists of three chapters on aerospace systems, specifically, unmanned aerial vehicles in Chapter 14, bank-to-turn missiles in Chapter 15, and hypersonic vehicles in Chapter 16. With interesting simulation results and applied examples of the proposed theoretical methods from previous chapters, DOBC is seen as a natural ingredient in control solutions for the aerospace industry, and readers will probably find this a rather interesting and entertaining section.

CONCLUSIONS

DOBC has been known as one of the most promising and effective methods in the control community for quite a long time. While there are many research papers, few academic books exist on the subject, and the authors attempt to fill this void. The book is well written and clearly illustrates the contributions of DOBC alongside established techniques in disturbance rejection. All theoretical results are given with rigorous mathematical proofs. In the applications sections, the simulation results are elegantly presented with plenty of comparative studies. Although most of the mathematical concepts and abbreviations are defined throughout the book, a glossary or list of symbols and abbreviations would be a welcome addition. The book would be a useful resource for an advanced graduate course in control, for researchers in the areas of systems and control, as well as an educational reference for practicing engineers.

REVIEWER INFORMATION

Argyrios Zolotas is a reader in control engineering in the College of Science, School of Engineering, at the University of Lincoln, United Kingdom, and the school's deputy director of research. He received a first class B.Eng. (Hons) degree in electronic and communications engineering from the University of Leeds, United Kingdom, in 1998 and the Ph.D. in electronic and electrical engineering from Loughborough University, United Kingdom, in 2002. He also holds an M.Sc. (Distinction) in advanced electronic and electrical engineering from the University of Leicester, United Kingdom. From January 2002 to August 2003 he was a post-doctoral research fellow with the Control and Power Research group in the Department of Electrical and Electronic Engineering at Imperial College London. Prior to joining the University of Lincoln, he held academic posts at Loughborough University and the University of Sussex. His current research interests are in robust control of linear and nonlinear systems, system uncertainty and robustness, applications of advanced control, transportation (vehicles), and emerging control applications. He is a Senior Member of IEEE and a fellow of the Higher Education Academy, United Kingdom.

REFERENCES

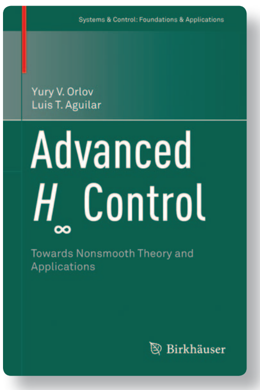
[1] B. A. Francis, *A Course in H-infinity Control Theory* (Lecture Notes in Control and Information Science, vol. 88). Berlin Heidelberg, Germany: Springer-Verlag, 1987.
[2] I. D. Landau, R. Lozano, M. M'Saad, and A. Karimi, *Adaptive Control: Algorithms, Analysis and Applications*, 2nd ed. Berlin Heidelberg, Germany: Springer-Verlag, 2011.
[3] C. Edwards and S. Spurgeon, *Sliding Mode Control: Theory and Applications*. Boca Raton, FL: CRC Press, 1998.
[4] M. Morari and E. Zafiriou, *Robust Process Control*. Englewood Cliffs, NJ: Prentice Hall, 1989.
[5] K. Ohishi, M. Nakao, K. Ohnishi, and K. Miyachi, "Microprocessor-controlled DC motor for load-insensitive position servo system," *IEEE Trans. Ind. Electron.*, vol. 34, no. 1, pp. 44–49, 1987.
[6] K. S. Kim, K. H. Rew, and S. Kim, "Disturbance observer for estimating higher order disturbances in time series expansion," *IEEE Trans. Autom. Contr.*, vol. 55, no. 8, pp. 1905–1911, 2010.
[7] L. B. Freidovich and H. K. Khalikl, "Performance recovery of feedback-linearization-based designs," *IEEE Trans. Autom. Contr.*, vol. 55, no. 8, pp. 2324–2334, 2008.
[8] A. Levant, "Higher-order sliding modes, differentiation and output-feedback control," *Int. J. Control*, vol. 76, nos. 9–10, pp. 924–941, 2003.

Book Announcements

Advanced H_∞ Control: Towards Nonsmooth Theory and Applications

by YURY V. ORLOV and
LUIS T. AGUILAR

This monograph covers disturbance attenuation in nonsmooth dynamic systems, developing an H_∞ approach in the nonsmooth setting. Similar to the standard nonlinear H_∞ approach, the proposed nonsmooth design guarantees both the internal asymptotic stability of a nominal closed-loop system and the dissipativity inequality, which states that the size of an error signal is uniformly bounded with respect to the worst-case size of an external disturbance signal. This book synthesizes various tools, including Hamilton–Jacobi–Isaacs partial differential inequalities and linear matrix inequalities. Along with the finite-dimensional treatment, the synthesis is extended to the infinite-dimensional setting, involving time-delay and distributed parameter systems. The book also focuses on electromechanical applications with nonsmooth phenomena caused by dry friction, backlash, and sampled-data measurements.



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