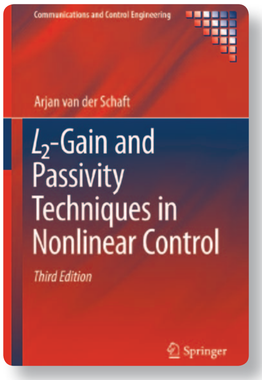
IEEE Control Systems Magazine welcomes suggestions for books to be reviewed in this column. Please contact either Scott R. Ploen, Hong Yue, or Hesuan Hu, the associate editors for book reviews.



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321 pages, US$129.

L_2-Gain and Passivity Techniques in Nonlinear Control, Third Edition

by A. VAN DER SHAFT

Reviewed by James Richard Forbes

The analysis and control of nonlinear systems is still an important and active area of research. Many excellent books on the topic, such as [1]–[9], have been written over the past five decades, and they have served students and researchers well as both instructional aids and references. Some texts, such as [2], [5], and [7]–[9], cover both Lyapunov-based and input–output-based approaches to nonlinear systems analysis and control design, while others, such as [1], [4], and [8], are more focused on input–output properties and stability.

For many years, Desoer and Vidyasager [1] provided the most popular reference for input–output properties and stability. This work adequately discussed input–output properties, such as L_2-gain and passivity, as well as input–output stability theorems such as the small gain and passivity theorems. It undoubtedly served the control community well and still does. After [1], other work addressing input–output properties and stability followed [2]–[10]. For example, to learn the fundamentals of input–output properties and stability, I fondly remember pouring over Vidyasagar [2], Ortega et al. [4], Marquez [7], Lozano et al. [8], and the second edition of *L_2-Gain and Passivity Techniques in Nonlinear Control* [10]. I found that the second edition of [10] summarized the critical notions of L_2-gain, passivity, the small gain theorem, and the passivity theorem from [1] and [2] exceptionally well. Overall, the book provided precise, yet accessible, presentations of dissipative systems in the context of L_2-gain and passivity, passivity-based control as a form of energy shaping, nonlinear passivation via state feedback, nonlinear factorizations, and nonlinear H_∞ control. A hallmark of the second edition was the connection between classic and modern interpretations of L_2-gain and passivity, that being a purely input–output view versus a state-space view, unified via the dissipative systems framework pioneered by J.C. William, van der Shaft's former thesis advisor [11], [12]. Additionally, the second edition provided readers who are new to nonlinear H_∞ control with an additional resource other than papers found in the literature.

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This third edition has not strayed from the roots of earlier editions. The text still provides a comprehensive presentation of L_2-gain and passivity theory from both the input–output and state-space viewpoints, connected through the dissipative systems framework. Additionally, the third edition is still a prime reference for energy shaping, nonlinear passivation via state feedback, nonlinear factorizations, and nonlinear H_∞ control. However, this new edition includes various rewritten chapters as well as the addition of new material. Specifically, the chapter on dissipative systems in the second edition is now three separate chapters on dissipative systems theory (Chapter 3), passive state-space systems (Chapter 4), and L_2-gain theory (Chapter 8). The chapter on port-Hamiltonian systems (PHSs) in the second edition was split into two chapters on PHS theory (Chapter 6) and control of PHSs (Chapter 7). The third edition has 11 chapters, compared to eight chapters in the second edition. A summary of each chapter is given next.

Chapter 1 reviews foundational material such as input–output maps, L_q-spaces and L_{qe}-spaces, causal maps, L_q-stability, L_q gain, and closed-loop stability. This chapter largely summarizes the critical concepts presented in [2].

In Chapter 2, the classical small gain and passivity theorems guaranteeing the closed-loop, input–output stability of the negative feedback interconnection of two systems are presented and proved. In addition to discussions on passivity, input strict passivity (ISP), output strict passivity (OSP), and very strictly passivity, three different versions of the passivity theorem are discussed in detail, culminating in Theorem 2.2.18. An interesting result of Theorem 2.2.18 is that a lack of passivity in one system in a negative feedback interconnection can be compensated by a surplus of passivity in another system. How to apply the small gain or passivity theorems via a loop transformation is also discussed as well as incremental L_2-gain and passivity.

Chapter 3 covers the dissipative systems framework, laying the groundwork for subsequent chapters. Specifically, a state-space interpretation of L_2-gain and passivity previously discussed in Chapters 1 and 2 is provided. Supply rates and storage functions are defined before moving on to properties

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of dissipative systems. The connection between dissipative systems and Lyapunov stability theory is discussed as well as the stability of dissipative systems connected in feedback. Chapter 3 closes with a discussion on the connection between dissipative systems and the inverse problem of optimal control.

The passivity of systems in state-space form is the focus of Chapter 4. After reviewing passivity, ISP, and OSP, the stability and stabilization of passive systems using the dissipative systems framework are discussed. The passivity theorem is revisited, and the converse passivity theorem is reviewed, noting that a feedback interconnection that is passive necessarily is composed of two passive systems. Applications of passive state-space systems, such as networked and Euler–Lagrange systems, are also presented.

The focus of Chapter 5 is the use of feedback to transform a nominally nonlinear nonpassive system into a nonlinear passive system. Necessary and sufficient conditions for the transformation are given as well as discussions on the stabilization of cascade systems and back-stepping control.

PHSs are discussed in Chapter 6. After defining PHSs, their general properties are reviewed as well as the PH nature of mechanical and electromechanical systems. Shifted passivity, PH differential algebraic equation systems, and PH network dynamics are also reviewed.

Chapter 7 continues discussing PHSs in the context of control. The main message is that, by interconnecting a PH plant with a PH controller, the closed-loop Hamiltonian can be shaped. Energy shaping as well as internal damping assignment is discussed in the context of PHSs.

In Chapter 8, the text returns to the L_2-gain and the small gain theorems to elaborate on the connection between the dissipative systems framework and L_2-gain of state-space systems. Input-to-state stability is also discussed.

Factorizations of nonlinear systems are presented in Chapter 9. The chapter begins with kernel and image representations of nonlinear systems. Nonlinear perturbation models with L_2-bounded uncertainty are also discussed. The parameterization of all stabilizing controllers, akin to a Youla-Kucera parameterization, is then reviewed.

Nonlinear H_∞ control is the focus of Chapter 10. The term "nonlinear H_∞ control" should perhaps be replaced with "nonlinear induced L_2-gain control." However, to draw a parallel to linear H_∞ control [13]–[15], the term "nonlinear H_∞ control" has become customary and is used in this text. Both full-state-feedback and output-feedback H_∞ are considered. The tools of dissipative systems are relied on heavily, tying Chapter 10 to Chapters 3 and 8. Additionally, the parameterization of all stabilizing controllers discussed in Chapter 9 is used to formulate and solve the output-feedback H_∞ control problem.

Hamilton–Jacobi equations and inequalities found in earlier chapters are discussed in detail in Chapter 11. Specifically, conditions for the solvability of Hamilton–Jacobi equations and inequalities are discussed in detail. The connection between Hamiltonian–Jacobi inequalities and Riccati inequalities found via linearization is highlighted.

CONCLUSIONS

The third edition of this text, like the second edition, is an excellent reference for both students and researchers. The expansion of the text in the forms of Chapters 3, 4, and 6–8 makes the material more complete and accessible. This text is sure to continue to be one of the go-to references for nonlinear control researchers and practitioners interested in both the classical and modern interpretations and applications of L_2-gain and passivity methods for nonlinear systems.

REVIEWER INFORMATION

James Richard Forbes received the B.A.Sc. degree in mechanical engineering from the University of Waterloo in 2006 and the M.A.Sc. and Ph.D. degrees in aerospace science and engineering from the University of Toronto Institute for Aerospace Studies in 2008 and 2011, respectively. He received the G.N. Patterson Award for the most outstanding Ph.D. thesis in 2011. From August 2013 to July 2015 he was an assistant professor of aerospace engineering at the University of Michigan. He is currently an assistant professor of mechanical engineering at McGill University, Montreal, where he is also a member of the Centre for Intelligent Machines. His research is focused on the dynamics, estimation, and control of robotic and aerospace systems including spacecraft, aircraft, and ground vehicles. With A. de Ruiter and C. Damaren, he coauthored *Spacecraft Dynamics and Control—An Introduction* (Wiley, 2013). He is a Member of the IEEE and AIAA, has chaired various sessions at IEEE and AIAA conferences, and has been awarded numerous "Best Presentation in Session" awards at these conferences.

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