Preface

The third edition of this book differs substantially from the second edition that came more than fifteen years ago. Approximately one-third of the book is new material, while existing parts have undergone major rewritings and extensions.

On the other hand, the spirit of the third edition as compared with the second and first edition has remained the same: to provide a compact presentation of the basic ideas in the theory of L_2-gain and passivity of nonlinear systems, starting from a brief summary of classical results on input–output maps, to a broad range of analysis and control theories for nonlinear state space systems, regarded from the unifying perspective of dissipative systems theory.

A major change with respect to the second edition is the splitting, as well as substantial extension, of the old Chap. 3 on dissipative systems, formerly also including passivity and L_2-gain theory, into three separate chapters on dissipative systems theory (Chap. 3), passive systems (Chap. 4), and L_2-gain theory (Chap. 8). Furthermore, the old Chapter 4 on port-Hamiltonian systems has been reworked and extended into two chapters on port-Hamiltonian systems theory (Chap. 6) and on control theory of port-Hamiltonian systems (Chap. 7). Also, the theory of all-pass factorizations (new Chap. 9) has been augmented with a treatment of nonlinear state space "spectral factorization" theory.

Apart from all the rewritings and extensions, a relative novelty from a conceptual point of view is the increased attention towards network dynamics and large-scale systems. The general concept of an interconnected system already was at the core of the passivity and small-gain theories, and even more so of the overarching theory of dissipative systems, having their origin in network theory and closed-loop stability, and emphasizing the "systems point of view." But the recent developments in dynamics on networks, including the use of algebraic graph theory, have certainly been influential in extending classical results, which is reflected in this new edition of the book.

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Groningen, The Netherlands — Arjan van der Schaft
September 2016

Preface to the First Edition

The first version of these lecture notes were prepared for part of a graduate course taught for the Dutch Graduate School of Systems and Control (DISC) in the spring trimester of 1994.

My main goal was to provide a synthesis between the classical theory of input-output and closed-loop stability on the one hand, and recent work on nonlinear $\mathcal{H}_\infty$ control and passivity-based control on the other hand. Apart from my own research interests in nonlinear $\mathcal{H}_\infty$ control and in passive and Hamiltonian systems, this motivation was further triggered by some discussions with David Hill (Sydney, Australia), Romeo Ortega, Rogelio Lozano (both Compiègne, France) and Olav Egeland (Trondheim, Norway), at a meeting of the GR Automatique du CNRS in Compiègne, November 1993, devoted to passivity-based and H_∞ control. During these discussions also the idea came up to organize a pre-CDC tutorial workshop on passivity-based and nonlinear H_∞ control, which took place at the 1994 CDC under the title “Nonlinear Controller Design using Passivity and Small-Gain techniques”. Some improvements of the contents and presentation of Chapter 2 of the final version of these lecture notes are directly due to the lecture [122] presented at this workshop, and the set of handwritten lecture notes [183].

As said before, the main aim of the lecture notes is to provide a synthesis between classical input-output and closed-loop stability theory, in particular the small-gain and passivity theorems, and the recent developments in passivity-based and nonlinear H_∞ control. From my point of view the trait d’union between these two areas is the theory of dissipative systems, as laid down by Willems in the fundamental paper [350], and further developed by Hill and Moylan in a series of papers [123, 124, 125, 126]. Strangely enough, this theory has never found its place in any textbook or research monograph; in fact I have the impression that the paper [350] is still relatively unknown. Therefore I have devoted Chapter 3 to a detailed treatment of the theory of dissipative systems, although primarily geared towards L_2-gain and passivity supply rates. One of the nice aspects of classical input-output and closed-loop stability theory, as well as of dissipative systems theory, is their firm rooting in electrical network analysis, with the physical notions of passivity, internal energy and supplied power. Furthermore, using the scattering transformation a direct link is established with the finite gain property. Passivity-based control, on the other hand, used these same physical notions but draws its motivation primarily from the control of mechanical systems, especially robotics. Indeed, a usual approach is via the Euler–Lagrange equations of mechanical systems. In Chapter 4 of the lecture notes my aim is to show that the passivity properties of electrical networks, of mechanical systems described by Euler–Lagrange equations, and of constrained mechanical systems, all can be unified within a (generalized) Hamiltonian framework. This leaves open, and provokes, the question how other properties inherent in the generalized Hamiltonian structure, may be exploited in stability analysis and design. The rest of the lecture notes is mainly devoted to the use of L_2-gain techniques in nonlinear control, with an emphasis on nonlinear H_∞ control. The approach mimics to a large extent similar developments in robust linear control theory, while the specific choice of topics is biased by my own recent research interests and recent collaborations, in particular with Joe Ball and Andrew Paice. The application of these L_2-gain techniques relies on solving (stationary) Hamilton–Jacobi inequalities, and sometimes on their nonlinear factorization. This constitutes a main bottleneck in the application of the theory, which is similar to the problems classically encountered in nonlinear optimal control theory (solving Hamilton–Jacobi–Bellman equtions), and, more generally, in nonlinear state space stability analysis (the construction of Lyapunov functions). On the other hand, a first-order approach (linearization) may already yield useful information about the local solvability of Hamilton–Jacobi inequalities.

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Arjan van der Schaft

Preface to the Second Edition

With respect to the first edition as Volume 218 in the Lecture Notes in Control and Information Sciences series the basic idea of the second edition has remained the same: to provide a compact presentation of some basic ideas in the classical theory of input-output and closed-loop stability, together with a choice of contributions to the recent theory of nonlinear robust and $\mathcal{H}_\infty$ control and passivity-based control. Nevertheless, some parts of the book have been thoroughly revised and/or expanded, in order to have a more balanced presentation of the theory and to include some of the new developments which have been taken place since the appearance of the first edition. I soon realized, however, that it is not possible to give a broad exposition of the existing literature in this area without affecting the spirit of the book, which is precisely aimed at a compact presentation. So as a result the second edition still reflects very much my personal taste and research interests. I trust that others will write books emphasizing different aspects. Major changes with respect to the first edition are the following: A new section has been added in Chapter 2 relating L_2-gain and passivity via scattering, emphasizing a coordinate-free, geometric, treatment. The section on stability in Chapter 3 has been thoroughly expanded, also incorporating some recent results presented in [312]. Chapter 4 has been largely rewritten and expanded, incorporating new developments. A new Chapter 5 has been added on the topic of feedback equivalence to a passive system, based on the paper [56].

Acknowledgements Many people have contributed to the genesis of this book. Chapter 3 is based on the work of my former thesis advisor Jan C. Willems, who also otherwise has shaped my scientific attitude and taste in a deep way. Chapter 4 owes a lot to an inspiring and fruitful cooperation with Bernhard Maschke, as well as with Romeo Ortega and Morten Dalsmo, while Chapter 6 is based on joint research with Andrew Paice, Joe Ball and Jacquelien Scherpen. Also I acknowledge useful and stimulating discussions with many other people, including Peter Crouch, Bill Helton, David Hill, Alberto Isidori, Gjerrit Meinsma, Carsten Scherer, Hans Schumacher, Rodolphe Sepulchre, Stefano Stramigioli, and my colleague Henk Nijmeijer. I thank the graduate students of the spring trimester of 1994 for being an attentive audience. Gjerrit Meinsma is furthermore gratefully acknowledged for his patient way of handling all sorts of LaTeX problems. Finally, I thank the Faculty of Mathematical Sciences, University of Twente, for providing me with secretarial support for the preparation of this book; in particular I sincerely thank Marja Langkamp, and for the first edition Marjo Mulder, for their great efforts in bringing the manuscript to its present form.

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