Pergamon

Automatica, Vol 33, No 9, pp 1769–1770, 1997

Printed in Great Britain
0005-1098/97 $17 00 + 0 00

Nonlinear Control Design*

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Nonlinear control theory has received considerable attention in the last decades. As a result, there exists nowadays a sophisticated framework using (differential) geometric methods for dealing with a large number of controller design problems. The book under review, *Nonlinear Control Design, Geometric, Adaptive and Robust* presents — according to the back cover of the book — "A self-contained introduction to nonlinear feedback control design for continuous time, finite-dimensional uncertain systems. It deals with nonlinear systems affected by uncertainties such as unknown constant parameters, time-varying disturbances and uncertain nonlinearities. Both state feedback and output feedback are considered ....".

The book consists of seven chapters and two appendices.

Chapter 1, the Introduction, presents in a lucid manner what the book is about. By means of simple instructive examples an illustration is given of possible controller designs, such as state feedback controllers, output feedback controllers or their adaptive modifications. The Introduction also describes models of a number of real-world physical systems, such as an induction motor, a rigid robot, a rigid body, a synchronous generator, a synchronous motor and others. These systems are used in the following chapters as to illustrate the various control schemes.

Following the Introduction, the material of the book is organized in two parts. First, Chapters 2–4, all deal with state feedback controllers, whereas Chapters 5–7 form their counterparts in which observers and output feedback controllers are considered. Throughout the book the authors have concentrated on single input and, where relevant, single output affine nonlinear control systems, i.e. $\dot{x} = f(x) + g(x)u$, $y = h(x)$, with at the end of each chapter a short resume on how to deal with the multivariable case.

Chapter 2 deals with the feedback linearization and the partial feedback linearization problem. That is, differential geometric conditions are derived such that under application of a suitable coordinate transformation $z = \varphi(x)$ and suitable state feedback $u = \alpha(x) + \beta(x)v$ the system becomes linear $\dot{z} = Az + bv$, or partially linear, which means the system in the new coordinates is a cascade of a lower-dimensional linear system and nonlinear system. In particular, in the latter case the stabilization for partially linear triangular form nonlinear systems is described. The recursive procedure for deriving the stabilizing feedback — sometimes called (integrator) backstepping, Krstić *et al.* (1995) — is a very useful tool in feedback stabilization. Chapter 3 is entitled Adaptive Feedback Linearization, but also contains a study of feedback stabilization of linearizable systems in the presence of structured ('matched') uncertainties. This includes robust stabilization and a self-tuning regulator, all on the basis of either static or dynamic state feedback. Once the unknown parameters enter in such a way that the parametrized system admits a triangular form, which for 'frozen' parameter values is equivalent to feedback linearizability of the 'frozen' system, then also the adaptive feedback linearization problem is solved.

In Chapter 4 the problem of output feedback tracking is considered. Typcially, the main ingredient to address the tracking problem, that is, have the system's output follow a prescribed trajectory, is to linearize the input–output behavior of the system via state feedback. Next, also uncertainties/disturbances are allowed to appear in the dynamics and the tracking problem is solved with disturbance rejection, disturbance attenuation or adaptive tracking under prescribed small truncated tracking error.

Chapter 5 deals with nonlinear observer design, both in a nonadaptive and adaptive setting. More specifically, the authors treat the class of nonlinear systems that admit an observer resulting in linear error dynamics. Injecting a modification depending on the inputs and outputs that is linear in the parameters, exactly yields systems for which the adaptive observer problem with linear error dynamics can be solved.

In Chapter 6 attention is devoted to the linearization, the stabilization and the exponential tracking via static or dynamic output feedback. Geometric, verifiable, (necessary and) sufficient conditions that guarantee the solvability of these problems are described.

Finally, in Chapter 7 the same questions are addressed but now the system dynamics are allowed to contain unknown parameters. Solutions now include robust output feedback stabilization and self-tuning output feedback regulation.

Appendices on differential geometry and stability of differential equations complement the material.

Nonlinear Control Design contains a wealth of material on (adaptive) state/output feedback controllers for certain classes of nonlinear systems. It reviews the authors' recent work on the subject. The material has been written with great care and only few minor errors or inaccuracies can be detected in the text. A very attractive feature is that in each chapter not only mathematical examples are used for illustration but also some of the physical examples from Chapter 1 return as to demonstrate, under suitable assumptions, the potential applicability of the theory. Several of these worked examples have not been published before and deserve attention as, for instance, the observer design for the model of a point mass satellite. Another useful feature of the book is that each chapter contains a (large) number of exercises dealing with the theory developed in the chapter.

Besides all these positive comments one fact should also be mentioned. The authors have very much concentrated on the technical details, and less on the explanation and motivation of several of the arguments used. Personally, I would have liked to see more of the latter. As an example, the iterative design for the stabilization of triangular form systems relies in each step on redefining the state components in a way that can be explained quite naturally, but unfortunately such a motivation is lacking, in strong contrast with the book of Krstić *et al* (1995). Throughout the book one may find similar examples like this. It may leave the uninitiated reader with mixed feelings about the presentation

Another, more technical comment is related to the definition of observers used by the authors. In contrast to the linear case, the authors require asymptotic convergence of the observer state towards the true state in case the state trajectory $x(t)$ is bounded for all t, thus excluding truely unstable dynamics in the system. This condition seems undesirable and is perhaps in some cases unnecessarily restrictive.

Notwithstanding these comments *Nonlinear Control Design* seems a useful and interesting book. Perhaps some readers want to compare the book with that of Krstić *et al.* (1995). In each case, one may find arguments in favor for each work

**Nonlinear Control Design*, by Riccardo Marino and Patrizio Tomei.

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About the reviewer

Henk Nijmeijer received his PhD in 1983 from the University of Groningen, Groningen. Since that year he has been with the Systems and Control Group of the Department of Applied Mathematics, University of Twente, where he presently is an Associate Professor. His research interests are in nonlinear control and systems and applications. He is on the editorial board of various scientific journals including the SIAM Journal on Control and Optimization, the International Journal of Robust and Nonlinear Control, and Automatica.