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Book Review

Nonlinear Systems Analysis*

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THIS IS a completely rewritten version of the first edition which appeared in 1978. At that time the book gave a good overview of the main body of nonlinear systems and control theory, except for nonlinear optimal control theory. The emphasis was very much on the *analysis* of systems (in open- or closed-loop configuration), instead of on the actual design of controllers. Most attention was being focused on *stability* issues, both from the input–output and the state-space point of view. Highlights in this theory were the concepts of input–output stability including Popov's criterion and the circle criterion (see also Desoer and Vidyasagar, 1975), the theory of Lyapunov stability, and perhaps the method of describing functions. Since the appearance of the first edition, geometric nonlinear control theory has become a prevailing trend. (In fact these developments were already initiated at the beginning of the seventies.) Geometric nonlinear control theory started as a successful approach to deal with basic system-theoretic questions in the state-space formulation of nonlinear control systems, such as controllability and observability properties and minimal realization theory. It gained strong impetus at the beginning of the eighties by the systematic study of nonlinear (state) feedback for various synthesis problems; also stimulated by the geometric approach to linear control theory of Wonham and Morse and Basile and Marro. In particular the Lie bracket conditions for controllability and feedback linearizability have become popular and powerful tools in nonlinear control. The books by Isidori (1989) and Nijmeijer and Van der Schaft (1990) are clear exponents of the achievements of geometric nonlinear control theory.

In the last couple of years one can witness some developments which can be looked at as attempts to bridge the gap between nonlinear systems and control theory as put forward in the first edition of the present book on the one hand, and geometric nonlinear control theory on the other hand. Indeed, in nonlinear adaptive control as well as in nonlinear robust control (including nonlinear $\mathcal{H}_\infty$-control) there is much need for the kind of stability concepts as exposed in the first edition of the book, while at the same time geometric nonlinear control theory offers an underlying structural framework. In particular passivity, and more generally, dissipativity concepts turn out to be extremely useful in these areas, especially within the context of the control of physical systems. Also, there has been recently some rapprochement between nonlinear input–output theory and (geometric) state-space theory. In my opinion these converging developments are very important and indeed offer promising perspectives for a truly nonlinear control design.

In the present second edition Professor Vidyasagar has made an admirable attempt to include at least an introduction to geometric nonlinear control theory in an additional chapter of the book. In fact, this new chapter deals with the perhaps most 'useful' parts of geometric nonlinear control theory such as controllability, feedback linearization and input–output linearization. The other most noticeable differences with the first edition are the inclusion of some results obtained since the writing of the first edition on observer–controller stabilization of nonlinar systems, the stability of hierarchical systems, relationships between Lyapunov and input–output stability, and on a useful class of transfer functions of distributed systems. Furthermore, a new section containing a rigorous analysis of the describing function method has been added, and material from Hahn (1967) on converse Lyapunov theory and from Desoer and Vidyasagar (1975) on feedback stability of time-varying and/or nonlinear systems has been included. Finally, to all chapters dealing with Lyapunov and input–output stability, a discussion of discrete-time systems has been added.

Overall, the present book is a very impressive scholarly effort, which brings together knowledge from various areas in an insightful manner. The book is very readable and succceeds in conveying to the reader the enthusiasm of the author. It certainly serves as a source of inspiration for researchers in the area, and as such I recommend it very much. How well the book is suited for an undergraduate course is a matter of taste. For example, the treatment of Lyapunov stability is performed immediately for the general case of time-varying systems, which complicates the terminology and results considerably. I guess most people would prefer to deal first with the time-invariant case and then to make the necessary refinements for the time-varying case, as is done, for example, in Khalil (1992). The material of the book is presented in a very careful and solid manner. The revisions of Chapters 1 to 6 have certainly further improved their contents, and the new additions are very useful and welcome. The last Chapter 7 on geometric nonlinear control theory contains some inaccuracies, which is almost unavoidable in a book which covers so many areas. In an admirable effort to present the material in a manner as simple as possible the author has sometimes gone a little too far. For instance, the definition of a vectorfield on an open part X of $\mathcal{R}^n$ as a smooth mapping from X to $\mathcal{R}^n$ is insufficient; one also has to specify how the image space of this mapping is going to transform under a coordinate transformation on X. (Since the image of every $x \in X$ is really an element of the tangent space of X at x, which, although isomorphic with $\mathcal{R}^n$, is directly connected with X.) This could have been easily remedied since tangent spaces are in fact being defined. The same applies to the definition of one-forms and distributions. There is an error in Theorem 7.3.41 where it is stated that a certain spanning Lie bracket condition ensures local reachability, instead of (the weaker notion of) local strong accessibility. Also the definition of local observability has been simplified too much, with the result that Corollary 7.3.112 is not fully correct anymore. The proof of the 'only if' part of Theorem 7.4.16 could have been shortened considerably. Finally, at the beginning of Chapter 7 it is remarked that only nonlinear systems of the form $\dot{x} = f(x) + g(x)u$ instead of the general form $\dot{x} = f(x, u)$ are being considered, and that, although it is possible to use differential geometric methods to study these general nonlinear systems as well, the increase in complexity is enormous. I do not fully agree with this statement (which is in fact a common misunderstanding). Although most papers on geometric nonlinear control only deal with the case $\dot{x} = f(x) + g(x)u$, the general case $\dot{x} = f(x, u)$ does not generally pose any additional *intrinsic* problems, as can be seen, e.g. from their treatment in Chapter 13 of Nijmeijer and Van der Schaft (1990).

Summarizing, I highly recommend the second edition of Vidyasagar's book to anyone interested in nonlinear control

* *Nonlinear Systems Analysis* by M. Vidyasagar.

theory in its various aspects, and I am sure it is a very useful and stimulating contribution to the rapid and promising developments in this area.

References

Desoer, C. A. and M. Vidyasagar (1975). *Feedback Systems: Input–Output Properties.* Academic Press, New York.

Hahn, W. (1967). *Stability of Motion.* Springer, Berlin.

Isidori, A. (1989). *Nonlinear Control Systems* (2nd edition). Springer, New York.

Khalil, H. K. (1992). *Nonlinear Systems.* MacMillan, New York.

Nijmeijer, H. and A. J. Van der Schaft (1990). *Nonlinear Dynamical Control Systems.* Springer, New York.