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Gauthier, Jean-Paul; Kupka, Ivan

Deterministic observation: theory and applications. (English)

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This is an extraordinary book, establishing a new paradigm in the observability theory of nonlinear systems. It is two-thread. The mathematical thread of the book is based on previous publications authored or co-authored by its authors [*J.-P. Gauthier*, *H. Hammouri* and *S. Othman*, IEEE Trans. Autom. Control 37, No. 6, 875-880 (1992; Zbl 0775.93020); the authors, SIAM J. Control Optim. 32, 975-994 (1994; Zbl 0802.93008); the authors, Math. Z. 223, No. 1, 47-78 (1996; Zbl 0863.93008); *P. Jouan* and *J.-P. Gauthier*, J. Dyn. Control Syst. 2, 255-288 (1996; Zbl 0944.93026)]. The engineering thread is concerned with state estimation and output stabilization of a distillation column and a polymerization reactor presented in [*F. Viel*, *E. Busvelle* and *J.-P. Gauthier*, Int. J. Control 67, No. 4, 475-505 (1997; Zbl 0866.93045) and Automatica 31, No. 7, 971-984 (1995; Zbl 0825.93539)]. The core of this book is mathematical. No one unacquainted with (differential) geometry (and topology) should ever enter chapters 2-7. The chemical engineering applications of the theory developed in chapter 8 might be accessible to control engineers. A great advantage for the sufficiently experienced reader is an appendix explaining necessary mathematical notions, and solutions to numerous exercises that essentially enrich the contents of the book, collected at its end. The mathematical bibliography of the book consists of most fundamental works; control theoretic references remain rather eclectic.

The subject of this book is nonlinear control systems of the form

$$(\Sigma) \qquad \begin{cases} \dot{x} = f(x,u), \\ y = h(x,u), \end{cases}$$

defined on a differentiable manifold X, with controls $u \in U$, where $U = \mathbb{R}^{d_u}$ or $U = I^{d_u}$, I a closed interval, and with outputs $y \in \mathbb{R}^{d_y}$. The control functions are assumed bounded measurable with values in U. The data defining Σ are in the smooth (C^r, C^∞) or analytic class. The uncontrolled case $U = \emptyset$ is also considered.

In chapter 2 of the book, five observability concepts are introduced: observability (corresponding to what is known classically as uniform observability), uniform infinitesimal observability, differential observability, strong differential observability and the phase-variable representation. The last concept means a possibility of computing a time derivative of the output of a given order on the basis of output derivatives of lower orders and input derivatives. Two different situations are considered: $d_y \leq d_u$ (chapter 3) and $d_y > d_u$ (chapter 4). In the former case uniform infinitesimal observability appears to be equivalent to the existence of a uniform canonical flag of the system. This means in particular that uniform inifinitesimal observability in systems whose number of inputs exceeds the number of outputs is very non-typical. In the latter case strong differential observability is generic, moreover, it is shown that any system can be approximated by an observable system with analytic inputs.

For a system whose initial-state-output trajectory map is singular, the phase-variable property becomes essential (chapter 5). For uncontrolled systems the phase-variable property can be established by a finite multiplicity analysis of an observation map. For a controlled system this property holds provided that the system is differentiably observable and satisfies the so-called ascending chain property.

Chapter 6 of the book is devoted to designing output and state observers for state estimation and dynamic output stabilization purposes. Two types of (high-gain) observers are discussed: Luenberger-type observers (constant correction gain), and Kalman-type observers (adjustable correction gain). Exponential Luenberger state observers have been designed for uniformly observable systems in the observability canonical form. Exponential Luenberger output observers are proposed for systems having the phase-variable representation. Similarly, for observable single-input affine control systems, the extended Kalman filter has been designed as an exponential state observer. For systems having the phase-variable representation, the extended Kalman filter is proved to be an exponential output observer.

In chapter 7 the Luenberger and Kalman-type observers are used to achieve a semi-global asymptotic output stabilization. Both for systems having a uniform canonical flag as well as for systems endowed with the phase-variable property, it has been established that, if a system can be stabilized by a state feedback, it can also be stabilized via observers, i.e. using only the output information.

The theory developed in the book is applied in chapter 8 to two chemical engineering problems: state (and feed) estimation as well as output stabilization of a distillation column and of a polymerization reactor. Solutions to these problems show clearly and convincingly the practical significance of the new paradigm set out in this book.

Krzysztof Tchoń (Wrocław)

Keywords : chemical engineering; observability; nonlinear systems; state estimation; output stabilization; distillation column; polymerization reactor; uniform infinitesimal observability; uniform canonical flag; strong differential observability; phase-variable property; finite multiplicity analysis; ascending chain property; Luenberger-type observers; Kalman-type observers; exponential output observer

Classification :

- ∗93-02 Research monographs (systems and control)
- 93B07 Observability
- 93C10 Nonlinear control systems
- 93B29 Differential-geometric methods in systems theory
- 92E20 Chemical flows, reactions, etc.