DETERMINISTIC OBSERVATION THEORY AND APPLICATIONS

This book presents a general theory as well as a constructive methodology to solve "observation problems," that is, reconstructing the full information about a dynamical process on the basis of partial observed data. A general methodology to control processes on the basis of the observations is also developed. Illustrative but also practical applications in the chemical and petroleum industries are shown.

This book is intended for use by scientists in the areas of automatic control, mathematics, chemical engineering, and physics.

J-P. Gauthier is Professor of Mathematics at the Université de Bourgogne, Dijon, France.

I. Kupka is Professor of Mathematics at the Université de Paris VI, France.

DETERMINISTIC OBSERVATION THEORY AND APPLICATIONS

JEAN-PAUL GAUTHIER

IVAN KUPKA

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521805933

First published 2001

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data
Gauthier, Jean-Paul.
Deterministic observation theory and applications / Jean-Paul Gauthier, Ivan Kupka.
p. cm.
Includes bibliographical references and index.
ISBN 0-521-80593-7
1. Observers (Control theory) 2. Missing observations (Statistics) I. Kupka, Ivan, 1937– II. Title.
QA402.3 .G378 2001
003–dc21 2001025571

ISBN 978-0-521-80593-3 hardback

Transferred to digital printing 2009

We dedicate this book to our wives, Irène and Prudence, respectively

The purpose of this book is to present a complete theory of observability and observation of finite dimensional nonlinear systems in the deterministic setting. The theory is used to prove very general results in dynamic output stabilization of nonlinear systems. Two real concrete applications are briefly described.

Dijon, September 9, 2000

Contents

Preface

A long time ago, while working on paper [19], we felt that there was a need to write a book on the subject of observability. Now, after many vicissitudes, this is a done thing.

During the conception of the book, the very novel point of view we had developed in our papers did not change. We discovered that it was really the right one, and was extremely efficient. In fact, based on it, we could build a totally new, complete, and general theory, and a new methodology for the problems related to observability, such as "output stabilization." At the same time, we applied our methodology to practical problems, and we realized that our methods were extremely efficient in practice.

At the very beginning, we intended to write a "survey" on the problems of observability, including nonlinear filtering. As the work progressed, we changed our minds. First, from the practical point of view, we faced a daunting task: a book of that type, had it ever seen the light of a day, would have been a monster. But, more important, our theory would have been drowned in a mass of disparate, disconnected facts.

Hence, this book presents only the general theory we have discovered, with a selection of real-life applications to convince the reader of the practical capability of the method. We strictly avoided the type of academic examples which are rife in many control theory publications.

Several principles guided us in the elaboration of this book:

- First, the book should be short. Including some developments in the stochastic context was a definite possibility, but this would have required the use of deep mathematical tools for meager returns. Enough mathematical theories already are used in the book.
- Second, the book is an excellent opportunity to convince people with a mathematical bent that "observation theory" is not out of place in mathematics. For that reason, the style of this book is a mathematical one. Also, we want to show that applied problems in the real world

can be dealt with by using beautiful mathematics. On the other hand, mathematics is not the main object of this book, but an excellent tool to achieve our goals.

- Third, we want to convince applied people (e.g., control engineers, chemical engineers) that our methodology is efficient. Therefore, they should strive to understand it and, above all, to use it. For this purpose, we want to point out the following:

  - We strove to make all the necessary mathematical tools accessible to uninitiated readers.
  - Bypassing the details of the proofs does not impair the understanding of the statements of the theoretical results and the constructive parts of the theory (many of the proofs are not obvious).
  - Chapter 8, containing the applications, is friendlier to the nonmathematical reader, albeit rigorous.

The development of the practical applications in this book, and of others not mentioned in it, was possible thanks to the cooperation with the French branch of the Shell company, its research center at "Grand-Couronne." One of the applications was actually implemented at the refinery of Petit-Couronne (France). The first author particularly wants to express his deep gratitude to the whole process control group there, more especially to Denis Bossane, François Deza, Marjoleine Van Doothing, and Frederic Viel, for their help, support, and for the good time we spent together. A very special and friendly remembrance goes to Daniel Rakotopara, the head of the group at that time, who so unfortunately died recently.

J-P. Gauthier expresses his warmest thanks to Jean-Jacques Dell'amico (head of the research center) and Pierre Sommelet (chief of the group), who not only took care of financial needs, but also are great friends.

Chapters 3, 4, 5, and 7 of this book contain, among others, the results of the papers [18], [19], [32]. For their kind permission to reproduce parts of papers [18], [19], and [32], we thank, respectively, the Society for Industrial and Applied Mathematics (Observability and observers for nonlinear systems, *SIAM Journal on Control*, Vol. 32, No. 4, pp. 975–994, 1994), Springer-Verlag (Observability for systems with more outputs than inputs, *Mathematische Zeitschrift* 223, pp. 47–78, 1996), and Kluwer Academic Publishers (with P. Jouan, Finite singularities of nonlinear systems. Output stabilization, observability, and observers. *Journal of Dynamical and Control Systems* 2(2), pp. 255–288, 1996).

Mexico City, September, 2000