Zsófia Lendek, Thierry Marie Guerra, Robert Babuška, and Bart De Schutter

Stability Analysis and Nonlinear Observer Design Using Takagi-Sugeno Fuzzy Models

Studies in Fuzziness and Soft Computing, Volume 262

Further volumes of this series can be found on our homepage: springer.com

Vol. 247. Michael Glykas
Fuzzy Cognitive Maps, 2010
ISBN 978-3-642-03219-6

Vol. 248. Bing-Yuan Cao
Optimal Models and Methods with Fuzzy Quantities, 2010
ISBN 978-3-642-10710-8

Vol. 249. Bernadette Bouchon-Meunier, Luis Magdalena, Manuel Ojeda-Aciego, José-Luis Verdegay, Ronald R. Yager (Eds.)
Foundations of Reasoning under Uncertainty, 2010
ISBN 978-3-642-10726-9

Vol. 250. Xiaoxia Huang
Portfolio Analysis, 2010
ISBN 978-3-642-11213-3

Vol. 251. George A. Anastassiou
Fuzzy Mathematics: Approximation Theory, 2010
ISBN 978-3-642-11219-5

Vol. 252. Cengiz Kahraman, Mesut Yavuz (Eds.)
Production Engineering and Management under Fuzziness, 2010
ISBN 978-3-642-12051-0

Vol. 253. Badredine Arfi
Linguistic Fuzzy Logic Methods in Social Sciences, 2010
ISBN 978-3-642-13342-8

Vol. 254. Weldon A. Lodwick, Janusz Kacprzyk (Eds.)
Fuzzy Optimization, 2010
ISBN 978-3-642-13934-5

Vol. 255. Zongmin Ma, Li Yan (Eds.)
Soft Computing in XML Data Management, 2010
ISBN 978-3-642-14009-9

Vol. 256. Robert Jeansoulin, Odile Papini, Henri Prade, and Steven Schockaert (Eds.)
Methods for Handling Imperfect Spatial Information, 2010
ISBN 978-3-642-14754-8

Vol. 257. Salvatore Greco, Ricardo Alberto Marques Pereira, Massimo Squillante, Ronald R. Yager, and Janusz Kacprzyk (Eds.)
*Preferences and Decisions,*2010
ISBN 978-3-642-15975-6

Vol. 258. Jorge Casillas and Francisco José Martínez López
Marketing Intelligent Systems Using Soft Computing, 2010
ISBN 978-3-642-15605-2

Vol. 259. Alexander Gegov
Fuzzy Networks for Complex Systems, 2010
ISBN 978-3-642-15599-4

Vol. 260. Jordi Recasens
Indistinguishability Operators, 2010
ISBN 978-3-642-16221-3

Vol. 261. Chris Cornelis, Glad Deschrijver, Mike Nachtegael, Steven Schockaert, and Yun Shi (Eds.)
35 Years of Fuzzy Set Theory, 2010
ISBN 978-3-642-16628-0

Vol. 262. Zsófia Lendek, Thierry Marie Guerra, Robert Babuška, and Bart De Schutter
Stability Analysis and Nonlinear Observer Design Using Takagi-Sugeno Fuzzy Models, 2010
ISBN 978-3-642-16775-1

Zsófia Lendek, Thierry Marie Guerra,
Robert Babuška, and Bart De Schutter

Stability Analysis and Nonlinear Observer Design Using Takagi-Sugeno Fuzzy Models

Springer

Authors

Dr. Zsófia Lendek
Delft Center for Systems and Control
Delft University of Technology
Mekelweg 2
2628 CD Delft
The Netherlands

Prof. Dr. Bart De Schutter
Delft Center for Systems and Control
Delft University of Technology
Mekelweg 2
2628 CD Delft
The Netherlands

Prof. Dr. Thierry Marie Guerra
Université de Valenciennes et du
Hainaut-Cambrésis
LAMIH CNRS FRE 3304
Le Mont Houy BP311
59313 Valenciennes Cedex 9
France

Prof. Dr. Robert Babuška
Delft Center for Systems and Control
Delft University of Technology
Mekelweg 2
2628 CD Delft
The Netherlands

ISBN 978-3-642-16775-1 e-ISBN 978-3-642-16776-8

DOI 10.1007/978-3-642-16776-8

Studies in Fuzziness and Soft Computing ISSN 1434-9922

Library of Congress Control Number: 2010938248

Typeset & Cover Design: Scientific Publishing Services Pvt. Ltd., Chennai, India.

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Preface

Many problems in decision making, monitoring, fault detection, and control rely on the knowledge of state variables and time-varying parameters that are not directly measured by sensors. In such situations, observers, or estimators, can be employed that use the measured input and output signals along with a dynamic model of the system in order to estimate the unknown states or parameters. An essential requirement in designing an observer is to guarantee the convergence of the estimates to the true values or at least to a small neighborhood of the true values. For linear models, a wide array of estimation techniques are available, such as the Kalman filter and its variants. However, no general method exists for the design of estimators for nonlinear systems. The design and tuning of a nonlinear observer is generally complicated and involves large computational costs.

This book provides a range of methods and tools to design observers for nonlinear systems represented by a special type of a dynamic nonlinear model – the Takagi–Sugeno (TS) fuzzy model. The TS model is a convex combination of affine linear models. This structure facilitates stability analysis and observer design by using effective algorithms based on Lyapunov functions and linear matrix inequalities. TS models are known to be universal approximators and, in addition, a broad class of nonlinear systems can be exactly represented as a TS system.

In the fuzzy systems literature, observer design is typically considered as a dual problem to control design, and as such it has not received much attention yet. This books aims at filling this gap by addressing observer design for TS systems in its own right, with a special attention to large-scale, decentralized systems. To this end, three particular structures of large-scale TS models are considered: cascaded systems, distributed systems, and systems affected by unknown disturbances. The reader will find in-depth theoretical analysis accompanied by illustrative examples and simulations of real-world systems. Stability analysis of TS models is also addressed in detail.

The intended audience are graduate students and researchers both from academia and industry. For newcomers to the field, the book provides a concise introduction dynamic TS fuzzy models along with two methods to construct TS models for a given nonlinear system.

While this monograph focusses mainly on the theory and methodology of state and parameter estimation in nonlinear distributed dynamic systems, the methods presented can readily be used in applications such as industrial processes, traffic systems, environmental systems, energy and water distribution networks, and so on.

Supplementary information relevant to this book is available at the website:

http://www.dcsc.tudelft.nl/fuzzybook/

Comments, suggestions, or questions concerning the book or the website are welcome. Interested readers are encouraged to get in touch with the authors using the contact information on the website.

We thank Janusz Kacprzyk, the series editor, for giving us the opportunity to publish our book with Springer, and the editorial and production team at Springer, especially Thomas Ditzinger, for their valuable help. We gratefully acknowledge the financial support of the BSIK-ICIS project Interactive Collaborative Information Systems (grant no. BSIK03024 of Senter, Ministry of Economic Affairs of the Netherlands), as well as of the International Campus on Safety and Intermodality in Transportation, the Nord-Pas-de-Calais Region, the European Community, the Regional Delegation for Research and Technology, the French Ministry of Higher Education and Research.

Finally, we thank our families for their continual understanding, patience, and support.

July 2010

Zsófia Lendek
Thierry Marie Guerra
Robert Babuška
Bart De Schutter

Contents

Acronyms

TS	Takagi-Sugeno
LMI	Linear Matrix Inequality
ISS	Input-to-State Stable
GAS	Globally Asymptotically Stable
UGAS	Uniformly Globally Asymptotically Stable
PDC	Parallel Distributed Compensation
SISO	Single-Input Single-Output
MIMO	Multi-Input Multi-Output
FP	Feasibility Problem
EVP	Eigenvalue Problem
GEVP	Generalized Eigenvalue Problem