Studies in Systems, Decision and Control

Volume 54

Series editor

Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

About this Series

The series "Studies in Systems, Decision and Control" (SSDC) covers both new developments and advances, as well as the state of the art, in the various areas of broadly perceived systems, decision making and control- quickly, up to date and with a high quality. The intent is to cover the theory, applications, and perspectives on the state of the art and future developments relevant to systems, decision making, control, complex processes and related areas, as embedded in the fields of engineering, computer science, physics, economics, social and life sciences, as well as the paradigms and methodologies behind them. The series contains monographs, textbooks, lecture notes and edited volumes in systems, decision making and control spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution and exposure which enable both a wide and rapid dissemination of research output.

More information about this series at http://www.springer.com/series/13304

Lixian Zhang · Ting Yang
Peng Shi · Yanzheng Zhu

Analysis and Design of Markov Jump Systems with Complex Transition Probabilities

Springer

Lixian Zhang
School of Astronautics
Harbin Institute of Technology
Harbin
China

Ting Yang
School of Astronautics
Harbin Institute of Technology
Harbin
China

Peng Shi
School of Electrical and Electronic Engineering
The University of Adelaide
Adelaide, SA
Australia

and

College of Engineering and Science
Victoria University
Melbourne, VIC
Australia

Yanzheng Zhu
School of Astronautics
Harbin Institute of Technology
Harbin
China

ISSN 2198-4182 ISSN 2198-4190 (electronic)
Studies in Systems, Decision and Control
ISBN 978-3-319-28846-8 ISBN 978-3-319-28847-5 (eBook)
DOI 10.1007/978-3-319-28847-5

Library of Congress Control Number: 2015960402

Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer International Publishing AG Switzerland

To Liying and Tony

—Lixian Zhang

To my families, teachers, and friends

—Ting Yang

To Fengmei, Lisa, and Michael

—Peng Shi

To my parents and my sister

—Yanzheng Zhu

Preface

The past decades have seen great advances in theories and applications of Markov jump systems (MJSs). The systems can effectively model dynamic systems involving stochastic switching (generally autonomous) subject to a Markov chain. Typical examples include various dynamic systems containing variable parameters, fault-tolerant control systems where abrupt faults occur randomly, networked control systems where network-induced communication imperfections vary in a stochastic way, and so on. Till date, quite a few fundamental control issues, such as stability and stabilization, performance analysis, diverse control methodologies, estimation and filtering, model reduction, fault detection and diagnosis, have been extensively studied and many alluring results have been available in the literature. However, as a crucial factor governing the behaviors of MJSs, the transition probabilities (TPs) are generally considered to be certain, completely known, and time-invariant in most studies. In practice, the assumption of ideal TPs is unrealistic and incomplete TPs are often encountered, especially when adequate samples of the transitions are costly or time-consuming to obtain. Meanwhile, due to the influence of various environmental factors, the time-varying TPs are not rare in real applications.

Considering the important role of TPs in determining the system behaviors and performance, this book collects some of the authors' existing results on MJSs subject to complex TPs as well as the original developments on the stability analysis of MJSs. Three categories of complex TPs will be considered: uncertain TPs where the precise values of TPs are not obtained and only the bounds of TPs are reachable, partially unknown TPs where not all the TPs are available, and time-varying TPs. For time-varying TPs, two descriptive methods will be considered in this book. The first method uses finite piecewise homogeneous TPs, which are governed by a slow switching signal or a stochastic variable subject to a higher-level Markov chain, to present the time-varying TPs. The second method abandons the "memoryless" property of TPs and the resulting TPs display a time-varying feature. The system with memory TPs is also called semi-Markov jump system (s-MJS). MJSs with ideal TPs, i.e., constant homogeneous TPs, can be deemed as special cases of s-MJSs.

Several basic control issues will be addressed in this book, including stability and stabilization, performance analysis, model reduction, and filter design, etc. According to the type of the complex TPs, the main body of this book is divided into three parts:

- Part I is devoted to the MJSs with partially unknown TPs. Under the stochastic stability notion, the criteria for stability analysis, stabilization, and filtering are presented and then extended to the case where the bound information of some unknown TPs is available.
- Part II focuses on the MJSs with piecewise homogeneous TPs under either nondeterministic switching or stochastic switching. Methodologies that can effectively handle control problems in the scenario are developed, including the one coping with the asynchronous switching phenomenon between the currently activated system mode and the controller/filter to be designed.
- Part III deals with the MJSs with memory TPs. The concept of σ-mean square stability is proposed such that the stability problem can be solved via a finite number of conditions. The systems involved with nonlinear dynamics, which are described via the Takagi–Sugeno (T–S) fuzzy model, are also investigated.

This book is aimed at providing an overview of the recent research advances on MJSs with complex TPs. It can be used in undergraduate and graduate study and is also suitable as a reference for engineers and researchers in this field. Prerequisite to reading this book is elementary knowledge on mathematics, matrix theory, probability, optimization techniques, and control system theory.

Harbin, China
October 2015

Lixian Zhang
Ting Yang
Peng Shi
Yanzheng Zhu

Acknowledgements

We are deeply indebted to our colleagues Prof. Richard D. Braatz (Department of Chemical Engineering, Massachusetts Institute of Technology, USA), Prof. Patrizio Colaneri (Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano and CNR-IEIIT, Italy), Prof. El-Kébir Boukas (Department of Mechanical Engineering, Ecole Polytechnique de Montreal, Canada), Prof. James Lam (Department of Mechanical Engineering, University of Hong Kong, China), Prof. Huijun Gao (Research Center of Intelligent Control and Systems, Harbin Institute of Technology, China), Prof. Michael V. Basin (Department of Physical and Mathematical Sciences, Autonomous University of Nuevo Leon, Mexico), and Prof. Ming Liu (Research Center of Satellite Technology, Harbin Institute of Technology, China), for inspiring our thinking, reading the manuscript, and offering plenty of valuable advice on the material to improve this book. Lixian Zhang would also like to thank his many current and former students Zepeng Ning, Lingjie Chen, Yusong Leng, Qingrui Zhang, Wei Yang, who are now working or studying all over the world in various occupations, for their great contributions and very helpful discussions.

The financial support of National Natural Science Foundation of China (61322301, 61573112, 61333012), National Natural Science Foundation of Heilongjiang (F201417, JC2015015), the Fundamental Research Funds for the Central Universities of China (HIT.BRETIII.201211, HIT.BRETIV.201306), Key Laboratory of Integrated Automation for the Process Industry, Northeast University, and Australian Research Council (DP140102180, LP140100471, LE150100079) are gratefully acknowledged.

Harbin, China
October 2015

Lixian Zhang
Ting Yang
Peng Shi
Yanzheng Zhu

Contents

Acronyms and Symbols

ARE	Algebraic Riccati Equation
BRL	Bounded Real Lemma
CCL	Cone Complementary Linearization
MJS	Markov Jump System
MJLS	Markov Jump Linear System
MJNN	Markov Jumping Neural Network
NCS	Networked Control System
NN	Neural Network
TRM	Transition Rates Matrix
TPM	Transition Probabilities Matrix
TR	Transition Rate
TP	Transition Probability
LMI	Linear Matrix Inequality
M'	Transpose of matrix M
$\mathbb{R}^n$	n dimensional Euclidean space
$\mathbb{R}^{m \times n}$	Set of all $m \times n$ real matrices
$\mathbb{N}^+$	Set of all positive integers
$\mathbb{C}^n$	n dimensional complex space
$\mathbb{C}^{m \times n}$	Set of all $m \times n$ complex matrices
$(\Omega, \mathcal{F}, \mathcal{P})$	Ω represents the sample space, $\mathcal{F}$ is the σ-algebra of subsets of the sample space and $\mathcal{P}$ is the probability measure on $\mathcal{F}$
$E[\cdot]$	Mathematical expectation
$*$	In symmetric block matrices or long matrix expressions, we use $*$ as an ellipsis for the terms that are introduced by symmetry, for example, $\begin{bmatrix} X & Y \\ * & Z \end{bmatrix} \triangleq \begin{bmatrix} X & Y \\ Y^T & Z \end{bmatrix}$
$diag\{\cdots\}$	A block-diagonal matrix $diag\{M_1, \ldots, M_n\} \triangleq \begin{bmatrix} M_1 & & 0 \\ & \ddots & \\ 0 & & M_n \end{bmatrix}$

$diag_{(N)}\{M\}$	A block-diagonal matrix $diag_{(N)}\{M\} \triangleq \begin{bmatrix} M & & 0 \\ & \ddots & \\ 0 & & M \end{bmatrix} \in \mathbb{R}^{nN \times nN}$ with $M \in \mathbb{R}^{n \times n}$
$P > 0$ (≥ 0)	Real symmetric positive (semi-positive) definite matrix P
$P < 0$ (≤ 0)	Real symmetric negative (semi-negative) definite matrix P
M_i	$M(i)$
$sym(U)$	$U + U'$
I	Identity matrix
0	Zero matrix
$\lambda_{\max}(A)$	Maximum eigenvalue of A
$\lambda_{\min}(A)$	Minimum eigenvalue of A
$\lvert\cdot\rvert$	Euclidean vector norm
$L_2[0,\infty)$	Space of square integrable functions on $[0,\infty)$
$l_2[0,\infty)$	Space of square summable infinite sequence on $\{0,1,2,\ldots\}$
$\lVert w\rVert_2$	$\lVert w\rVert_2 = \sqrt{\sum_{k=0}^{\infty}\lvert w(k)\rvert^2}$, where $w = \{w(k)\} \in l_2[0,\infty)$
$\lVert e\rVert_{E_2}$	$\lVert e\rVert_{E_2} = \sqrt{E\left[\sum_{k=0}^{\infty}\lvert e(k)\rvert^2\right]}$, where $e = \{e(k)\} \in l_2((\Omega, \mathcal{F}, \mathcal{P}), [0,\infty))$
$\Pr(A)$	Occurrence probability of the event A
$\inf\{A\}$	Infimum or greatest lower bound of A
$\sup\{A\}$	Supremum or least upper bound of A
$\min\{A\}$	Minimum value of A
class $\mathcal{K}$	Set of continuous and strictly increasing functions that vanish at zero
class $\mathcal{K}_\infty$	Set of unbounded class $\mathcal{K}$ functions

Matrices, if their dimensions are not explicitly stated, are assumed to becompatible for algebraic operations.