Lecture Notes in Control and Information Sciences 391

Editors: M. Thoma, F. Allgöwer, M. Morari

Ali Khaki-Sedigh and Bijan Moaveni

Control Configuration Selection for Multivariable Plants

Springer

Authors

Prof. Ali Khaki-Sedigh

Faculty of Electrical and Computer Engineering
Department of Control Engineering
K. N. Toosi University of Technology
Tehran, 14317-14191
Iran
E-mail: sedigh@kntu.ac.ir

Dr. Bijan Moaveni

School of Railway Engineering
Iran University of Science and Technology
Tehran, 16846-13114
Iran
E-mail: b_moaveni@iust.ac.ir

ISBN 978-3-642-03192-2 e-ISBN 978-3-642-03193-9

DOI 10.1007/978-3-642-03193-9

Lecture Notes in Control and Information Sciences ISSN 0170-8643

Library of Congress Control Number: Applied for

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

Printed in acid-free paper

5 4 3 2 1 0

springer.com

Lecture Notes in Control and Information Sciences

Edited by M. Thoma, F. Allgöwer, M. Morari

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

Vol. 391: Khaki-Sedigh, A.; Moaveni, B.:
Control Configuration Selection for Multivariable Plants
232 p. [978-3-642-03192-2]

Vol. 390: Chesi, G.; Garulli, A.;
Tesi, A.; Vicino, A.:
Homogeneous Polynomial Forms for Robustness Analysis of Uncertain Systems
197 p. [978-1-84882-780-6]

Vol. 389: Bru, R.; Romero-Vivó, S. (Eds.):
Positive Systems
398 p. [978-3-642-02893-9]

Vol. 388: Jacques Loiseau, J.; Michiels, W.;
Niculescu, S-I.; Sipahi, R. (Eds.):
Topics in Time Delay Systems
418 p. [978-3-642-02896-0]

Vol. 387: Xia, Y.;
Fu, M.; Shi, P.:
Analysis and Synthesis of Dynamical Systems with Time-Delays
283 p. 2009 [978-3-642-02695-9]

Vol. 386: Huang, D.;
Nguang, S.K.:
Robust Control for Uncertain Networked Control Systems with Random Delays
159 p. 2009 [978-1-84882-677-9]

Vol. 385: Jungers, R.:
The Joint Spectral Radius
144 p. 2009 [978-3-540-95979-3]

Vol. 384: Magni, L.; Raimondo, D.M.;
Allgöwer, F. (Eds.):
Nonlinear Model Predictive Control
572 p. 2009 [978-3-642-01093-4]

Vol. 383: Sobhani-Tehrani E.;
Khorasani K.;
Fault Diagnosis of Nonlinear Systems Using a Hybrid Approach
360 p. 2009 [978-0-387-92906-4]

Vol. 382: Bartoszewicz A.;
Nowacka-Leverton A.;
Time-Varying Sliding Modes for Second and Third Order Systems
192 p. 2009 [978-3-540-92216-2]

Vol. 381: Hirsch M.J.; Commander C.W.;
Pardalos P.M.; Murphey R. (Eds.)
Optimization and Cooperative Control Strategies: Proceedings of the 8th International Conference on Cooperative Control and Optimization
459 p. 2009 [978-3-540-88062-2]

Vol. 380: Basin M.
New Trends in Optimal Filtering and Control for Polynomial and Time-Delay Systems
206 p. 2008 [978-3-540-70802-5]

Vol. 379: Mellodge P.; Kachroo P.;
Model Abstraction in Dynamical Systems: Application to Mobile Robot Control
116 p. 2008 [978-3-540-70792-9]

Vol. 378: Femat R.; Solis-Perales G.;
Robust Synchronization of Chaotic Systems Via Feedback
199 p. 2008 [978-3-540-69306-2]

Vol. 377: Patan K.
Artificial Neural Networks for the Modelling and Fault Diagnosis of Technical Processes
206 p. 2008 [978-3-540-79871-2]

Vol. 376: Hasegawa Y.
Approximate and Noisy Realization of Discrete-Time Dynamical Systems
245 p. 2008 [978-3-540-79433-2]

Vol. 375: Bartolini G.; Fridman L.; Pisano A.;
Usai E. (Eds.)
Modern Sliding Mode Control Theory
465 p. 2008 [978-3-540-79015-0]

Vol. 374: Huang B.; Kadali R.
Dynamic Modeling, Predictive Control and Performance Monitoring
240 p. 2008 [978-1-84800-232-6]

Vol. 373: Wang Q.-G.; Ye Z.; Cai W.-J.;
Hang C.-C.
PID Control for Multivariable Processes
264 p. 2008 [978-3-540-78481-4]

Vol. 372: Zhou J.; Wen C.
Adaptive Backstepping Control of Uncertain Systems
241 p. 2008 [978-3-540-77806-6]

Vol. 371: Blondel V.D.; Boyd S.P.;
Kimura H. (Eds.)
Recent Advances in Learning and Control
279 p. 2008 [978-1-84800-154-1]

Vol. 370: Lee S.; Suh I.H.;
Kim M.S. (Eds.)
Recent Progress in Robotics:
Viable Robotic Service to Human
410 p. 2008 [978-3-540-76728-2]

Vol. 369: Hirsch M.J.; Pardalos P.M.;
Murphey R.; Grundel D.
Advances in Cooperative Control and
Optimization
423 p. 2007 [978-3-540-74354-5]

Vol. 368: Chee F.; Fernando T.
Closed-Loop Control of Blood Glucose
157 p. 2007 [978-3-540-74030-8]

Vol. 367: Turner M.C.; Bates D.G. (Eds.)
Mathematical Methods for Robust and Nonlinear
Control
444 p. 2007 [978-1-84800-024-7]

Vol. 366: Bullo F.; Fujimoto K. (Eds.)
Lagrangian and Hamiltonian Methods for
Nonlinear Control 2006
398 p. 2007 [978-3-540-73889-3]

Vol. 365: Bates D.; Hagström M. (Eds.)
Nonlinear Analysis and Synthesis Techniques for
Aircraft Control
360 p. 2007 [978-3-540-73718-6]

Vol. 364: Chiuso A.; Ferrante A.;
Pinzoni S. (Eds.)
Modeling, Estimation and Control
356 p. 2007 [978-3-540-73569-4]

Vol. 363: Besançon G. (Ed.)
Nonlinear Observers and Applications
224 p. 2007 [978-3-540-73502-1]

Vol. 362: Tarn T.-J.; Chen S.-B.;
Zhou C. (Eds.)
Robotic Welding, Intelligence and Automation
562 p. 2007 [978-3-540-73373-7]

Vol. 361: Méndez-Acosta H.O.; Femat R.;
González-Álvarez V. (Eds.):
Selected Topics in Dynamics and Control of
Chemical and Biological Processes
320 p. 2007 [978-3-540-73187-0]

Vol. 360: Kozlowski K. (Ed.)
Robot Motion and Control 2007
452 p. 2007 [978-1-84628-973-6]

Vol. 359: Christophersen F.J.
Optimal Control of Constrained
Piecewise Affine Systems
190 p. 2007 [978-3-540-72700-2]

Vol. 358: Findeisen R.; Allgöwer
F.; Biegler L.T. (Eds.): Assessment and Future
Directions of Nonlinear
Model Predictive Control
642 p. 2007 [978-3-540-72698-2]

Vol. 357: Queinnec I.; Tarbouriech
S.; Garcia G.; Niculescu S.-I. (Eds.):
Biology and Control Theory: Current Challenges
589 p. 2007 [978-3-540-71987-8]

Vol. 356: Karatkevich A.:
Dynamic Analysis of Petri Net-Based Discrete
Systems
166 p. 2007 [978-3-540-71464-4]

Vol. 355: Zhang H.; Xie L.:
Control and Estimation of Systems with
Input/Output Delays
213 p. 2007 [978-3-540-71118-6]

Vol. 354: Witczak M.:
Modelling and Estimation Strategies for Fault
Diagnosis of Non-Linear Systems
215 p. 2007 [978-3-540-71114-8]

Vol. 353: Bonivento C.; Isidori A.; Marconi L.;
Rossi C. (Eds.)
Advances in Control Theory and Applications
305 p. 2007 [978-3-540-70700-4]

Vol. 352: Chiasson, J.; Loiseau, J.J. (Eds.)
Applications of Time Delay Systems
358 p. 2007 [978-3-540-49555-0]

Vol. 351: Lin, C.; Wang, Q.-G.; Lee, T.H., He, Y.
LMI Approach to Analysis and Control of
Takagi-Sugeno Fuzzy Systems with Time Delay
204 p. 2007 [978-3-540-49552-9]

Vol. 350: Bandyopadhyay, B.; Manjunath, T.C.;
Umapathy, M.
Modeling, Control and Implementation of Smart
Structures 250 p. 2007 [978-3-540-48393-9]

Vol. 349: Rogers, E.T.A.; Galkowski, K.;
Owens, D.H.
Control Systems Theory
and Applications for Linear
Repetitive Processes
482 p. 2007 [978-3-540-42663-9]

Vol. 347: Assawinchaichote, W.; Nguang,
K.S.; Shi P.
Fuzzy Control and Filter Design
for Uncertain Fuzzy Systems
188 p. 2006 [978-3-540-37011-6]

Vol. 346: Tarbouriech, S.; Garcia, G.; Glattfelder,
A.H. (Eds.)
Advanced Strategies in Control Systems
with Input and Output Constraints
480 p. 2006 [978-3-540-37009-3]

Vol. 345: Huang, D.-S.; Li, K.; Irwin, G.W. (Eds.)
Intelligent Computing in Signal Processing
and Pattern Recognition
1179 p. 2006 [978-3-540-37257-8]

Vol. 344: Huang, D.-S.; Li, K.; Irwin, G.W. (Eds.)
Intelligent Control and Automation
1121 p. 2006 [978-3-540-37255-4]

Preface

Control of multivariable industrial plants and processes has been a challenging and fascinating task for researchers in this field. The analysis and design methodologies for multivariable plants can be categorized as centralized and decentralized design strategies. Despite the remarkable theoretical achievements in centralized multivariable control, decentralized control is still widely used in many industrial plants. This trend in the beginning of the third millennium is still there and it will be with us for the foreseeable future. This is mainly because of the easy implementation, maintenance, tuning, and robust behavior in the face of fault and model uncertainties, which is reported with the vast number of running decentralized controllers in the industry. The main steps involved in employing decentralized controllers can be summarized as follows:

- Control objectives formulation and plant modeling.
- Control structure selection.
- Controller design.
- Simulation or pilot plant experiments and Implementation.

Nearly all the textbooks on multivariable control theory deal only with the control system analysis and design. The important concept of control structure selection which is a key prerequisite for a successful industrial control strategy is almost unnoticed. Structure selection involves the following two main steps:

- Inputs and outputs selection.
- Control configuration selection or the input-output pairing problem.

This book focuses on control configuration selection or the input-output pairing problem, which is defined as the procedure of selecting the appropriate input and output pair for the design of SISO (or block) controllers. An improper input-output pairing selection can be detrimental to closed loop stability and performance. The main objective in selecting an appropriate control configuration is to minimize the loop interactions. This will facilitate the single input single output independent design that is the basis of many industrial control systems.

This book reviews the main control configuration selection methods available in the literature. The seminal work of Bristol, the Relative Gain Array (RGA) introduced in 1966 is the first method proposed for input-output paring. This empirical method is the most widely control configuration selection strategy used in the practical designs of process control systems. During the nearly 4 decades after introducing the RGA, there are now many extensions and generalizations to the conventional RGA methodology.

Moreover, input-output pairing selection from other viewpoints such as the state space, passivity and soft computing has been introduced. Other approaches include, control configuration selection for nonlinear multivariable plants and pairing problem in the face of time varying parameters or plant uncertainties.

This book is the first monograph to deal in depth with the issue of control configuration selection. It is designed and written to serve the needs of a wide audience working in the area of decentralized control systems both in the academia and industry. The engineers and students interested in control configuration selection techniques, engineers already acquainted with the basic concepts and willing to be familiar with the more advanced strategies and postgraduate students who in addition to the aforementioned points want to get to the frontiers of research in the field may find this book useful.

The book achieves these objectives by reviewing and explaining the concepts involved in the techniques, starting with the RGA and to the latest methodologies available in the literature. Worked examples and simulation results are also available to further explain and clarify the main points. This book will also be useful to process control engineers, postgraduate students in process, electrical, and mechanical engineering disciplines. It is assumed that the reader is acquainted with a basic knowledge about linear and nonlinear system theory, analysis and design of linear multivariable control systems.

Most of the numerical examples are solved using MATLAB software and are available over the internet. Also, corrections and comments can be accessed from the authors' homepages:

- http://saba.kntu.ac.ir/eecd/khakisedigh
- http://webpages.iust.ac.ir/b_moaveni

Feedback from our readers will be appreciated and will help in improving the materials in this book. Please send any questions and comments you may have to authors email addresses: sedigh@kntu.ac.ir and b_moaveni@iust.ac.ir.

Finally, we would like to acknowledge the support of all the people who in some way helped us during the preparation of this book. In particular, we would like to thank our colleagues and graduate students at K. N. Toosi University of Technology, Shahid Rajaee Teacher Training University, and the staff of the Springer-Verlag for their support. The whole manuscript has been revised by our post graduate student Mr Nima Monshizadeh Naini and his technical comments and proof reading the draft chapters of the book is very much appreciated. Last, but not least, we would like to sincerely thank our families for their encouragement, support and patience during the holidays and evenings devoted to this book, the moments that truly belonged to them.

Tehran
July 2009

Ali Khaki-Sedigh
Bijan Moaveni

List of Abbreviations

ARMA	Auto Regressive Moving Average
BRG	Block Relative Gain
CSTR	Continuous Stirred Tank Reactor
DBRG	Dynamic Block Relative Gain
DIC	Decentralized Integral Controllability
Digraph	Direct Graph
DIOPM	Dynamic Input-Output Pairing Matrix
DMRS	Decentralized Model Reference Schemes
DRGA	Dynamic Relative Gain Array
ERGA	Effective Relative Gain Array
GBDD	Generalized Block Diagonal Dominant
GDRG	Generalized Dynamic Relative Gain
GNI	Generalized Niederlinski Index
HIIA	Hankel Interaction Index Array
HSV	Hankel Singular Value
IC	Integral Controllability
ICI	Integral Controllability with Integrity
IM	Interaction Measure
IMC	Internal Model Control
LFT	Linear Fractional Transform
MIMO	Multi-Input Multi-Output
NBRG	Nonsquare Block Relative Gain
NDBRG	Nonsquare Dynamic Block Relative Gain
NI	Niederlinski Index
NRGA	Nonlinear Relative Gain Array
NSRG	Nonsquare Relative Gain
NSRGA	Nonsquare Relative Gain Array
PM	Participation Matrix
PRG	Partial Relative Gain
PRGA	Performance Relative Gain Array
QBDD	Quasi Block Diagonal Dominance
RGA	Relative Gain Array
RIA	Relative Interaction Array
RLS	Recursive Least Square
SIMO	Single-Input Multi-Output
SISO	Single-Input Single-Output

SSE	Sum Squared Error
SSV	Structured Singular Value
STR	Self Tuning Regulator
SV	Singular Value
upper-LFT	Upper Linear Fractional Transform

Contents