**DISTRIBUTED FUZZY CONTROL
OF MULTIVARIABLE SYSTEMS**

**INTERNATIONAL SERIES IN
INTELLIGENT TECHNOLOGIES**

Prof. Dr. Dr. h.c. Hans-Jürgen Zimmermann, Editor
European Laboratory for Intelligent
Techniques Engineering
Aachen, Germany

Other books in the series:

Applied Research in Fuzzy Technology
by Anca L. Ralescu

Analysis and Evaluation of Fuzzy Systems
by Akira Ishikawa and Terry L. Wilson

Fuzzy Logic and Intelligent Systems
edited by Hua Li and Madan Gupta

*Fuzzy Set Theory and Advanced Mathematical
Applications*
edited by Da Ruan

DISTRIBUTED FUZZY CONTROL OF MULTIVARIABLE SYSTEMS

by

ALEXANDER GEGOV

Institute of Control and Systems Research,
Bulgarian Academy of Sciences,
Sofia, Bulgaria

Springer-Science+Business Media, B.V.

Library of Congress Cataloging-in-Publication Data

Gegov, Alexander.

Distributed fuzzy control of multivariable systems / by Alexander Gegov.

p. cm. -- (International series in intelligent technologies ; 6)

Includes bibliographical references and index.

1. Automatic control. 2. Fuzzy systems. 3. Control theory.

I. Title. II. Series.

TJ213.G379 1996

629.8'312--dc20

95-47422

ISBN 978-90-481-4652-9 ISBN 978-94-015-8640-5 (eBook)

DOI 10.1007/978-94-015-8640-5

Printed on acid-free paper

All Rights Reserved

© 1996 Springer Science+Business Media Dordrecht
Originally published by Kluwer Academic Publishers in 1996.

Softcover reprint of the hardcover 1st edition 1996

No part of the material protected by this copyright notice may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage and retrieval system, without written permission from the copyright owner.

To my motherland

TABLE OF CONTENTS

Preface	xi
Acknowledgements	xiii
Chapter 1. Introduction	1
Chapter 2. Dimensional reduction of fuzzy relations in multivariable control systems	4
2.1 Problem statement	4
2.2 Theoretical preliminaries	8
2.3 Control algorithms	12
2.4 Number of on-line computations	13
2.5 Numerical examples	13
2.6 Analysis of results	18
Chapter 3. Decomposition of multivariable systems for distributed fuzzy control	19
3.1 Problem statement	19
3.2 Theoretical preliminaries	19
3.3 Method of decomposition	21
3.3.1 Introductory considerations	21
3.3.2 Decomposition algorithms	26
3.4 Application to an electric power system	28
3.5 Analysis of results	34
Chapter 4. Hierarchical fuzzy control of multivariable systems . . .	35
4.1 Problem statement	35
4.2 Theoretical preliminaries	35
4.3 Method of control	37
4.3.1 Introductory considerations	38
4.3.2 Control law theorems	39
4.3.3 Number of fuzzy relations	40
4.3.4 Control algorithms	41
4.4 Application to an urban traffic network	42
4.5 Analysis of results	49
Chapter 5. Decentralized fuzzy control of multivariable systems by passive decomposition	50
5.1 Problem statement	50
5.2 Theoretical preliminaries	53

5.3 Control algorithms	60
5.4 Numerical examples	62
5.5 Analysis of results	65
Chapter 6. Decentralized fuzzy control of multivariable systems by active decomposition	67
6.1 Problem statement	67
6.2 Theoretical preliminaries	67
6.3 Control algorithms	78
6.4 Numerical examples	80
6.5 Analysis of results	86
Chapter 7. Decentralized fuzzy control of multivariable systems by direct decomposition	87
7.1 Problem statement	87
7.2 Theoretical preliminaries	87
7.3 Control algorithms	97
7.4 Numerical examples	98
7.5 Analysis of results	103
Chapter 8. Multilayer fuzzy control of multivariable systems by passive decomposition	105
8.1 Problem statement	105
8.2 Theoretical preliminaries	106
8.3 Control algorithms	116
8.4 Numerical examples	118
8.5 Analysis of results	122
Chapter 9. Multilayer fuzzy control of multivariable systems by active decomposition	124
9.1 Problem statement	124
9.2 Theoretical preliminaries	124
9.3 Control algorithms	136
9.4 Numerical examples	138
9.5 Analysis of results	143
Chapter 10. Multilayer fuzzy control of multivariable systems by direct decomposition	144
10.1 Problem statement	144
10.2 Theoretical preliminaries	144
10.3 Control algorithms	154
10.4 Numerical examples	155

10.5 Analysis of results	160
Chapter 11. Distributed fuzzy fault diagnosis in multivariable control systems	162
11.1 Problem statement	162
11.2 Basic stages in fault diagnosis	164
11.3 Application of the distributed fuzzy approach	165
Chapter 12. Conclusions	168
Appendix	170
References	175
Index	183

PREFACE

It is known that many control processes are characterized by both quantitative and qualitative complexity. The quantitative complexity is usually expressed in a large number of state variables, respectively high dimensional mathematical model. The qualitative complexity is usually associated with uncertain behaviour, respectively approximately known mathematical model.

If the above two aspects of complexity are considered separately, the corresponding control problem can be easily solved. On one hand, large scale systems theory has existed for more than 20 years and has proved its capabilities in solving high dimensional control problems on the basis of decomposition, hierarchy, decentralization and multilayers. On the other hand, the fuzzy linguistic approach is almost at the same age and has shown its advantages in solving approximately formulated control problems on the basis of linguistic reasoning and logical inference. However, if both aspects of complexity are considered together, the corresponding control problem becomes non-trivial and does not have an easy solution.

Modern control theory and practice have reacted accordingly to the above mentioned new challenges of the day by utilizing the latest achievements in computer technology and artificial intelligence - distributed computation and intelligent operation. In this respect, a new field has emerged in the last decade, called "Distributed intelligent control systems". However, the majority of the familiar works in this field are still either on an empirical or on a conceptual level and this is a significant drawback.

This research monograph presents some recent results in distributed fuzzy control of multivariable systems. The results are obtained within a systematic investigation, extending over the empirical and conceptual level of most familiar works. Large scale systems theory and the fuzzy linguistic approach are used as tools for distributed control and intelligent modelling. In this respect, the monograph is also an

attempt for mutual consideration of these separately developed fields.

The work is written in a structured "method-algorithm-example" form which facilitates its reading and understanding. It is suitable for undergraduate and postgraduate students, as well as researchers from the academic domain. Some of the results could be also of interest for industrial engineers, involved in implementation of fuzzy technologies.

The monograph may be used as a reference in lecture courses on intelligent control for electrical and mechanical engineers. Moreover, it could be used for similar purposes by lecturers in applied mathematics and informatics.

The work presents fundamentals and new directions for extending fuzzy control theory for multivariable and large scale systems. In this sense, its purpose is not only to show some solutions of existing problems but also to stimulate further investigations by the scientific community which could have a significant impact on modern control theory and practice.

The monograph is structured as follows: section 1 gives an introduction, section 2 is devoted to dimensional reduction of fuzzy relations in multivariable control systems, section 3 considers the problem of decomposition of multivariable systems for distributed fuzzy control, section 4 is concerned with hierarchical fuzzy control of multivariable systems, sections 5, 6 and 7 consider the problem of decentralized fuzzy control of multivariable systems by passive, active and direct decomposition, sections 8, 9 and 10 are concerned with multilayer fuzzy control of such systems by passive, active and direct decomposition, section 11 presents an extension of the results for distributed fuzzy fault diagnosis and section 12 gives conclusions. Some terms and definitions from fuzzy set theory are given in the Appendix.

ACKNOWLEDGEMENTS

This work has been carried out mainly within a Research Fellowship from the Alexander von Humboldt Foundation and partly within a Research Grant from the Commission of the European Communities. In this respect, I would like to thank both Institutions for the financial support.

I am very grateful to my german academic hosts Prof. Paul Frank and Prof. Nour Eldin for the valuable recommendations to the content of the manuscript. The organizational assistance of Mrs. Sabine Bay and Mrs. Renate Wach, as well as the provision of necessary facilities by the Department of Measurement and Control at the University of Duisburg and the Department of Automatic Control and Technical Cybernetics at the University of Wuppertal are also greatly acknowledged.

I am indebted to my former research advisor Prof. Todor Stoilov and the Director of the Institute of Control and Systems Research at the Bulgarian Academy of Sciences Prof. Jordan Zaprianov for the cooperation with regard to this research. I would also like to thank my wife Juliet for her patience and understanding. Last but not least, I am very thankful to my friends and relatives who did not forget me during my long absence abroad and especially to my colleagues from the rock-band "Argus" who helped me to feel the inspiration of music.

Alexander Gegov