Fuzzy Control of Industrial Systems
Theory and Applications

FUZZY CONTROL OF INDUSTRIAL SYSTEMS

THEORY AND APPLICATIONS

by

IAN S. SHAW
Industrial Electronic Technology Research Group
Rand Afrikaans University, Johannesburg
Republic of South Africa

Kluwer Academic Publishers
Boston/Dordrecht/London

Distributors for North, Central and South America:
Kluwer Academic Publishers
101 Philip Drive
Assinippi Park
Norwell, Massachusetts 02061 USA

Distributors for all other countries:
Kluwer Academic Publishers
Distribution Centre
Post Office Box 322
3300 AH Dordrecht, THE NETHERLANDS

Library of Congress Cataloging-in-Publication Data

A C.I.P. Catalogue record for this book is available
from the Library of Congress.

The front cover illustration has been derived from clip art published in Corel MegaGallery 2 and reproduced here with their permission.

Printed on acid-free paper.

Printed in the United States of America

FUZZY CONTROL OF INDUSTRIAL SYSTEMS

THEORY AND APPLICATIONS

NOTE TO INSTRUCTORS

A set of questions related to each chapter, suitable for classroom instruction or self testing, are available from the author free of charge by writing to: Author, P.O.Box 93519, Yeoville 2143, Republic of South Africa. Fax: +27-11-487-1880. e-mail: ishaw@global.co.za.

To Gladys...

PREFACE

This volume has been planned as an introductory textbook on intelligent control systems such as *fuzzy logic* and *neurofuzzy* systems. The objective was to create a linkage between an undergraduate text and a practical guide for experienced engineers wishing to upgrade their knowledge. To this end, both theoretical as well as practical design aspects are presented. However, basic familiarity with linear continuous and discrete systems, feedback, Proportional-Integral-Derivative (*PID*) controllers, and the principles of stability, dead time, frequency response, state space, would be necessary prerequisites. In contrast to linear systems, fuzzy and neurofuzzy control systems are rather specialized and the design engineer must be able to recognize situations when they would offer certain advantages over traditional methods, particularly in controlling highly nonlinear and time-variant plants and processes. The various off-the-shelf hardware and software-based fuzzy controllers described in trade journals and practically oriented seminars are relatively easy to understand and the mathematics involved are neither difficult nor obscure. However, both engineering students and practitioners need a deeper insight as to how fuzziness fits into modern control theory in order to gauge the accuracy, reliability and the limitations of their practical results.

Those interested in science in general and the role it plays in our everyday thinking will appreciate the philosophical and cultural implications of fuzzy logic. While not neglecting directly applicable knowledge, the classical goal of advanced technical education implies the engendering of a scientific world-view. In this process, some cultural preferences induced by axioms postulated hundreds of years ago might be superseded by something new that encompasses the old as a special case. It is not the first time that something like this happened. Think of relativity theory, the dual nature of light in physics, or the uncertainty relation in quantum mechanics as typical examples, each of which had forced a drastic change in our scientific world-view.

The special characteristics of fuzzy logic theory (also referred to as *possibility theory*) represent a novel way of handling uncertainty, quite different from *probability theory*. Possibility theory aims to predict the *degree* to which an event is happening, as opposed to probability theory which aims to predict the *chance* of an event happening. Furthermore, fuzzy theory can handle nonlinearities with ease, hence it provides a method to translate the vague, imprecise, qualitative, verbal expressions common in human communication into numeric values. This opens the door to convert human experience into a form understandable by computers. Thus fuzzy technology has an immense practical value because it allows to include the experience of human control operators into our current plant and process control design methodology. In addition, it provides a novel method to solve complex decision-making problems that often involve contradictory conditions. Neural networks and neurofuzzy systems represent a further extension by adding the capability of learning. Vague, uncertain, qualitative, verbal communication, learning and decision-making are distinctly human characteristics, hence fuzzy, neural and neurofuzzy techniques are often being referred to as being *intelligent* because they emulate human intelligence. The current worldwide success of fuzzy technology in industrial applications shows that it can contribute another useful design tool to the disciplines of industrial control engineering, manufacturing, human-machine communication and decision-making. It is time to get aboard!

The structure of this book is as follows.

In Chapter 1 the concepts of an intelligent system and the fundamental objectives of intelligent control are highlighted.

After reviewing the need for control system modeling and various modeling techniques in Chapter 2, more specific attention is devoted to fuzzy logic as an example of heuristic modeling. In turn, the basic principles of bivalence as an idealized world attribute and multivalence as a real-world attribute are discussed, along with the inherent imprecision of human communication which,, by necessity, attempts to express and manipulate the real-world. On this basis, the fuzzy implementation of intelligent control strategies are presented and some typical successful application examples are shown.

Chapters 3 and 4 present the basic theoretical framework of crisp and fuzzy set theory, relating these concepts to control engineering by pointing out the analogy between the *Laplace* transfer function of linear systems and the fuzzy relation of a nonlinear fuzzy system. As a result, the compositional rule of inference that uses the fuzzy relation to compute the output from a given input is shown as the fundamental rule that permits us to design nonlinear control systems based on fuzzy logic.

Chapter 5 deals with the generic structural aspects of fuzzy systems such as membership functions, fuzzification and defuzzification and gives practical guidelines as to how to handle the high degrees of freedom associated with fuzzy systems in choosing the most appropriate one from among the many techniques available.

Chapter 6 discusses three different fuzzy modeling techniques: rule-based, parametric and relational equation based. Although they are equivalent, each has certain advantages and disadvantages of which a fuzzy control design engineer must be aware. After a discussion of general problems related to industrial control, fuzzy *PID*, multivariable and supervisory control techniques and their practical realization are also discussed.

Chapter 7 discusses fuzzy systems identification, including adaptive and learning fuzzy systems. These techniques are particularly useful whenever there is no experienced human operator available and fuzzy controller parameters must be obtained from measurements

Chapter 8 takes a look at stability from a practical viewpoint and presents a method to determine practical stability limits for a fuzzy controller.

Chapter 9 presents an introduction to neural networks as a technology complementary to fuzzy logic which gives rise to neruofuzzy systems. It also gives a qualitative as well as a quantitative analysis of the backpropagation training algorithm which is the learning method used in neurofuzzy control systems. In particular, the trade-offs between obtaining fuzzy controller parameters from experienced human operators and/or measurements are examined in more detail.

Chapter 10 gives a detailed account of practical fuzzy controller design tools and discusses in detail the required features and practical uses of a generic fuzzy controller software design package.

Chapter 11 highlights several examples for successful practical industrial fuzzy controllers constructed and tested world wide. Its main objective is to act as an aid to the designer in recognizing potential applications for fuzzy control.

In as much as the original idea behind fuzzy control was the realization and inclusion of human control operator knowledge in automatic controllers, Chapter 12 examines classical and fuzzy human operator models to establish the optimum functioning of human operators, their capabilities and limitations in driving various industrial systems. An important part of this chapter is the validation of such models and the handling of intersubject variability.

Chapter 13 is an investigation of collaboration between various intelligent systems, including the information exchange between a human operator and a trained fuzzy controller. Some examples of implemented systems of the collaborative kind are described in more detail.

Chapter 14 draws general conclusions in the hope that future reasearch will greatly extend the practical application of fuzzy logic for industrial uses.

CONTENTS

FIGURES