52. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCCEDINGS | 10 - 13 September 2007

FACULTY OF COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME I

Session 1 - Systems Engineering and Intelligent Systems
Session 2 - Advances in Control Theory and Control Engineering
Session 3 - Optimisation and Management of Complex Systems and Networked Systems
Session 4 - Intelligent Vehicles and Mobile Systems
Session 5 - Robotics and Motion Systems

TECHNISCHE UNIVERSITÄT
ILMENAU

Bibliografische Information der Deutschen Bibliothek
Die Deutsche Bibliothek verzeichnet diese Publikation in der deutschen
Nationalbiografie; detaillierte bibliografische Daten sind im Internet über
http://dnb.ddb.de abrufbar.

ISBN 978-3-939473-17-6

Impressum

Herausgeber:
Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion:
Referat Marketing und Studentische Angelegenheiten
Kongressorganisation
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Redaktionsschluss: Juli 2007

Verlag:
Technische Universität Ilmenau/Universitätsbibliothek
Universitätsverlag Ilmenau
Postfach 10 05 65
98684 Ilmenau
www.tu-ilmenau.de/universitaetsverlag

Herstellung und Auslieferung:
Verlagshaus Monsenstein und Vannerdat OHG
Am Hawerkamp 31
48155 Münster
www.mv-verlag.de

Layout Cover: www.cey-x.de

Bezugsmöglichkeiten:
Universitätsbibliothek der TU Ilmenau
Tel.: +49 3677 69-4615
Fax: +49 3677 69-4602

Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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Paper submitted after copy deadline

2 Advances in Control Theory and Control Engineering

52^{nd} Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
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V.Nissen

Management Applications of Fuzzy Control

Introduction

Fuzzy control [1] is one of the oldest and best established application areas of fuzzy set theory. In this paper, the concept of a fuzzy controller as a knowledge-based system is transfered from the well-established technical to the management domain. Similarities and differences are highlighted and sample applications in management are given.

Fuzziness is a form of uncertainty. It embraces in particular linguistic and informational uncertainty [2]. Linguistic uncertainty is characterized by a lack of precision and the indefinite nature of human language. ("*high*" interest rates). Informational uncertainty exists when many descriptors are necessary to describe a term clearly ("*creditworthy*" company). In contrast to stochastic uncertainty, it is not adequate to model these forms of uncertainty based on probability theory.

Since the mid 1960s, fuzzy set theory has been developed by Zadeh [3], Zimmermann [2] and others as a theoretical basis in order to model fuzziness. Fuzzy Set Theory is well-known in the technical domain. In 1975, a cement kiln built in Denmark became the first industrial application of fuzzy control. Later, the idea of fuzzy control was particularly successful in Japan. Today, we find fuzzy control applications in many aspects of daily life, such as automatized chemical process control, gear shifts that adapt to the car driver, and driverless train operations. In addition, many applications of other fuzzy techniques, such as fuzzy data analysis and hybrid approaches, such as Neuro-Fuzzy systems, can be identified.

Fuzzy systems are successful, because they allow for a relatively straightforward modelling and transparent model structure even in complex tasks [4]. Moreover, they demonstrate robust behaviour, for instance in dynamic environments.

The adequate treatment of fuzziness also has great significance in management. For example, qualitative expert judgements, potential information overflow and vague relationships characterize important management domains such as knowledge management, strategic foresight and customer relationship management. Nevertheless, productive management applications of fuzzy set theory are still rare.

Fuzzy Set Theory and Fuzzy Control

Fuzzy systems and fuzzy methods have a solid mathematical basis. In classical set theory, an element *x* from a basic set X ($x \in X$) either definitely belongs to a set A or it definitely does not belong to A. However, for many real circumstances such a strict distinction does not render an appropriate representation. In fact, gradual membership prevails in reality. Thus a fuzzy set $\tilde{A}$ is characterized by the fact that the membership of an element *x* to $\tilde{A}$ can be indicated by a real number which is usually standardized on the range of values [0,1], thus describing formally a fuzzy set $\tilde{A}$ by a real value membership function $\mu_{\tilde{A}}$ is: $\mu_{\tilde{A}} : X \rightarrow [0,1]$. Herein, a value $\mu_{\tilde{A}}(x) = 0$ means that *x* does not belong to the fuzzy set $\tilde{A}$, while a value $\mu_{\tilde{A}}(x) = 1$ indicates full membership. Values within the interval $0 \leq \mu_{\tilde{A}}(x) \leq 1$ indicate a partial membership of *x* in the set $\tilde{A}$. The classical, non-fuzzy set A can be interpreted as a special fuzzy set, where only two alternatives, no membership or full membership, exist.[1]

The application domain of technical control is characterised by the goal to automize the supervision and correcting activities for complex (non-linear) technical processes. In classical control theory, the design of a controller is based on a mathematical model of the technical process, frequently in the form of differential equations that define the system response to it’s inputs. Fuzzy controllers differ from that by modeling the know how of a human control expert for the technical process [4]. Usually, this know how is expressed in logic rules (IF-THEN statements) where fuzzy sets are employed to model qualitative terms like “high” and “low” that the expert uses in his rules.

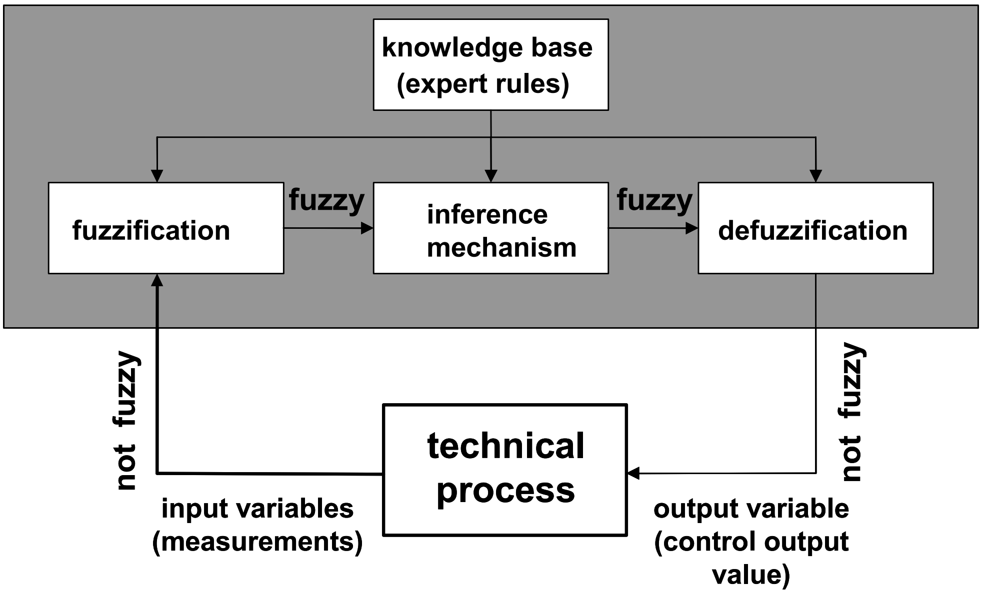

Fig. 1: Structure of a fuzzy controller

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[1] For a more detailed introduction to fuzzy set theory see [2], [4], and [5].

Figure 1 outlines the general structure of a fuzzy controller. The input and output of the controller are generally crisp (not fuzzy) values, while the inference mechanism is based on fuzzy data. Thus, initially the input data is individually mapped from crisp to fuzzy values, a step that uses sets of membership functions. The result is for each fuzzy set a real value in the interval [0,1]. This is called “fuzzfication”. Because neighbouring fuzzy sets overlap, an input variable’s state does not jump abruptly from one state to the next. Instead, it loses value in one membership function while gaining value in the next. Through fuzzification the compatibility of the facts (measurements) with rule antecedents is determined. In contrast to classical expert systems, rule antecendents of fuzzy controllers may only be fulfilled partly. All rules from the knowledge base with antecedents that have strictly positive membership values are activated in parallel. Even conflicting rules may be simultaneously active.

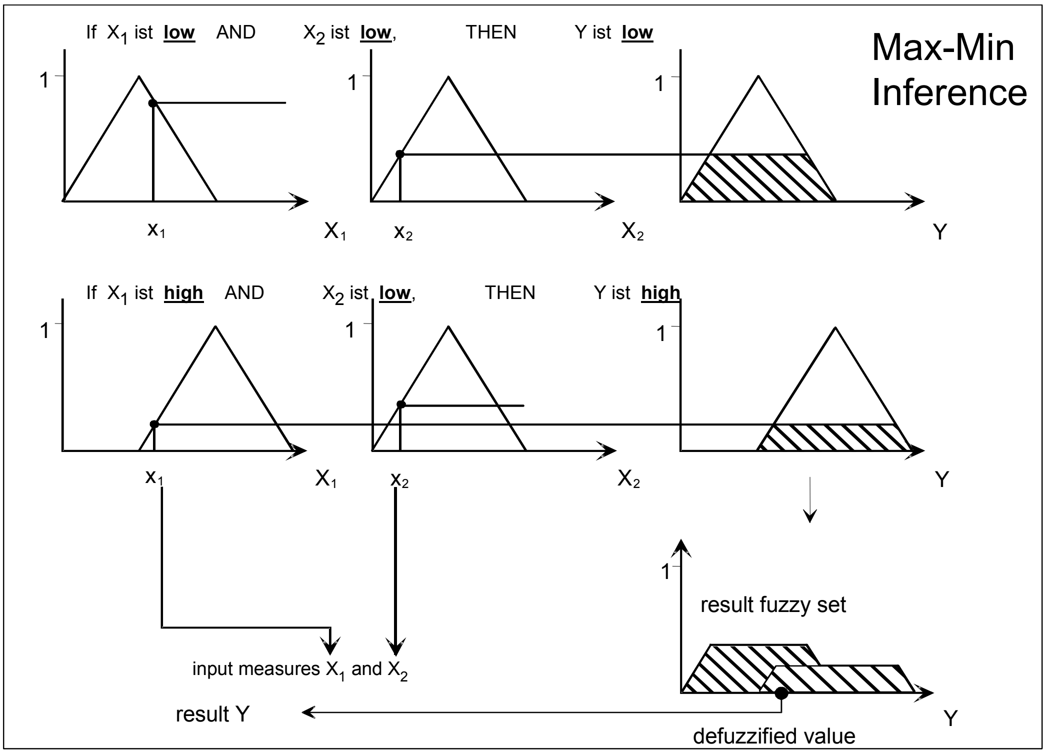

Fig. 2: Principle of max-min inference and center of gravity defuzzification

Usually, rules have several antecedents that are aggregated using fuzzy operators, such as AND, OR, and NOT. Moreover, rules may be weighted to express the conficence of the process expert in the rule. Then, by applying fuzzy inference the fuzzy values of input variables are mapped on the output variable of the fuzzy controller. Frequently, the fuzzy minimum operator (AND) is used for this purpose. Figure 2 highlights, for the example of the AND-operator, how fuzzy sets of the output variable are cut off at the level of the minimum of fuzzified inputs. As several rules can be active simultaneously, their results must be accumulated. Often this is achieved by using the fuzzy maximum operator (OR). The combination of max and min operators is called max-min-inference and a common form of inference mechanism to determine the fuzzy output of the controller. At last, a “defuzzification” step provides a crisp output value, often by calculating the center of gravity for the combined output fuzzy set of all active rules (figure 2).

Applying Fuzzy Control in Management

On an abstract level, fuzzy controllers are used to model human knowledge about complex, non-linear processes in a transparent, formal way that allows for automated execution. In the management domain during the 80ies and 90ies, there was a strong movement to model human expertise in rule-based “expert systems”. These generally suffered from brittleness at the border of their domain of expertise, as well as from often great complexity in the rule base and inference mechanism that prompted design and performance problems. Fuzzy controllers are also rule-based systems, but contrary to classical expert systems, the structure of their knowledge base is much simpler, and they rely on a simple feedforward inference mechanism without backtracking.

Potential applications of fuzzy control-like systems in management can be found where:

- analytical models of the domain are impossible or require a prohibitive effort,
- the results of analytical models are intransparent and have no acceptance,
- qualitative judgements and/or vague relationships are important,
- human expertise about the complex application domain is available in the company.

Based on these criteria, many areas of management qualify for the application of fuzzy rule based systems. In our research group, amongst others, the following successful applications were developed:

- weather-dependent production planning in an industrial bakery [6],
- fuzzy analysis of company balance sheets [7],
- forecasting consulting effort for IT-projects [8],
- modelling corporate strategy in a fuzzy balanced scorecard [9],
- modelling qualitative information in management simulation games [10].

The system structure is always basically equivalent to that of a fuzzy controller as given in figure 1. Again, the rule base contains expert knowledge (if-then statements) about important relationships between variables of the application domain. However, some important differences between technical fuzzy controllers and similar fuzzy rule-based systems in management applications exist:

- Contrary to technical process control, where in short intervals repeated measurements are performed and a control variable is adapted, the cycle of determining inputs, reasoning, and deciding about the output is only performed once in management applications. Thus, the output result is of greater importance than in traditional fuzzy control, as it can not be corrected by a consecutive inference cycle. (However, the fuzzy system may be used for simulations with different input combinations [9].)
- The rule base is generally more complex, because the number of relevant input (and sometimes output) variables is higher in management, so that expert knowledge cannot be summarized in only five to ten rules, as can be done in many technical control applications. To avoid problems with large knowledge bases, fuzzy rule-based systems in management applications frequently take the form of a hierarchical fuzzy controller, where several interrelated rule bases exist that individually solve parts of the overall problem. The total output is then determined by a hierarchical cascade of intermediate results.
- Hence, the system design process can be more complex than in technical fuzzy controllers. Moreover, determining the output quality during the design phase of the rule-based system is sometimes difficult and may rely on expert judgements.
- A true automization of decision making is often not the goal with fuzzy rule-based systems in management. It is more a device for supporting human decisions.
- Input data is frequently quantitative, as in technical control, but it may suffice or render desired extra information to have the output also in qualitative form, giving all positive membership values for output fuzzy sets. Thereby, information about the risk of the decision (output) is available to management.
- To increase management acceptance for the fuzzy rule-based output in decision support, it is desirable (and possible) to construct an explanation component. Such a componant makes use of intermediate results of the hierarchical fuzzy system to explain how the final output was generated [11].

A brief example [8] will help to make these differences more accessible. Figure 3 outlines the general structure of a fuzzy rule-based system that takes certain characteristics of a planned consulting project as input (left side of fig. 3) and generates an estimation of required consulting effort (man-days), separated for different parts of the project, as output. The result can then be used in the quotation of the consulting company to win the respective customer order. The idea in this case was to support and eventually even automize the otherwise laborious manual process of estimating consulting effort. Know how of experienced consultants was structured in several rule bases to allow for a hierarchical decomposition of the overall estimation problem. Every triangle in fig. 3 corresponds to one fuzzy controller, roughly analogous in structure to fig. 1. A cascade of intermediate results (only an excerpt of the whole system is given in fig. 3) then leads to the final effort estimation. This tool showed good performance in practical tests when compared to manual results. Of course, effort estimation is always domain-specific, but the general idea can be quickly transferred from one consulting domain to another.

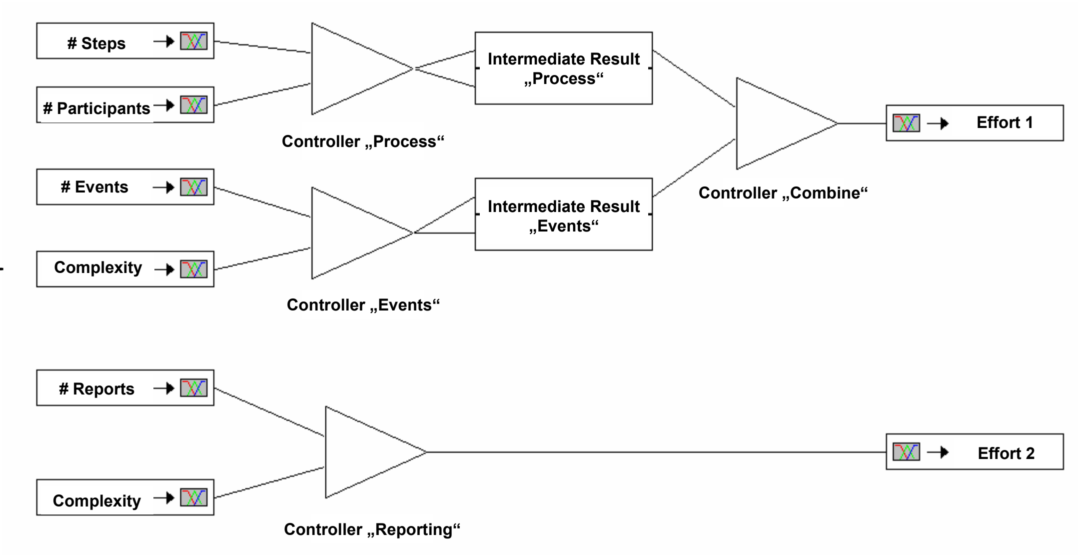

Fig. 3: Structure of a hierarchical fuzzy controller that estimates consulting effort, based on project characteristics that sales staff provided (excerpt) [8]

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