Fuzzy Versus Conventional Control

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Abstract

This article presents notes from the interdisciplinary course ECE 5831 Fuzzy Sets Theory and Its Applications and an introduction part to ECE 4951 Design Workshop dedicated to Intelligent Control, both taught at the ECE Department, University of Minnesota Duluth. What are the advantages and disadvantages of fuzzy control as compared to conventional control? What are the perspectives of conventional control engineers on fuzzy control? In this paper we will attempt to give answers to these questions by asking, and at least partially answering, a series of questions that we have accumulated over the years from a variety of engineers in industry and universities concerned about whether to use fuzzy or conventional control.

1. Introduction

Two approaches are available for study of conventional control systems [13], [14]. The first is known as the classic technique. This technique is based on converting a system's differential equation to an algebraic equation and to a transfer function. The primary disadvantage of the classical technique is its limited applicability. It can be applied only to linear, time-invariant system. A major advantage is that they rapidly provide stability and transient response information. The second is the state space approach. This technique is a unified method for modeling, analyzing, and designing nonlinear and time-varying system. This approach can be applied for a wide range of systems, including the same group modeled by the classical approach however the state-space technique is not as intuitive as the classical approach. The designer has to engage in several calculations before the physical interpretation of the model is apparent.

In our educational program for undergraduate students, the coverage of both conventional approaches are limited to linear, time-invariant systems or systems that can be linearized using Taylor series and it is a subject of ECE 2111 Signal and Systems and ECE 3151 Control Systems courses. Leonhard Euler (1707-1783), Jean Baptiste Joseph Fourier (1768-1830), Pierre Simon Laplace (1749-1827) dominant in these courses [12].

The study of other classes of systems could be presented on an elective three credit ECE 5831 Fuzzy Sets Theory and Its Applications or on required four credits ECE 4951 Design Workshop-Intelligent Control course.

In conventional control deliver during ECE 3151 Control Systems, required three credit course, the prime desiderata are precision, certainty, and rigor. By contrast, the point of departure in fuzzy control in ECE 5831 Fuzzy Sets Theory and Its Applications is the thesis that precision and certainty carry a cost and that control should exploit the tolerance for imprecision and uncertainty [13]. The exploitation of the tolerance for imprecision and uncertainty underlies the remarkable human ability to understand distorted speech, summarize text, recognize and classify images, drive a vehicle in dense traffic and, more generally, make rational decisions in an environment of uncertainty and imprecision. In effect, fuzzy control uses the human mind as a role model. A fuzzy sets theory is an important part of the intelligent control.

It is now realized that complex real-world problems require intelligent systems that combine knowledge, techniques, and methodologies from various sources. These intelligent systems are supposed to posse's humanlike expertise within a specific domain, adapt themselves and learn to do better in changing environments, and explain how they make decisions or take actions. As opposed to PID, lead-lag, and state feedback control where the focus is on modeling and the use of this model to construct a controller that is described by diff erential equations, in fuzzy control we focus on gaining an intuitive understanding of how to best control the process, then we load this information directly into the fuzzy controller.

2. Fuzzy Sets Theory

As Professor Lotfi A. Zadeh from University of California, Berkeley, pointed out in 1965 in his seminal paper entitled "Fuzzy Sets" such imprecisely defined sets or classes "play an important role in human thinking, particularly in the domains of pattern recognition, communication of information, and abstraction". Note, that the fuzziness does not come from the randomness of the constituent members of the sets, but from the uncertain and imprecise nature of abstract thoughts and concepts. The main contribution of fuzzy logic is a methodology for computing with words [3], [7], [9]. A key aspect of computing with words is that it involves a fusion of natural languages and computation with fuzzy variables. A selection of fuzzy if-then rules forms the key component of fuzzy inference system that can effectively model human expertise in specific applications. Because of its multidisciplinary nature, the fuzzy inference system is known also by other names, such as fuzzy expert system, fuzzy-rule-based system, fuzzy associative memory, fuzzy system, and fuzzy logic controller (Fig.1).

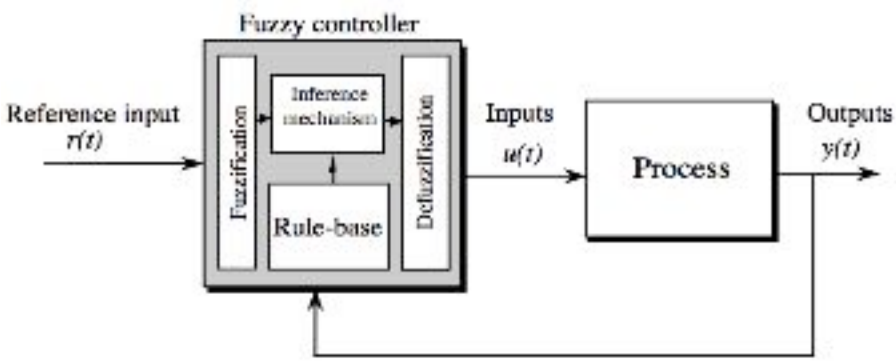

Fig. 1. Fuzzy logic controller

Professor L.A. Zadeh introduced initial ideas of fuzzy control explicitly in 1972, the actual research on fuzzy controllers was started by Professor Mamdani and his students at Queen Mary College in London in the mid -1970s. According to the literature, the first commercially available fuzzy controller for cement kilns was developed by I. P. Holmblad and K. J. Ostergaard in 1982. An automatic-drive fuzzy control system for subway trains in Sendai City (1987) was extremely successful. It is generally praised as superior to other comparable systems based on classical control. The fuzzy controller achieves not only a higher precision in stopping at any designated point, but makes each stop more comfortable; in addition, it saves about 10% of energy. A complete list of other industrial projects, including control problems that are considered beyond the capabilities of classical control theory, that employ fuzzy control would be too long. Fuzzy controllers have also been installed with great success in variety of consumer products, including TV sets, video cameras, vacuum cleaners, washing machines, automobiles (antiskid brake systems, automatic transmissions) and many others [10], [11].

3. Objectives ECE 5831 Fuzzy Sets Theory and Its Applications course

This forty-five hours interdisciplinary course provides the comprehensive treatment of the constituent methodologies underlying fuzzy set theory, an evolving branch within the scope of computational intelligence that is drawing increasingly more attention. In particular, course put equal emphases on theoretical aspects of covered methodologies, as well as some empirical observations and verifications of various applications in practice. The problems in this course are based on current and potential applications in disciplines of computer science, electrical engineering, mechanical engineering, biomedical engineering, medicine, and business.

4. Objectives ECE 4951 Design Workshop course

In this workshop no formal lectures were taught. However the students received an intensive review covering the topics of the 68HC12 microcontroller [6], sensors, and twelve hours lectures and three labs related to Fuzzy Logic Control [5]. During this workshop, the students worked in small groups and were required to design, build and program the controller with intelligent behaviors using fuzzy logic. The Problem Based Learning (PBL) principles [1], [2], [3] were applied. As results, students obtained specific technical knowledge, got group work and managing the project experience as well as presenting the poster and final report. It improved also their communication skills.

Fuzzy Logic has emerged as a practical alternative that provides a convenient method to implement nonlinear controllers. Fuzzy controllers work differently than conventional controllers; expert knowledge is used instead of differential equations to describe a system. This knowledge can be expressed in a very natural way using linguistic variables, which are described by fuzzy sets. Fuzzy Logic has been used primarily on large-scale computing systems and personal computers. The technology involved in intelligent and fuzzy systems is of such a fundamental nature that in 21 century it will be standard knowledge for all engineers and scientists. Overall, in comparing fuzzy to conventional control, it is interesting to note that there are conventional control schemes that are analogous to fuzzy ones:

1. Direct fuzzy control is analogous to direct nonlinear control,

2. Fuzzy adaptive control is analogous to conventional adaptive control (e.g., model reference adaptive control), and

3. Fuzzy supervisory control is analogous to hierarchical control.

Does there exist an analogous conventional approach to every fuzzy control scheme? If so, then in doing fuzzy control research it seems to be very important to compare and contrast the performance of the fuzzy versus the conventional approaches.

The introduction of Motorola's MC68HC12 microcontroller, which incorporates several Fuzzy Logic primitives in its instruction set, has made possible the implementation of fuzzy controllers in microprocessor-based systems [5], [6], [7], [8].

5. Final Results

Following projects of the ECE 4951-Spring-2010 Design Workshop: Intelligent Control Design Using S12 Microcontroller were presented successfully by students during 15th Annual UMD Undergraduate Research/Artistic Showcase (speech and posters presentations, hardware demonstrations), Kirby Ballrooms, UMD, April 29, 2010 as well as posters presentation in Minnesota Power, Headquarter, Duluth, April 30 - May 7, 2010. Dr. Christopher Carroll and Dr. Marian S. Stachowicz from ECE Department, UMD, conducted this workshop.

1. Matthew Wright and Andrew Pedersen,
Intelligent Wallet
2. Jared Sweet and Michael Phillips,
Intelligent Greenhouse Control
3. Alex Kamrud and Nic Westing,
Color Recognition for Tracking Robots
4. Emily Hamilton and Derrick Keffeler,
Path Tracking Vehicle with Fuzzy Control
5. Chris Pflepsen and Stephen Cheruiyot,
Voice Controlled Lights
6. Mark Bretall and Joe Engebretson,
Voice Activated Control of a Direct Current Motor
7. Andrew Becklund and Robert Yang,
Intelligent Helmet – Threat Detection

6. Conclusions

During four years that we have been offering the Design Workshop course on intelligent systems we have found that students were more motivated in the learn fuzzy set theory and microcontroller programming by applying them to the design and implementation to real problems. We could say that students gained an excellent understanding of the both topics of microcontrollers and fuzzy logic control. The workshop was organized in such way that students worked during whole semester on their projects. Students were exposed to teamwork, managing the project and had the opportunity to improve their written and oral communication skills. We should view the fuzzy controller as an artificial decision maker that operates in a closed-loop system in real time. The more students understand conventional control, the more they will be able to appreciate some fine details of the operation of fuzzy control system.

The future improvements to the Design Workshop course will be through addition the following aspects: multidisciplinary teams including students from different engineering departments, for example, from electrical, mechanical, industrial or computer science. The students also should address in the final reports the environmental, ethical, and economical issues that would be affected by their projects. Furthermore the project work should be created using principle of the Problem Based and Project Organized Learning with concrete goals and criteria. Fuzzy set theory will inevitably play important role in any problem area that involves natural language.

7. References

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