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BOOK REVIEW

Adaptive Fuzzy Systems and Control: Design and Stability Analysis

By Li Xin Wang, PTR Prentice Hall, Englewood Cliffs, NJ, 232 pp.

Fuzzy logic systems technology, particularly fuzzy control and fuzzy modeling techniques, is one of the most successful practical applications of fuzzy set and logic theory. In the past few years, the trend has been to combine fuzzy logic systems technology with artificial neural network technology to produce so called neural-fuzzy or fuzzy-neural systems. The objective is to take the advantages of both technologies to make adaptive intelligent machines capable of learning from numerical training data generated by sensors as well as from linguistic rules from human experts. This 232-page monograph, with a foreword by Professor Lotfi A. Zadeh, is one of the first books on this combined technology and, in my opinion, is one of the best. The main purpose of the book is to show how to combine numerical and linguistic information into a common framework in a systematic and efficient way. The author clearly presents his theory with rigorous mathematical proofs, and the example applications are accompanied by computer simulations.

The book contains 13 chapters, which are divided into two parts. In the first part (chaps. 1–7), a detailed description of fuzzy logic systems, especially those with product *and* fuzzy logic, is given, and four training algorithms are developed to learn output fuzzy sets and fuzzy control rules for the fuzzy logic systems. The resultant adaptive fuzzy logic systems are used to solve some control and signal processing problems in computer simulation, and the performance is compared to that of artificial neural networks. In the second part (chaps. 8–13), several adaptive fuzzy controllers and fuzzy identifiers are designed for nonlinear control and filtering applications. Rigorous stability and performance analyses are conducted.

Some basic concepts of fuzzy sets and fuzzy logic are reviewed in chapter 2. Each component of a number of fuzzy logic systems is described, and then the systems are formulated mathematically and proved to be universal approximators. (That is, it is shown that these fuzzy systems can approximate any continuous function over a compact set to arbitrary accuracy.) In chapter 3, the fuzzy logic systems are represented as forward networks, and backpropagation training algorithms are developed to modify the parameters of the fuzzy logic systems. The resulting adaptive fuzzy systems are used as identifiers for nonlinear dynamic systems, and their performance is compared to that of neural networks.

A better and faster training algorithm is developed in chapter 4, based on the classical orthogonal least-squares algorithm. Some parameters of the fuzzy systems are first fixed so that the fuzzy systems can be represented as linear combinations of the so-called fuzzy basis functions. The orthogonal least-squares algorithm is employed to select the significant fuzzy basis functions and the corresponding optimal coefficients. As a sample application, the resultant fuzzy system is used to approximate a controller for the nonlinear ball-and-beam system.

Chapter 5 presents a very simple and much faster training algorithm, which performs a one-pass operation on the training data. Fuzzy IF-THEN rules are generated from the training data and are combined with rules from human experts to form the final fuzzy rules. As sample applications, this adaptive fuzzy system is used to solve

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a truck backer-upper control problem and a time series prediction problem.

An adaptive optimal fuzzy system is developed in chapter 6, based on nearest neighborhood clustering, which can match all the input–output pairs in the training set to any given accuracy. The effectiveness of the fuzzy system is demonstrated by the control of nonlinear dynamic systems. In chapter 7, the adaptive fuzzy systems are compared with neural networks, including as a multilayer-perceptron, radial-basis function network and a probabilistic general regression. It is shown that the most important advantage of adaptive fuzzy systems is that numerical information from sensors and linguistic information from human experts can, in a systematic and efficient manner, be combined into a common framework, whereas neural networks can only make use of numerical information.

In chapter 8, the rationale for fuzzy control is first presented, and adaptive fuzzy controllers are classified as indirect and direct types. Indirect adaptive fuzzy controllers are capable of incorporating a fuzzy description of the unknown system under control. Two indirect adaptive fuzzy controllers are designed using the Lyapunov synthesis approach for the control of high-order nonlinear systems. The resulting closed-loop systems are proved globally stable, and the tracking error between the system output and the reference trajectory converges to zero under certain conditions. The fuzzy controllers are demonstrated via the control of the inverted pendulum to track a given trajectory.

Two direct adaptive fuzzy controllers capable of incorporating fuzzy control rules are designed in chapter 9. It is mathematically proved that the fuzzy controllers can guarantee a global stable closed-loop system; the tracking error converges to zero under some conditions. The designed fuzzy controllers are utilized to control an unstable system and a chaotic Duffing forced-oscillation system. In chapter 10, adaptive fuzzy controllers are designed based on the classical input–output linearization. The designed controllers control the ball-and-beam system to track a trajectory in computer simulation.

In chapter 11, two fuzzy identifiers (based on the adaptive fuzzy systems) are designed for a general nonlinear system. All variables in the identifiers are uniformly bound, and the estimated model converges to the true system under some conditions. Simulated results for a chaotic glycolytic oscillator are shown. Chapter 12 develops two nonlinear adaptive filters (a recursive least-squares filter and a least-mean-squares fuzzy adaptive filter) based on adaptive fuzzy systems. The filters are used as equalizers for nonlinear communication channels and can incorporate fuzzy descriptions about the unknown channels into the equalizers.

The final chapter contains general conclusions and a discussion of future research in fuzzy systems technology. Proof of the universal approximation and stability theorems are given in appendix A; references are provided in appendix B.

The book is very well written and organized, and is complete with many excellent illustrations presenting the concepts and the results of the examples. It is virtually self-contained, and can be used as a textbook or reference book for (advanced) engineering and computer-science courses in fuzzy logic systems technology; of course, some background in neural network, control theory, and system identification is necessary to fully understand the book. It should be noted that the fuzzy controllers and fuzzy identifiers presented in the book are primarily of the Mamdani type; the Takagi and Sugeno type is mentioned only briefly. The book may also be used as a reference book to theory- or application-oriented researchers and engineers.