Fuzzy Logic
for
Embedded Systems Applications

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PREFACE

Fuzzy logic and its applications are now well-established and arguments for and against it have reached a steady-state. There is an overwhelming volume of literature on the topic making it an uneasy task for a practicing engineer, beginner researcher, or an advanced student to grasp the topic and then apply the acquired knowledge with only a small investment of time and money. This book is intended to present fuzzy logic and its applications for embedded systems succinctly, yet comprehensively, in a self-contained, simple, readable approach. Simplicity here means the omission of extraneous inert sentences and phrases, and the exclusion of non-applied mathematical and research-oriented details. It is intended for the intelligent reader with an alert mind. The approach, the organization, and the presentation of this book are also hoped to enhance the accessibility to existing knowledge beyond its contents. An extensive bibliography not only of printed material but also of annotated Web links is provided at the end of each chapter.

The book is divided into 9 chapters in addition to a set of quizzes, an appendix, a list of symbols and acronyms, and a glossary. Chapter 1 gives an overview of embedded systems and their implementation techniques. The chapter introduces the wide scope of embedded systems. The relation between fuzzy logic and embedded systems is also outlined.

Chapters 2 and 3 introduce succinctly the concepts of fuzzy sets, fuzzy operations, and fuzzy relations with illustrative examples. The discussion is geared toward what would be needed in order to design fuzzy embedded systems.

In chapter 4, embedded fuzzy logic applications are introduced with simplified case studies. Contrasting fuzzy logic control with conventional control is emphasized. It is hoped that by the end of this chapter that the reader would be able to apply fuzzy logic to the design of an embedded system of interest. The reader may wish to consult chapter 8, Fuzzy Software Tools and select a few tools and start experimenting with fuzzy systems design and simulation.

A critique of fuzzy logic is presented in chapter 5, a topic that is not commonly discussed in the engineering literature on fuzzy logic. It is, however, important for engineers to understand the limitations and implications of any methodology they intend to use. No tool is suitable for everything, it must be used skillfully within its bounds of applicability. Further, most engineers are interested in intellectual discussions relevant to the topic at hand as long as it is communicated properly and is to the point. The discussion in this chapter is brief , but with an extensive bibliography provided for those who may like to further research any of the points discussed.

Chapter 6 presents the fundamentals of artificial neural networks, which is closely related to fuzzy logic but with fundamentally different concepts. The chapter introduces basic structures and learning algorithms of neural networks. The discussion is hoped to enable the reader to gain

insight into the concepts of neural networks and be prepared for the discussion of hybrid systems where both fuzzy logic and neural networks techniques converge into a single system, discussed in Chapter 7.

Hardware realizations are outlined in Chapter 8. Both analog and digital implementations are discussed. Chapter 9 provides the reader with an opportunity to gain hands-on experience with a minimum investment of time and money. The chapter gives an overview of numerous software tools for fuzzy logic systems, neural networks, and neuro-fuzzy systems. The software reviewed include C, C++, and Java source codes; in addition to M-files for MATLAB. Design and analysis software tools with graphical user interfaces are also discussed, and software that is meant to demonstrate fundamental concepts. All software tools, or a working demo of them, are available for downloading through the Web along with documentation and examples in most cases.

Since most of the ideas presented are now well established there is no referencing given within the text of the chapters. However, further reading and expansion on the information presented is facilitated by the selected bibliography provided at the end of each chapter. The Web resources selected are those available at no charge, relevant to the topics discussed, and expected to be reliable.

The idea of citing references from the Web does not yet hold wide acceptance in some academic circles. The major argument against the idea is the questionable reliability of the content and its sustained availability. It should be remembered that content does not become reliable just because it is printed on paper, and unreliable when it is posted freely on the Web. Nevertheless, many of the resources cited as accessible through the Web are documents that were published on paper as well, the Web simply enhances their availability. The use of the Web is intrinsic for some of the resources such as interactive demos. It should also be remembered that books are known to go out of print and many may not be physically accessible with ease. Of course, an available, well written book constitutes a better and more convenient source of knowledge. The accessibility through the Web would be the next best thing, but it requires guidance, as provided here, to make the most out of it.

The set of quizzes with answers provided is to meant to help the reader ponder about the subjects introduced without being side-tracked from the final goal that could be better reached by using the resources of chapter 9; thus learning through practice.

The appendix introduces the fundamental concepts of Genetic Algorithms, GAs. It is an optimization technique sometimes used in conjunction with the design of fuzzy and neural systems. A classified, annotated Web bibliography is provided for the reader who may wish to study the topic further.

A list of symbols and acronyms is provided along with the circuit symbols of MOSFETs that appeared in literature on fuzzy logic embedded implementations to help the reader avoid possible confusion when consulting the resources.

A glossary of terms related to embedded systems, fuzzy logic, and neural networks is provided. Although it refers to terms used in the various chapters of the book, it also introduces some terms to expand the coverage and provoke further interest in the general topic.

If an instructor is to use this book as a teaching resource, there are numerous application-oriented exercises and mini-projects that can be assigned to the students if the instructor wishes to do so. For example:

- The quizzes provided could be the basis for class discussion on the fundamentals of fuzzy logic and neural networks.
- An item from the numerous Web resources provided could be selected and students asked to research it further and expand on the short review given.
- Students could be asked to further research entries from the glossary.
- Students could be asked to run a selected demo simulation or Java applet provided from the resources provided in Chapter 9, observe its action and document their observations and relate it to the theory.
- Students could be assigned a system of interest such as a refrigerator, vacuum cleaner, auto-focusing, level control, speed control, etc. They identify the inputs and outputs, design a linguistic model, then simulate it using one of the tools discussed.
- Students could be also asked to produce their own source code and executable file to solve one of the above problems.
- A topic from Chapter 5, Fuzzy Logic Critique, could be selected for further research and discussion.

It is hoped that through this book the reader will:

- Gain an understanding of the wide range of embedded systems and their future trend.
- Be able to use fuzzy sets and fuzzy logic algebra.
- Recognize when and why it would be advantageous to use fuzzy logic.
- Understand the fundamentals of neural networks and recognize when it is advantageous to use them.
- Gain familiarity with the hardware implementations approaches of fuzzy logic for embedded systems applications.
- Be able to experiment with the design of fuzzy systems for embedded systems applications.
- Be able to pursue further details of a topic within fuzzy logic embedded systems applications with relative ease.

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About the Author

Dr. Ibrahim is a senior member of the Institute of Electrical and Electronics Engineers (IEEE), a member of the Association of Professional Engineers of Ontario (APEO), the Material Research Society (MRS), the American Association of Engineering Education (ASEE), and the International Banknote Society (IBS). He lectured in the area of Electronics on three continents to a diverse population of students and presented seminars and workshops to practicing engineers. He has a wide range of publications including papers in refereed journals and conferences. Dr. Ibrahim has organized and chaired sessions on *Current Trends in Electronics Education* during the IEEE Conferences IECON'01, Denver, Colorado, USA, IECON'02, Sevilla, Andalucia, Spain. and IECON'03, Roanoke, Virginia, USA. He was a guest editor for the 2003 Special Issue of the International Journal of Engineering Education on *Current Trends in Electronics Education.* He was a member of the International Advisory Committee of the First and Second International Conferences on Distance Learning held at the Belarussian State University of Informatics and Radioelectroics, Minsk, Belarus in the years 2001 and 2002. Dr. Ibrahim has a B.Sc. (EE) degree from Ain Shams University, Cairo, Egypt, a Maters (Eng Phys.) and a Ph.D. (EE) degrees from McMaster University, Hamilton, Ontario, Canada. At present he is with DeVry, Mississauga, Ontario, Canada.

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalued logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL.Â In Fuzzy Logic Toolboxâ„¢ software, fuzzy logic should be interpreted as FL, that is, fuzzy logic in its wide sense. Fuzzy Logic is defined as a many-valued logic form which may have truth values of variables in any real number between 0 and 1. It is the handle concept of partial truth. In real life, we may come across a situation where we can't decide whether the statement is true or false. At that time, fuzzy logic offers very valuable flexibility for reasoning. Fuzzy logic algorithm helps to solve a problem after considering all available data. Then it takes the best possible decision for the given the input. Fuzzy Logic resembles the human decision-making methodology. It deals with vague and imprecise information. This is gross oversimplification of the real-world problems and based on degrees of truth rather than usual true/false or 1/0 like Boolean logic.Â Fuzzy Logic - Set Theory. Fuzzy sets can be considered as an extension and gross oversimplification of classical sets. It can be best understood in the context of set membership.