INTRODUCTION TO INTERVAL TYPE-2 FUZZY LOGIC SYSTEMS

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Contents

Summary

Type-1 Fuzzy Logic Systems (FLSs) have been applied to date with great success to different applications. However, for many real-world applications, there is a need to cope with large amounts of uncertainties. The traditional Type-1 FLSs that use crisp Type-1 fuzzy sets cannot directly handle such uncertainties. Type-2 FLSs that use Type-2 fuzzy sets can handle such uncertainties to produce a better performance. Hence, Type-2 FLSs will have the potential to overcome the limitations of Type-1 FLSs and produce a new generation of fuzzy systems with improved performance for many applications which require handling high levels of uncertainty. This chapter will provide an overview of interval Type-2 fuzzy sets and interval Type-2 FLSs and their advantages. We will also present different techniques to avoid the computational overheads and thus enabling the interval Type-2 FLSs to produce a good real time response. Furthermore, we will present a brief overview of interval Type-2 FLSs applications.

1. Introduction

A Fuzzy Logic System (FLS) is credited with being an adequate methodology for designing robust systems that are able to deliver a satisfactory performance in the face of uncertainty and imprecision. In addition, FLSs provide a way of constructing systems by means of linguistic labels and linguistically interpretable rules in a user-friendly way closer to human thinking and perception.

However, there are many sources of uncertainty facing the FLS in dynamic real-world unstructured environments and many real-world applications; some of the uncertainty sources are as follows:

- Uncertainties in inputs to the FLS, which translate into uncertainties in the antecedents' membership functions as the sensors measurements are affected by high noise levels from various sources. In addition, the input sensors can be affected by the conditions of observation (i.e. their characteristics can be changed by the environmental conditions such as wind, sunshine, humidity, rain, etc.).
- Uncertainties in outputs, which translate into uncertainties in the consequents' membership functions of the FLS. Such uncertainties can result from the change of the actuators' characteristics, which can be due to wear, tear, environmental changes, etc.
- Linguistic uncertainties as the meaning of words that are used in the antecedents' and consequents' linguistic labels can be uncertain, as words mean different things to different people (Mendel 2001). In addition, experts do not always agree and they often provide different consequents for the same antecedents. A survey of experts will usually lead to a histogram of possibilities for the consequent of a rule; this histogram represents the uncertainty about the consequent of a rule (Mendel 2001).
- Uncertainties associated with the change in the operation conditions. Such uncertainties can translate into uncertainties in the antecedents' and/or consequents' membership functions.
- Uncertainties associated with the use of noisy training data that could be used to learn, tune or optimize the FLS.

All of these uncertainties translate into uncertainties about fuzzy set membership functions (Mendel 2001). The vast majority of the FLSs that have been used to date were based on the traditional Type-1 FLSs. However, Type-1 FLSs cannot fully handle or accommodate the linguistic and numerical uncertainties associated with dynamic unstructured environments as they use Type-1 fuzzy sets. Type-1 fuzzy sets handle the uncertainties associated with the FLS inputs and outputs by using *precise and crisp* membership functions that the user believes capture the uncertainties. Once the Type-1 membership functions have been chosen, all the uncertainty disappears because Type-1 membership functions are precise (Mendel 2001). The linguistic and numerical uncertainties associated with dynamic unstructured environments cause problems in determining the exact and precise antecedents' and consequents' membership functions during the FLS design. Moreover, the designed Type-1 fuzzy sets can be sub-optimal under specific environment and operation conditions; however, because of the environment changes and the associated uncertainties, the chosen Type-1 fuzzy sets might not be appropriate anymore. This can cause degradation in the FLS performance, which can result in poor efficiency and we might end up wasting time in frequently redesigning or tuning the Type-1 FLS so that it can deal with the various uncertainties (Hagras 2004).

A Type-2 fuzzy set is characterized by a fuzzy Membership Function (MF), i.e. the membership value (or membership grade) for each element of this set is a fuzzy set in [0,1], unlike a Type-1 fuzzy set where the membership grade is a crisp number in [0,1] (Mendel 2001). The MFs of Type-2 fuzzy sets are three dimensional and include a footprint of uncertainty. It is the new third dimension of Type-2 fuzzy sets and the footprint of uncertainty that provide additional degrees of freedom that make it possible to directly model and handle uncertainties (Mendel 2001). The Type-2 fuzzy sets are useful where it is difficult to determine the exact and precise membership functions. Type-2 FLSs that use Type-2 fuzzy sets have been used to date with great success where the Type-2 FLSs have outperformed their Type-1 counterparts in several applications where there is high level of uncertainty (Hagras 2007a).

In the next section, we will introduce the Type-2 fuzzy sets and their associated terminologies. Section 3, will introduce briefly the interval Type-2 FLS and its various components. Section 4, will provide a practical example to clarify the various operations of the Type-2 FLS. Section 5 will present different techniques to avoid the computational overheads and thus enabling the interval Type-2 FLSs to produce a good real time response. Section 6 will provide a brief overview of applications of interval Type-2 FLSs. Finally conclusions and future directions are presented in Section 7.

2. Type-2 Fuzzy Sets

Type-1 FLSs employ crisp and precise Type-1 fuzzy sets. For example, consider a Type-1 fuzzy set representing the linguistic label of "*Low*" temperature in Figure 1a: if the input temperature x is 15^{o} C, then the membership of this input to the "*Low*" set will be the certain and crisp membership value of 0.4. However, the center and endpoints of this Type-1 fuzzy set can vary due to uncertainties (which could arise for example from noise) in the measurement of temperature (numerical uncertainty) and in the situations in which 15^{o} C could be called "Low" (linguistic uncertainty) (in the Arctic 15^{o} C might be considered "High", while in the Caribbean it would be considered "low"). If this linguistic label was employed with a fuzzy logic system, then the Type-1 FLS would need to be frequently tuned to handle such uncertainties. Alternatively, one would need to have a group of separate Type-1 sets and Type-1 FLSs where each FLS will handle a certain situation.

On the other hand, a Type-2 fuzzy set is characterized by a fuzzy Membership Function (MF), i.e. the membership value (or membership grade) for each element of this set is itself a fuzzy set in [0,1]. For example if the linguistic label of "*Low*" temperature is represented by a Type-2 fuzzy set as shown in Figure 1b, then the input x of 15^{o} C will no longer have a single value for the MF. Instead, the MF takes on values wherever the vertical line intersects the area shaded in gray. Hence, 15^{o} C will have *primary membership* values that lie in the interval [0.2, 0.6]. Each point of this interval will have also a weight associated with it. Consequently, this will create an amplitude distribution in the third dimension to form what is called a *secondary membership function*, which can be a triangle as shown in Figure 1c. In case the secondary membership function is equal to 1 for all the points in the primary membership and if this is true for $\forall x \in X$, we have the case of an interval Type-2 fuzzy set. The input x of 15^{o} C will now have a primary membership and an associated secondary MF. Repeating this for all $x \in X$ creates a three-dimensional MF (as shown in Figure 1d) —a Type-2 MF—that characterizes a Type-2 fuzzy set. The MFs of Type-2 fuzzy sets are three dimensional and include a Footprint of Uncertainty (FOU) (shaded in gray in Figure1b). It is the new third-dimension of Type-2 fuzzy sets and the FOU that provide additional degrees of freedom and that make it possible to directly model and handle the numerical uncertainties and linguistic uncertainties.

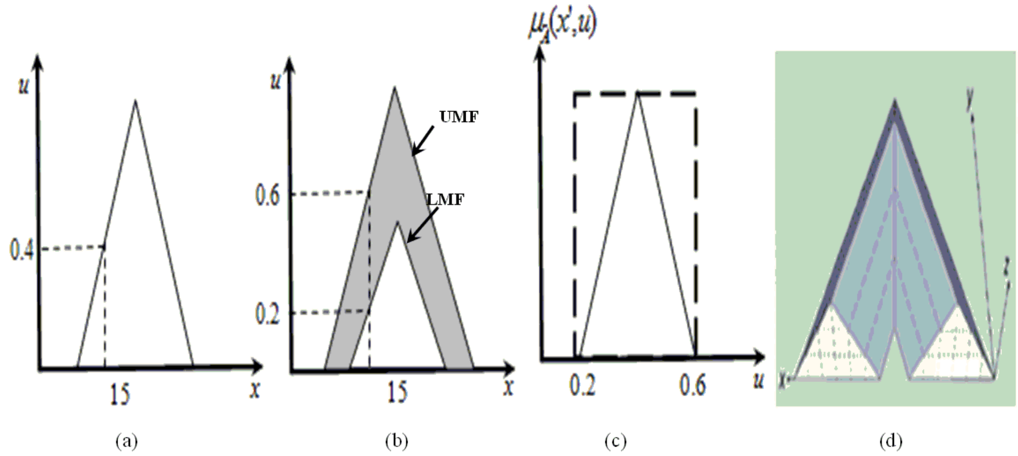

Figure 1. a) A Type-1 fuzzy set. b) A Type-2 fuzzy set- primary membership function. c) An interval Type-2 fuzzy set secondary MF (drawn with dotted lines) and a general Type-2 MF (solid line) at a specific point x'. d) 3-d view of a general Type-2 fuzzy set

2.1. Type-2 Fuzzy Sets Terminologies and Operations

A Type-2 fuzzy set $\tilde{A}$ is characterized by a Type-2 MF $\mu_{\tilde{A}}(x,u)$ (Mendel 2001) where $x \in X$ and $u \in J_x \subseteq [0,1]$, i.e.,

$$\tilde{A} = \left\{((x,u), \mu_{\tilde{A}}(x,u)) \mid \forall x \in X, \forall u \in J_x \subseteq [0,1]\right\} \qquad (1)$$

in which $0 \le \mu_{\tilde{A}}(x,u) \le 1$. $\tilde{A}$ can also be expressed as follows (Mendel 2001):

$$\tilde{A} = \int_{x \in X} \int_{u \in J_x} \mu_{\tilde{A}}(x,u) / (x,u) \qquad J_x \subseteq [0,1], \qquad (2)$$

where $\iint$ denotes union over all admissible x and u. For discrete universes of discourse $\int$ is replaced by $\sum$ (Mendel 2001).

At each value of x say $x = x'$, the 2-D plane whose axes are u and $\mu_{\tilde{A}}(x',u)$ is called a vertical slice of $\mu_{\tilde{A}}(x,u)$. A *secondary membership function* is a vertical slice of $\mu_{\tilde{A}}(x,u)$. It is $\mu_{\tilde{A}}(x = x',u)$ for $x \in X$ and $\forall u \in J_{x'} \subseteq [0,1]$ (Mendel 2001), i.e.

$$\mu_{\tilde{A}}(x = x',u) \equiv \mu_{\tilde{A}}(x') = \int_{u \in J_{x}'} f_{x'}(u) / (u) \qquad J_{x'} \subseteq [0,1] \qquad (3)$$

in which $0 \le f_{x'}(u) \le 1$. Because $\forall x \in X \quad x \in X$, the prime notation on $\mu_{\tilde{A}}(x')$ is dropped and we refer to $\mu_{\tilde{A}}(x)$ as a secondary membership function (Mendel 2002a); it is a Type-1 fuzzy set which is also referred to as a secondary set. Many choices are possible for the secondary membership functions. According to Mendel (2001) the name that we use to describe the entire Type-2 membership function is associated with the name of the secondary membership functions; so, for example if the secondary membership function is triangular then we refer to $\mu_{\tilde{A}}(x,u)$ as a triangular Type-2 membership function. Figure 1c shows a triangular secondary membership function at x' which is drawn using the thick line. Based on the concept of secondary sets, Type-2 fuzzy sets can be written as the union of all secondary sets (Mendel 2001).

The domain of a secondary membership function is called *primary membership* of x (Mendel 2001). In Eq. (1), J_x is the primary membership of x, where $J_x \subseteq [0,1]$ for $\forall x \in X$ (Mendel 2001). When $f_x(u) = 1$, $\forall u \in J_x \subseteq [0,1]$, then the secondary membership functions are interval sets, and, if this is true for $\forall x \in X$, we have the case of an *interval Type-2 membership function* (Mendel 2001). Interval secondary membership functions reflect a uniform uncertainty at the primary memberships of *x*. Figure 1c shows the secondary membership at x' (drawn in dotted lines in Figure 1c) in case of interval Type-2 fuzzy sets.

2.1.1. Footprint of Uncertainty

The uncertainty in the primary memberships of a Type-2 fuzzy set $\tilde{A}$, consists of a bounded region that is called the *footprint of uncertainty* (FOU) (Mendel 2002a). It is the union of all primary memberships (Mendel 2002a), i.e.,

$$\mathrm{FOU}(\tilde{A}) = \bigcup_{x \in X} J_x \qquad (4)$$

The shaded region in Figure 1b is the FOU. It is very useful, because according to Mendel and John (2002a) it not only focuses our attention on the uncertainties inherent in a specific Type-2 membership function, whose shape is a direct consequence of the nature of these uncertainties, but it also provides a very convenient verbal description of the entire domain of support for all the secondary grades of a Type-2 membership function. The shaded FOU implies that there is a distribution that sits on top of it—the new third dimension of Type-2 fuzzy sets. What that distribution looks like depends on the specific choice made for the secondary grades. When they all equal one, the resulting Type-2 fuzzy sets are called *interval Type-2 fuzzy sets*. Establishing an appropriate FOU is analogous to establishing a probability density function (pdf) in a probabilistic uncertainty situation (Mendel 2001). The larger the FOU the more uncertainty there is. When the FOU collapses to a curve, then its associated Type-2 fuzzy set collapses to a Type-1 fuzzy set, in much the same way that a pdf collapses to a point when randomness disappears.

2.1.2. Embedded Fuzzy Sets

For continuous universes of discourse X and U, an embedded Type-2 set $\tilde{A}_e$ is defined as follows (Mendel 2001):

$$\tilde{A}_e = \int_{x\in X} [f_x(u)/u]/x \quad u \in J_x \subseteq U = [0,1] \tag{5}$$

Set $\tilde{A}_e$ is embedded in $\tilde{A}$ and there is an uncountable number of embedded Type-2 sets is $\tilde{A}$ (Mendel 2002b). For discrete universes of discourse X and U, *an embedded Type-2 set* $\tilde{A}_e$ has N elements, where $\tilde{A}_e$ contains exactly one element from $J_{x_1}, J_{x_2}, ...J_{x_N}$, namely $u_1, u_2, \ldots, u_N$, each with its associated secondary grade $f_{x_1}(u_1), f_{x_2}(u_2), ... f_{x_N}(u_N)$ [Mendel 2001], i.e.,

$$\tilde{A}_e = \sum_{d=1}^{N} [f_{x_d}(u_d)/u_d]/x_d \quad u_d \in J_{x_d} \subseteq U = [0,1] \tag{6}$$

Set $\tilde{A}_e$ is embedded in $\tilde{A}$ and there is a total of $\prod_{d=1}^{N} M_d$ $\tilde{A}_e$ [23]. Where M_d is the discretization levels of u_d^j at each x_d.

For continuous universes of discourse X and U, an embedded Type-1 set $\tilde{A}_e$ is defined as follows (Mendel 2002a)

$$\tilde{A}_e = \int_{x\in X} u/x \qquad u \in J_x \subseteq U = [0,1] \tag{7}$$

Set A_e is the union of all the primary memberships of set $\tilde{A}_e$ in Eq. (5) and there is an uncountable number of A_e.

For discrete universes of discourse X and U *an embedded Type-1 set* A_e has N elements, one each from $J_{x_1}, J_{x_2}, ...J_{x_N}$, namely $u_1, u_2, \ldots\ldots u_N$, (Mendel 2002b), i.e.,

$$A_e = \sum_{d=1}^{N} u_d / x_d \quad u_d \in J_{x_d} \subseteq \mathrm{U} = [0,1] \tag{8}$$

There is a total of $\prod_{d=1}^{N} M_d A_e$ (Mendel 2002a).

It has proven by Mendel and John (2002a) that a Type-2 fuzzy set $\tilde{A}$ can be represented as the union of its Type-2 embedded sets, i.e.,

$$\tilde{A} = \sum_{l=1}^{n''} \tilde{A}_e^l \quad \text{where } n'' \equiv \prod_{d=1}^{N} M_d \tag{9}$$

Figure 2a shows three Type-1 fuzzy sets (*Very Very Low, Very Low and Low*) used to express in detail the different fuzzy levels of Low for an input to the FLS. In Figure 2b notice that the Type-1 fuzzy sets for *Very Very Low*, *Very Low and Low* are embedded in the interval Type-2 fuzzy set *Low*, not only this but there is a large number of other embedded Type-1 fuzzy sets (uncountable for continuous universes of discourse).

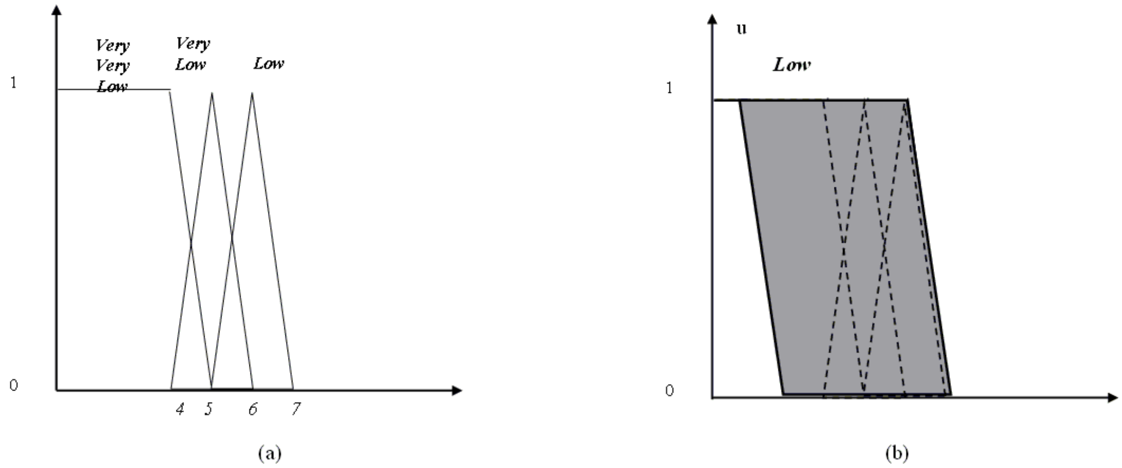

Figure 2. a) Three Type-1 fuzzy sets representing an input to the FLS. b) The three Type-1 fuzzy sets in Figure 2a are embedded in the LOW Type-2 fuzzy set

2.1.3. Interval Type-2 Fuzzy Sets

In Eq. (3) when $f_x(u) = 1,\ \forall u \in J_x \subseteq [0,1]$, then the secondary membership functions are interval sets, and, if this is true for $\forall x \in X$, we have the case of an *interval Type-2 membership function* which characterizes the interval Type-2 fuzzy sets. Interval secondary membership functions reflect a uniform uncertainty at the primary memberships of x. Interval Type-2 sets are very useful when we have no other knowledge about secondary memberships (Liang 2000). The membership grades of the interval Type-2 fuzzy sets are called “interval Type-1 fuzzy sets”. Since all the memberships in an interval Type-1 set are unity, in the sequel, an interval Type-1 set is represented just by its domain interval, which can be represented by its left and right end-points as $[l, r]$ (Liang 2000). The two end-points are associated with two Type-1 membership functions that are referred to as *Lower MF (LMF)* and *Upper MF (UMF)* ($\underline{\mu}_{\tilde{A}}(x), \overline{\mu}_{\tilde{A}}(x)$) (Liang 2000).

Bibliography

S. Coupland, M. Gongora, R. John, K. Wills, (2006) "A Comparative Study of Fuzzy Logic Controllers for Autonomous Robots" *Proceedings of the 2006 Information Processing and Management of Uncertainty in Knowledge-based Systems conference*, pp. 1332-1339, Paris, France, 2006.[This presents a comparative study or type-1, interval type-2 and general type-2 Fuzzy Logic Controllers for Mobile Robors]

J. Figueroa, J. Posada, J. Soriano, M. Melgarejo and S. Roj, (2005) "A Type-2 fuzzy logic controller for tracking mobile objects in the context of robotic soccer games," *Proceeding of the 2005 IEEE International Conference on Fuzzy Systems*, pp. 359-364, Reno, USA, May 2005. [This provides a type-2 fuzzy logic controller for simulated robotic soccer games]

H.Hagras, (2004) "A Hierarchical Type-2 Fuzzy Logic Control Architecture for Autonomous Mobile Robots". *IEEE Transactions on Fuzzy Systems*, Vol.12, pp. 524-539, April 2004. [This provides the first type-2 fuzzy logic hierarchical control structure applied for real world control of mobile robots]

H. Hagras, (2007a) "Type-2 FLCs: A new Generation of Fuzzy Controllers", *IEEE Computational Intelligence Magazine*, Vol. 2, No. 1, pp. 30-43, February 2007**.**[This provides a survey of type-2 fuzzy logic control applications up to year 2007]

H. Hagras, F. Doctor, A. Lopez, V. Callaghan, (2007b) "An Incremental Adaptive Life Long Learning Approach for Type-2 Fuzzy Embedded Agents in Ambient Intelligent Environments", IEEE Transactions on Fuzzy Systems, Vol. 15, No.1, pp.41-55, February 2007. [This provides a type-2 fuzzy agents for Ambient Intelligent Environments]

S. Huang, Y. Chen, (2005) "VLSI Implementation of Type-2 Fuzzy Inference Processor" Proceedings of the IEEE International Symposium on Circuits and Systems, pp. 3307— 3310, 2005. [This provides a VLSI Implementation of Type-2 Fuzzy Inference Processor]

E. Jammeh, M. Fleury, C. Wagner, H. Hagras, M. Ghanbari, (2009) "Interval Type-2 Fuzzy Logic Congestion Control for Video Streaming across IP Networks", *IEEE Transaction on Fuzzy Systems*, pp.1123-1142, Vol. 17, No.5, October 2009. [This provides a type-2 fuzzy logic controller for Video Streaming across IP Networks]

C. Lee, M. Wang, H. Hagras, (2010) "A Type-2 Fuzzy Ontology and its Application to Personal Diabetic Diet Recommendation**",** *IEEE Transactions on Fuzzy Systems*, Vol. 18, No.2, pp.374-395, April 2010. [This provides a type-2 fuzzy ontology for personal diabetic diet recommendation]

Q. Liang, and J. Mendel, (2000) "Interval Type-2 fuzzy logic systems: theory and design," *IEEE Transactions on Fuzzy Systems*, Vol. 8, pp. 535-550, October 2000. [This presents the interval type-2 fuzzy logic systems theory and design]

P.Lin, C. Hsu, T. Lee, (2005) "Type-2 Fuzzy Logic Controller Design for Buck DC-DC Converter" *Proceedings of the 2005 IEEE International Conference on Fuzzy Systems*, pp. 365-2370, Reno, USA, 2005. [This presents a type-2 fuzzy logic controller for Buck DC-DC Converter]

C. Lynch. H. Hagras and V. Callaghan, (2006) "Using uncertainty bounds in the design of an embedded real-time Type-2 neuro-fuzzy speed Controller for marine diesel engines," *Proceeding of the 2006 IEEE International Conference on Fuzzy Systems*, pp. 7217-7224, Vancouver, Canada, July 2006. [This presents a neuro type-2 fuzzy logic controllers which avoids using type-reduction with application to marine diesel engines]

C. Lynch, H. Hagras, V. Callaghan, **(**2007**)** " Parallel Type-2 Fuzzy Logic Co-Processors for Engine Management" *Proceedings of the 2007 IEEE International Conference on Fuzzy Systems*, pp. 907—912, London, UK, 2007. [This presents type-2 fuzzy logic co-processors for marine diesel engine management]

M. Melgarejo, A. Garcia, C. Pena-Reyes, C, (2004) "Pro-Two: A Hardware Based Platform for Real Time Type-2 Fuzzy Inference. *Proceedings of the IEEE International Conference on Fuzzy Systems*, pp.977—982, Budapest, Hungary, 2004 [This provides a hardware implementation of a type-2 fuzzy logic controller]

J. Mendel (2001), Uncertain Rule-Based Fuzzy Logic Systems: Introduction and New Directions, Upper Saddle River, NJ: Prentice- Hall, 2001. [This presents a comprehensive review of type-2 fuzzy logic systems]

J. Mendel, R. John, (2002a) "Type-2 fuzzy sets made simple," *IEEE Transactions on Fuzzy Systems*, Vol. 10, pp. 117-127, April 2002. [This presents the representation theorem to simplify the representation of type-2 fuzzy sets]

J. Mendel, H. Wu, (2002b) "Uncertainty versus choice in rule-based fuzzy logic systems," *Proceedings of IEEE International Conference on Fuzzy Systems*, pp. 1336-1342, Honolulu, USA, 2002. [This presents uncertainty handling issues in rule-based fuzzy systems]

R.Sepúlveda, O. Castillo, P. Melin, A. Diaz, O. Montiel, (2005) “Handling Uncertainty in Controllers Using Type-2 Fuzzy Logic” *Proceeding of the 2005 IEEE International Conference on Fuzzy Systems*, pp. 248-253, Reno, USA, 2005. [This presents an approach for handling uncertainties in type-2 fuzzy logic controllers]

C. Wagner, H. Hagras, (2010) “Towards General Type-2 Fuzzy Logic Systems based on zSlices”, *IEEE Transactions on Fuzzy Systems*, Vol.18, No.4 pp.637-660, August 2010. [This presents an approach to simplify the representation of general type-2 fuzzy systems to enable their real-time performance]

H. Wu, J. Mendel, (2002) “Uncertainty Bounds and Their Use in the Design of Interval Type-2 Fuzzy Logic Systems” *IEEE Transactions on Fuzzy Systems*, Vol. 10, pp. 622-639, 2002 [This presents a method to approximate type-reduction in type-2 fuzzy logic systems]

Wu and W. Tan, (2004) “Type-2 fuzzy logic controller for the liquid-level process” *Proceeding of the 2004 IEEE International Conference on Fuzzy Systems*, pp. 248-253, Budapest, Hungary, July 2004. [This presents a type-2 fuzzy logic controller for the liquid-level process]

D. Wu, W.Tan, (2005) “Type-2 FLS Modeling Capability Analysis”, *Proceeding of the 2005 IEEE International Conference on Fuzzy Systems*, pp. 242-247, Reno, USA, May 2005. [This presents a theoretical analysis of the type-2 fuzzy logic systems]

F. Zarandi, B. Turksen, T. Kasbi, (2007) “Type-2 Fuzzy Modeling for Desulphurization of Steel Process” *Expert Systems with Applications*, Vol. 32, No. 1, 157—171, 2007. [This presents a type-2 fuzzy logic systems for application in the steel industry]

Biographical Sketch

Prof. Hani Hagras is a Professor of Computational Intelligence, the School of Computer Science and Electronic Engineering, Director of the Computational Intelligence Centre and the Head of the Fuzzy Systems Research Group in the University of Essex, UK.

His major research interests are in computational intelligence, notably Type-2 fuzzy systems, fuzzy logic, neural networks, genetic algorithms, and evolutionary computation. His research interests also include ambient intelligence, pervasive computing and intelligent buildings. He is also interested in embedded agents, robotics and intelligent control.

He has authored more than 200 papers in international journals, conferences and books. His work has received funding that totaled to about £4 Million in the last five years from the European Union, the UK Technology Strategy Board (TSB), the UK Department of Trade and Industry (DTI), the UK Engineering and Physical Sciences Research Council (EPSRC), the UK Economic and Social Sciences Research Council (ESRC), Higher Education Funding Council for England (HEFCE), the German Federal Ministry of Education and Research (IB-BMBF), the Taiwan National Science Foundation, the Korea- UK S&T fund as well as several industrial companies including. He has also three industrial patents in the field of computational intelligence and intelligent control.

He is a Fellow of the Institution of Engineering and Technology (IET (IEE)) and a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE). He served as the Chair of IEEE Computational Intelligence Society (CIS) Senior Members Sub-Committee. He served also as the chair of the IEEE CIS Task Force on Intelligent Agents. He is currently the Chair of the IEEE CIS Task Force on Extensions to

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His research has won numerous prestigious international awards where most recently he was awarded by the IEEE Computational Intelligence Society (CIS), the Outstanding Paper Award in the IEEE Transactions on Fuzzy Systems. He was also the Chair of the IEEE CIS Chapter that won the 2010 IEEE CIS Outstanding Chapter award. In addition, he was awarded the IET Knowledge Networks Award. His work with IP4 Ltd has won the 2009 Lord Stafford Award for Achievement in Innovation for East of England.

He is an Associate Editor of the IEEE Transactions on Fuzzy Systems. He is also an Associate Editor of the International Journal of Robotics and Automation, the Journal of Cognitive Computation, the Journal of Applied Computational Intelligence and Soft Computing and the Journal of Ambient Computing and Intelligence. He served also as a guest editor in the Journal of Information Sciences and the Journal of Ubiquitous Computing and Intelligence.

He is a member of the IEEE Computational Intelligence Society (CIS) Fuzzy Systems Technical Committee. He is also a member of the IEEE Industrial Electronics Society (IES) Technical Committee of the Building Automation, Control and Management. In addition he served member of the Executive Committee of the IET Robotics and Mechatronics Technical and Professional Network.

Prof. Hagras chaired several international conferences where most recently he served as the Progarmme Chair of the 2010 International Conference of Intelligent Systems Design and Applications (ISDA 2010). He is also acting as the General Co-Chair of the 2011 IEEE Symposium on Intelligent Agents, and the 2011 IEEE International Symposium on Advances to Type-2 Fuzzy Logic Systems. He was also the General Co-Chair of the 2007 IEEE International Conference on Fuzzy systems London, July 2007 and he also served as Programme Chair for the 2008 IET International Conference on Intelligent Environments, Seattle, USA and he served as the Programme Chair of 2009 IEEE Symposium on Intelligent Agents, Nashville, USA, April 2009 and he served also a Programme Area Chair (control) for the 2009 IEEE International Conference on Fuzzy Systems, Jeju Island, Korea, August 2009. He was also the Programme Chair for the 2008 IET International Conference on Intelligent Environments, Seattle, USA and, the Programme Chair for the 2007 IET International Conference on Intelligent Environments, Ulm, Germany, September 2007. He served as a member of the international program committees of numerous international conferences.