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3D FUZZY LOGIC SYSTEMS FOR SPATIO- TEMPORAL APPLICATION

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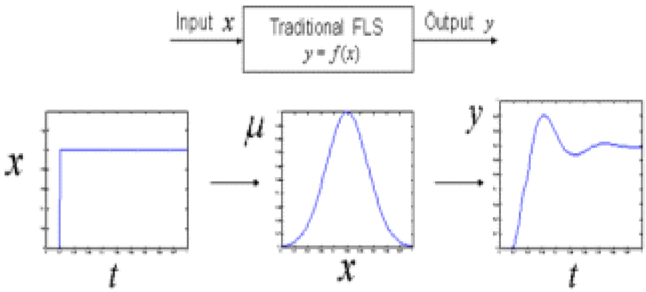
***Abstract*—Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence. The traditional,fuzzy logic system (FLS) can only model and control the process in two-dimensional nature. Many real-world systems are of multi-dimensional features, such as, thermal & fluid processes with spatio-temporal dynamics, biological systems or decision-making processes that contain stochastic and imprecise uncertainties. These types of systems are difficult for the traditional FLS to model and control because they require a third dimension for spatial or probabilistic information. The type-2 fuzzy set provides the possibility to develop a three-dimensional fuzzy logic system for modelling and control of these processes in three-dimensional nature.**

This paper describes two computer-aided design (CAD) tools for automatic synthesis of fuzzy logic-based inference systems. The tools share a common architecture for efficient hardware implementation of fuzzy modules, but are based on two different design strategies. One of them is focused on the generation of standard VHDL code, which can be later implemented on FPGA[6]. The other one uses the MATLAB/Simulink environment and tools for development of digital signal processing (DSP) systems on Xilinx's FPGAs. Both tools are included in the last version of Xfuzzy, which is a specific environment for designing complex fuzzy systems.

Index Terms*—*Computer-aided design (CAD) tools, fuzzy inference systems, spatio-temporal process

I. INTRODUCTION

The success of fuzzy logic in the last decade of the past century caused the development of many tools dedicated to the design of fuzzy inference systems. FUZZY logic provides an adequate tool to deal with the uncertainty and imprecision those are typical of the reasoning system used by the human brain. The traditional, fuzzy logic system (FLS) provides a nonlinear mapping from input x to output y [1] and further improves its performance with the neural learning. In reality, many of industrial processes have multi-physical dimensions or variables that need to handle. For example, the complex stochastic process requires a third dimension for stochastic information; and many industrial processes are of spatio- temporal nature, often called "distributed parameter systems (DPS)", which require a third dimension to spatial information. The traditional,fuzzy system will find its difficulty in modelling and control of these three-dimensional (3D) systems. A completely new configuration of FLS is needed for these applications It can be seen as a two- dimensional temporal system in Figure1.



(x - input; y - output; μ - fuzzy grade; t - time)
Figure 1: Input-output mapping of a traditional FLS

A new configuration of fuzzy systems, called the Type-2 FLS was introduced by the end of last decade to handle the uncertainty of linguistic expression. This type-2 fuzzy set consists of two traditional fuzzy sets, which were used by the type-2 FLS for processing uncertainties of the uncertainty. The type-2 FLS has been applied in various applications including mobile robots and environment control [1]. An interval type-2 FLS was developed later to reduce its computational complexity. Thus, a three-dimensional fuzzy logic system (3D-FLS) can be produced as shown in Figure 2 based on the concept of type-2 fuzzy system.

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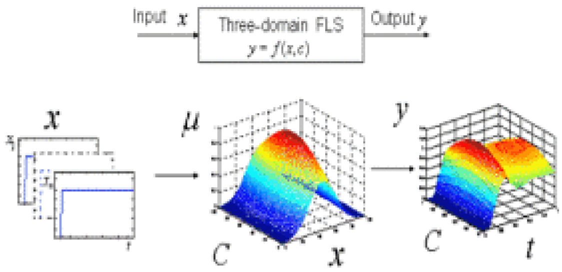

(x – input; y – output; μ – fuzzy grade; t – time; c – 3rd domain)
Figure 2: Input-output mapping of a 3D FLS

II. ACTIVE-RULE-BASED ARCHITECTURE FOR FUZZY SYSTEM

From an implementation point of view, a fuzzy system is composed of three stages: fuzzification, inference, and defuzzification. The fuzzification stage is in charge of accepting the inputs to the inference system and evaluating the similarity degree between these inputs and the membership functions associated with the linguistic labels used in the rule antecedents. The inference engine evaluates the different rules in the knowledge base. The activation degree of each rule is calculated from the activation degree of its antecedents and according to the interpretation of the different connectives in use. Finally, the conclusions of the different rules are combined, and the defuzzification stage is used to provide the output of the inference system[2]. The implementation scheme followed by both automatic synthesis tools is based on the architecture shown in Fig. 3.

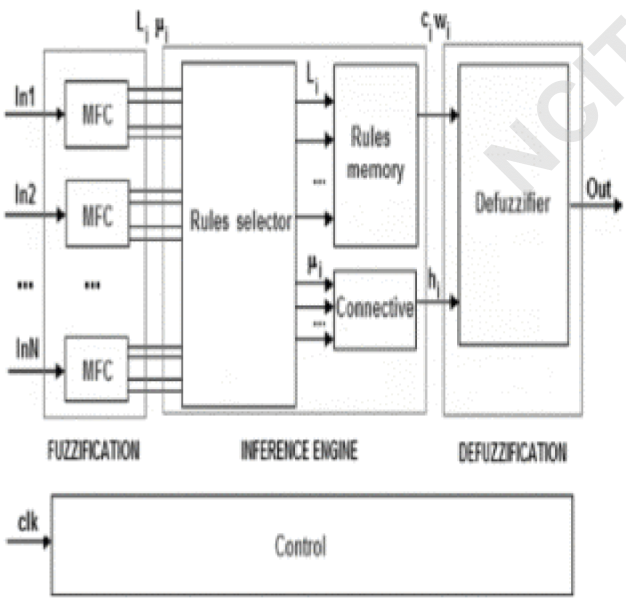

Figure 3: Architecture for a Mamdani's type fuzzy system with a processing strategy based on active rules

III. MEMBERSHIP FUNCTIONS AND RULE BASE

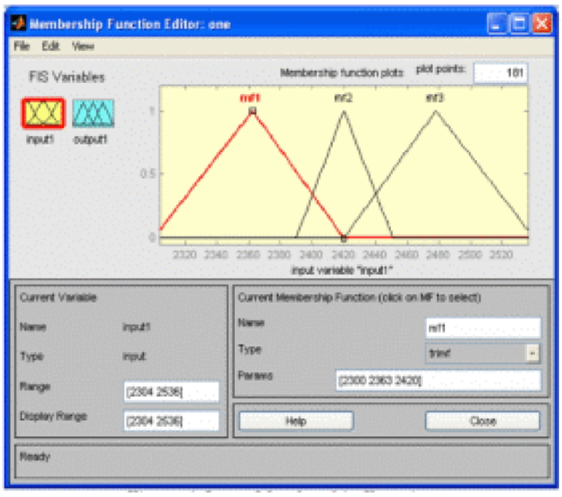

Figure 4: Input membership function

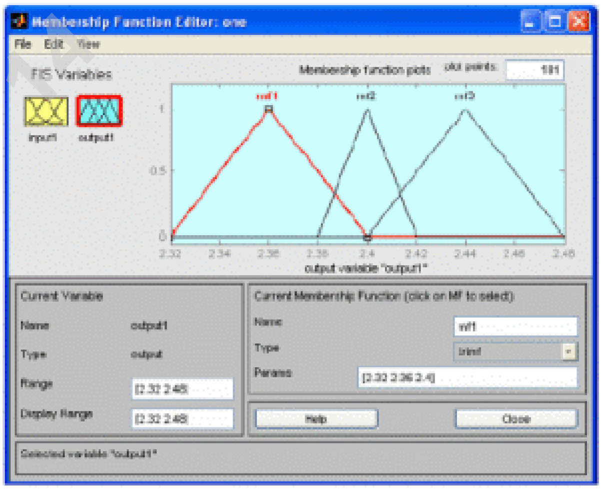

Figure 5: Output membership function

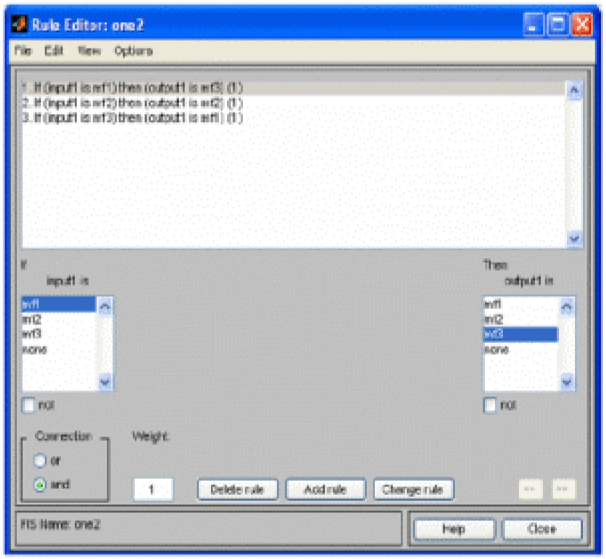

Figure 6: Rule base

IV. METHODOLOGY

1. CONCEPTUAL DEVELOPEMENTOF TRADITIONAL FUZZY LOGIC SYSTEMS

The traditional FLS will find its difficulty in modelling of this complex process with both fuzzy and stochastic uncertainties.

(i) Fuzzy uncertainty – it usually comes from the coarse measurement or imprecise perception of the process due to the harsh industrial environment.

(ii) Stochastic variations - This is the nature of the universe.

The external disturbance, insufficient sampling data, and missing dynamics, will make the situation worse. The block diagram for traditional FUZZY LOGIC SYSTEM is shown below in figure6. FLC (FUZZY LOGIC CONTROLLER) consists of an input stage, a processing stage, and an output stage [3]. The input stage maps sensor or other inputs, such as switches to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

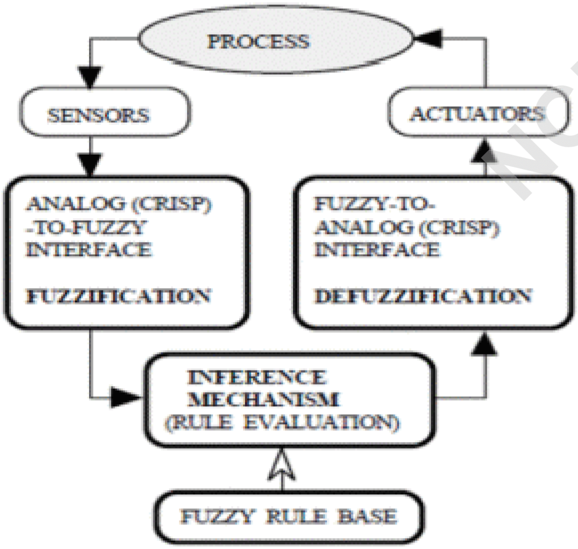

Figure 6: Traditional fuzzy logic system

2. CONCEPTUAL DEVELOPEMENT OF 3D FUZZY LOGIC SYSTEMS

Based on the development principle described previously, the 3-Dimensional Probabilistic fuzzy logic systems (3D-PFLS) are designed to have similar functions to the traditional FLS[4]. A potential configuration of 3D-PFLS has probabilistic fuzzification, rule base, probabilistic/fuzzy inference engine and probabilistic defuzzification, as shown in Figure.7. Different to the ordinary FLS, the PFLS uses the probabilisticfuzzy set (PFS) to express the informationwith stochastic uncertainties [5].

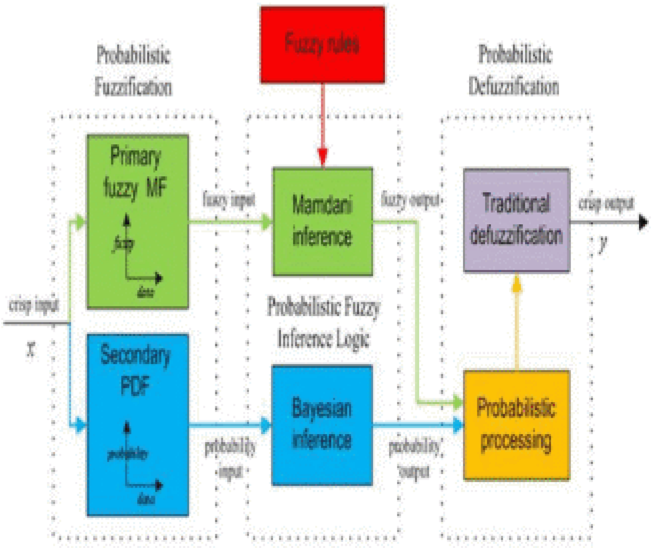

Figure 7: Block diagram of 3D fuzzy logic system

(i) PROBABILISTIC FUZZIFICATON

The significant difference of PFLS to FLS is that the fuzzification procedure is based on PFS instead of ordinary fuzzy sets. The primary MF will be fuzzy function and the secondary one will be designed as aPDF as in Figure.7. Formation of these two will establish a 3D-MF to express both fuzzy and stochastic information.

(ii) PROBABILISTICFUZZY INFERENCE

In the earlier version of PFLS, the Mamdani inference engine was modified to include the probabilistic reasoning using Bayesian inference, which works well under complete dynamics. Since the secondary PDF is obtained from data learning, which always contains incomplete dynamics, the Bayesian inference may not be able to provide reliable reasoning under incomplete PDF. The most critical problem is how to integrate fuzzy reasoning and probabilistic reasoning in a more rigorous and logic way. The exponential growth of rules for multi-variables is also an important issue to address.

(iii) PROBABILISTIC DEFUZZIFICATION

The existing work has integrated the expectation and centroid computation together for stochastic and fuzzy information to develop the crisp output, where the probabilistic defuzzification improves the traditional Defuzzification method with the probabilistic processing method. For the decision-making system, a defuzzfication mechanism that provides a 3D output in probabilistic distribution would be useful to extract rules in probability of data.

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3. 3D FUZZY LOGIC CONTROLLER FOR SPATIO-TEMPORAL PROCESS

In the real world, many industrial processes and systems are spatio-temporal dynamic processes called Distributed parameter system. The distinguished features of this kind of process are that the states, controls and outputs depend on the spatial position. The configuration of the FLC is designed to have the inherent ability to deal with spatial information as shown in Figure 8.

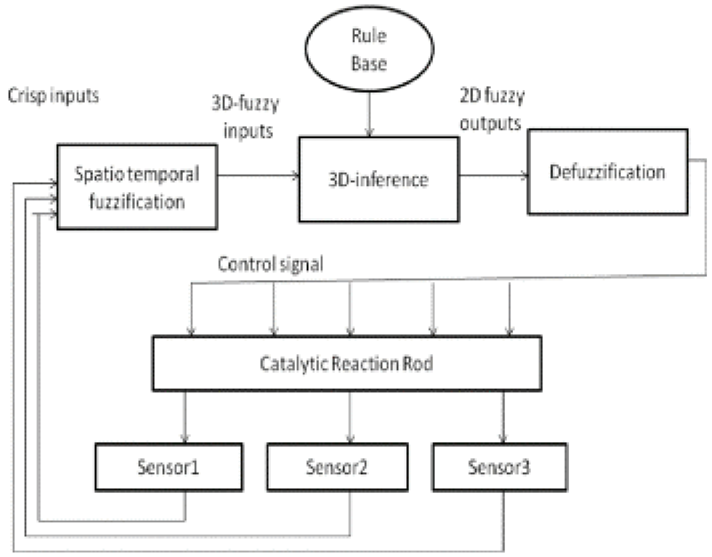

Figure 8: 3D fuzzy logic controller for spatio-temporal process

A catalytic reaction rod is a long, thin rod in a reactor as shown in Figure 8. A zeroth order exothermic catalytic reaction takes place on the rod. Since the reaction is exothermic, a cooling medium that is in contact with the rod is used to control its temperature. The long and thin rod is a typical distributed parameter system with temperature varying temporally and spatially. The rod temperature is unstable without control as shown in Figure 8.

V. RESULTS

The traditional FLC will find it difficult to stabilize the process over the whole spatial domain as shown in Figure 9

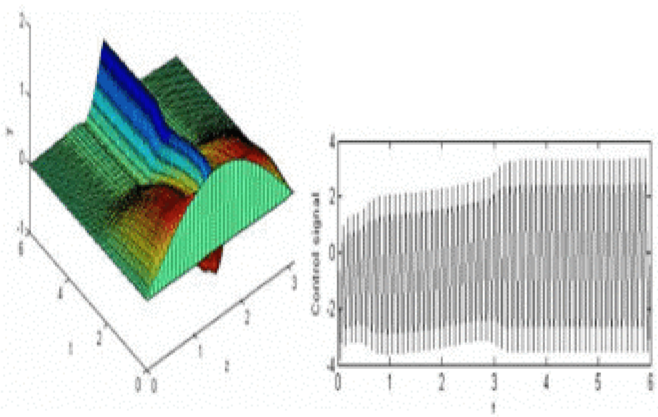

Figure 9: Unsatisfactory performance of the traditional FLC

However, the proposed 3D FLC can stabilize the rod temperature easily and achieve satisfactory performance as shown in Figure 10.

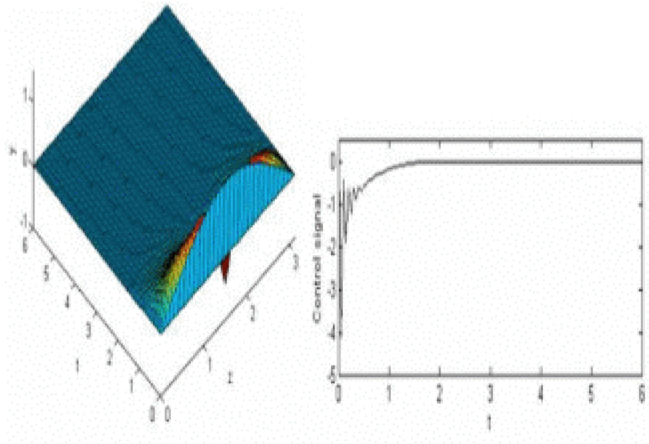

Figure 10: Satisfactory performance from 3D FLC.

VI. CONCLUSION

The proposed 3D fuzzy systems have good potential to a wide range of real-world applications because the stochastic variation is the nature of the universe and spatio-temporal dynamics widely exist. The 3D output of FUZZY LOGIC SYSTEM will be extremely useful for the decision-making of the expert system. Thus type-2 fuzzy set provides the possibility to develop a three-dimensional fuzzy logic system for modeling and control of these processes in three-dimensional nature.

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