Integrated development platform for intelligent control systems based on type-2 fuzzy logic

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Abstract

Uncertainty is an inherent part in controllers for real world applications. The use of new methods for handling incomplete information is of fundamental importance in engineering applications. This work deals with the creation of an integrated development platform for intelligent control systems based on type-2 fuzzy sets. The principal idea with this platform is to give the user a tool to realize an "on-line" and 'off-line" comparative analysis between type-1 Fuzzy Logic Control (FLC), and type-2 FLC, of the systems' response in the presence of uncertainty.

Keywords: Type-1 fuzzy logic, Type-2 fuzzy controller, ISE, IAE, ITA.

1. Introduction

Uncertainty affects all decision making and appears in a number of different forms. The concept of information is fully connected with the concept of uncertainty, the most fundamental aspect of this connection is that uncertainty involved in any problem-solving situation is a result of some information deficiency, which may be incomplete, imprecise, fragmentary, not fully reliable, vague, contradictory, or deficient in some other way [1]. The general framework of fuzzy reasoning allows handling much of this uncertainty, fuzzy systems employ type-1 fuzzy sets, which represents uncertainty by numbers in the range [0, 1] [2]. However, when something is uncertain, like a measurement, it is difficult to determine its exact value, and of course type-1 fuzzy sets makes more sense than using crisp sets, but it is not reasonable to use an accurate membership function for something uncertain, so in this case what we need is another type of fuzzy sets, those which are able to handled uncertainties, the so called type-2 fuzzy sets [3-4]. So, the amount of uncertainty in a system can be reduced by using type-2 fuzzy logic because it offers better capabilities to handle linguistic uncertainties by modeling vagueness and unreliability of information.

This work deals with the creation of an integrated development platform for intelligent control systems based on type-2 fuzzy sets. The principal idea with this platform is to give the user a tool to realize a comparative study between type-1 FLC, and type-2 FLC, of the systems' response in the presence of uncertainty.

2. Type-1 Fuzzy controller

In the 40's and 50's, many research works proved that many dynamic systems can be mathematically modeled using differential equations. These previous works represent the foundations of the Control theory which, in addition with the Transform theory, provided an extremely powerful means of analyzing and designing control systems [5]. These theories were being developed until the 70's, when the area was called System theory to indicate its definitiveness. Its principles have been used to control a very big amount of systems taking mathematics as the main tool to do it during many years. Unfortunately, in too many cases this approach could not be sustained because many systems have unknown parameters or highly complex and nonlinear characteristics that make them not to be amenable to the full force of mathematical analysis as dictated by the Control theory [6,7].

Soft computing techniques have become a research topic, which are applied in the design of controllers. They have tried to avoid the commented drawbacks, and they allow us to obtain efficient controllers, which utilizes the human experience in a more related form than the conventional mathematical approach. In the cases in which a mathematical representation of the controlled systems cannot be obtained, the process operator should be able to express the relationships existing in them, that is, the process behavior.

3. Type-2 Fuzzy controllers

A Fuzzy Logic System (FLS), described using at least one type-2 fuzzy set is called a type-2 FLS. Type-1 FLSs are unable to directly handle rule uncertainties, because they use type-1 fuzzy sets that are certain. On the other hand, type-2 FLSs, are very useful in circumstances where it is difficult to determine an exact certainties, and measurement uncertainties [3].

It is known that type-2 fuzzy sets let us to model and to minimize the effects of uncertainties in rule-based FLS. Unfortunately, type-2 fuzzy sets are more difficult to use and understand than type-1 fuzzy sets; hence, their use is not widespread yet. In [3] were mentioned at least four sources of uncertainties in type-1 FLSs:

1. The meanings of the words that are used in the antecedents and consequents of rules can be uncertain (words mean different things to different people).
2. Consequents may have histogram of values associated with them, especially when knowledge is extracted from a group of experts who do not all agree.
3. Measurements that activate a type-1 FLS may be noisy and therefore uncertain.
4. The data used to tune the parameters of a type-1 FLS may also be noisy.

All of these uncertainties translate into uncertainties about fuzzy set membership functions. Type-1 fuzzy sets are not able to directly model such uncertainties because their membership functions are totally crisp. On the other hand, type-2 fuzzy sets are able to model such uncertainties because their membership functions are themselves fuzzy. A type-2 membership grade can be any subset in [0,1], the primary membership, and corresponding to each primary membership, there is a secondary membership (which can also be in [0,1]) that defines the possibilities for the primary membership. A type-1 fuzzy set is a special case of a type-2 fuzzy set; its secondary membership function is a subset with only one element, unity.

A type-2 FLS is again characterized by IF-THEN rules, but its antecedent or consequent sets are now type-2. Type-2 FLSs, can be used when the circumstances are too uncertain to determine exact membership grades such as when training data is corrupted by noise. In our case, we are simulating that the instrumentation elements (instrumentation amplifier, sensors, digital to analog, analog to digital converters, etc.) are introducing some sort of unpredictable values in the collected information.

In the case of the implementation of the type-2 FLC, we have the same characteristics as in type-1 FLC, but we used type-2 fuzzy sets as membership functions for the inputs and for the output. In [15, 16], we can see some examples of application of type-2 FLC.

4. Performance criteria

For evaluating the transient closed-loop response of a computer control system we can use the same criteria that normally are used for adjusting constants in PID (Proportional Integral Derivative) controllers. These are [8]:

1. Integral of Square Error (ISE).
$$ISE = \int [e^2]\, dt \quad (1)$$
2. Integral of the Absolute value of the Error (IAE).
$$IAE = \int |e|\, dt \quad (2)$$
3. Integral of the Time multiplied by the Absolute value of the Error (ITAE).
$$ITAE = \int t|e|\, dt \quad (3)$$

Similar to a type-1 FLS, a type-2 FLS includes fuzzifier, rule base, fuzzy inference engine, and output processor.

The output processor includes type-reducer and defuzzifier; it generates a type-1 fuzzy set output (from the type-reducer) or a crisp number (from the defuzzifier).

The selection of the criteria is depending on the type of response desired, the errors will contribute different for each criterion, so we have that large errors will increase the value of ISE more heavily than to IAE. ISE will favor responses with smaller overshoot for load changes, but ISE will give longer settling time. In ITAE, time appears as a factor, and therefore, ITAE will penalize heavily errors that occurs late in time, but virtually ignores errors that occurs early in time. Designing using ITAE will give us the shortest settling time, but it will produce the largest overshoot among the three criteria considered. Designing considering IAE will give us an intermediate results, in this case, the settling time will not be so large than using ISE nor so small than using ITAE, and the same applies for the overshoot response. The selection of a particular criterion is depending on the type of desired response.

5. Platform Development

The integrated platform development for teaching and develop applications on real time is based on MATLAB. It provides the user a type-1 fuzzy controller, and a type-2 fuzzy controller. Through this interface, it is possible to select between a real

system or an ideal one; to select a graphics mode, the time response, ISE, IA, ITAE.
It is also possible to select the input data source, for example if they are data from a file, data from a serial port (channel 1), data from a USB interface (channel 2). In a similar way it is possible to select where to save the output data, or where they are going to go.

6. Experimental Results

We have performed some tests with linear and nonlinear dynamical systems. Next we will describe one of this tests.
Using the block diagram shown in Fig. 2, as a plant or process, it was selected the plant represented by equation (4).

$$y(i) = 0.2 \cdot y(i-3) \cdot 0.7 y(i-2) + 0.9 \cdot y(i-1) + 0.005 \cdot u(i-1) + 0.5 \cdot u(i-2) \quad (4)$$

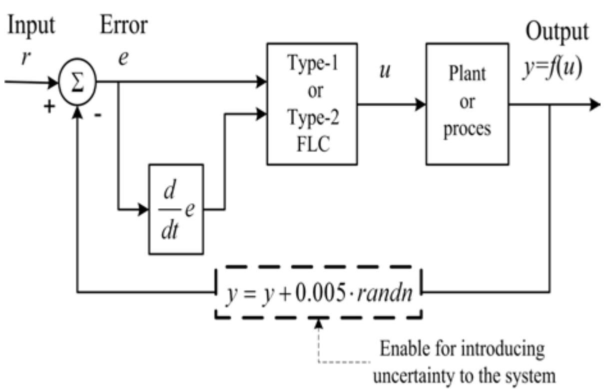

Fig.1. System used for obtaining experimental results.

In figure 2, we can observe that we are referring to type-1 and type-2 fuzzy controllers because they are used in the experiments to make a comparative study. So we have two input variables to the fuzzy controller, $e(t)$ y $\Delta e(t)$, which are defined by equations (5) and (6), respectively,

$$e(t) = r(t) - y(t) \quad (5)$$

$$\Delta e(t) = e(t) - e(t-1) \quad (6)$$

The output of the controller is applied directly to the plant. For type-1 fuzzy controller, the output is feedback directly to the input "summing". For type-2 fuzzy controller, it was utilized equation (7) to introduce uncertainty to the feedback,

$$y(i) = y(i) + 0.05 \cdot randn \quad (7)$$

In both cases, the type-1 and type-2 fuzzy controllers, were used the same values for mean and standard deviation for the gaussian member functions, with the Foot Of Uncertainty (FOU) for the type-2 membership functions. In figures 3,4, and 5 we have the membership functions for the type-2 fuzzy controller.

The system was tested using as an input a unitary step *r(i)* free of noise.

Table I, shows the values obtained for the different performance evaluation criteria (ISE, IA, ITAE) considering 400 time units. For computing ITA, it was considered $T_s = 0.1$ seconds as the sampling frequency. Next we describe the four experiments performed with this configuration.

Experiment 1. Type-1 ideal system.
It was not added uncertainty in the information to the system.

Experiment 2. Type-2 ideal system.
Here we have the same conditions as in experiment 1, but using the membership functions showed in figures 2 3and 4.

Experiment 3. Type-1 real system (with uncertainty).
The same conditions as in experiment 1, but using equation (7) in the feedback loop to add uncertainty.

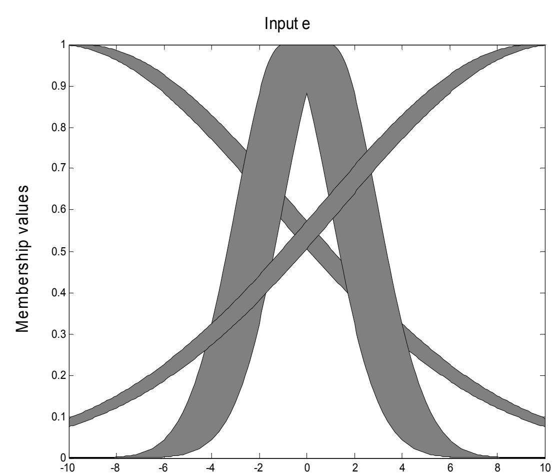

Fig 2. Type-2 membership functions for the input error (*e*).

Experiment 4. Type-2 real system (with uncertainty).
The same conditions as in experiment 2, but using equation (7) in the feedback loop to add uncertainty.

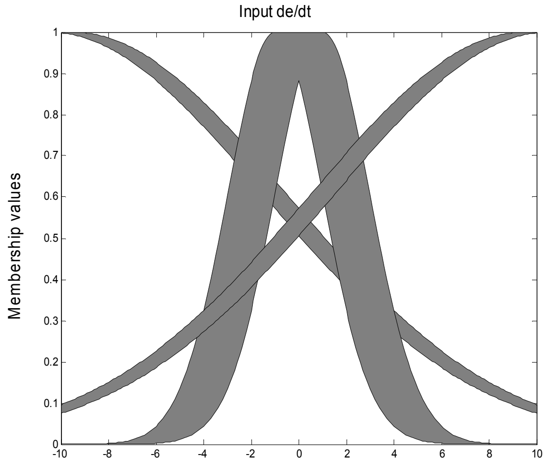

Fig.3 Type-2 membership functions for the input change of error with time .

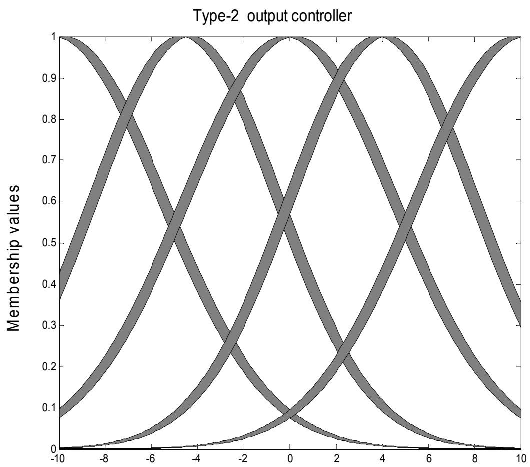

Fig.4. Type-2 membership functions for the controller's output.

Table I. Comparison of performance criteria for type-1 and type-2 fuzzy logic controllers. Values obtained after 400 samples.

Perform. criteria	Type-1 FLC		Type-2 FLC	
	Ideal system	System with uncertainty	Ideal System	System with uncertainty
ISE	5.2569	15.1143	5.4479	9.5516
IAE	13.8092	57.9542	14.2045	45.4106
ITAE	59.9589	1,111.20000	61.6360	877.5299

7. Conclusions

Through the use of the performance evaluation criteria ISE, IAE and ITAE, it was observed and quantified that in systems without uncertainty, ideal systems, using type-1 is a good option, since they perform a little better, they are easier to implement and they are faster. It is a fact that type-1 fuzzy controllers can manage non- linearities and uncertainty in some way.

For real systems where the non-linearities and uncertainty are inherent, based on our experiments and measures, we concluded that the type-2 fuzzy controllers can be a better option just for its ability to manage uncertainty. However, it is necessary to continue working in the development of efficient implementations to avoid the time limitations in the processing of certain on line applications.

At the moment, the integrated development platform for intelligent control systems based on type-2 fuzzy logic, has the ability to perform type-1 and type-2 algorithms, and others developed with analytical methods, to be part of this platform. In the real time processing, we are working in the implementation of dynamical libraries to be able to be out of MATLAB through the universal serial bus (USB).

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