Parametrized Program-interface for Simulation-based Operator Evaluation

Márta Takács

Institute of Intelligent Engineers Systems

Budapest Tech

Népszínház utca 8, H-1081 Budapest,

Hungary

takacs.marta@nik.bmf.hu

Abstract. The article analyse a system, which will be controlled by FLC, and modelled by a first order differential equation. The program language environment, applied by simulation, supports the choosing of suitable fuzzy operators and their parameters. The simulation result are analysed, depending on the efficacy of the operator choice in approximate reasoning model.

Márta Takács graduated at the University of Belgrade, Faculty of mathematics, branch: numerical mathematics and cybernetics, and she obtained the degree of Doctor of University, ELTE, specialization in informatics, and the degree of Doctor of University in mathematical logic, the title of the thesis. She obtained Master degree from the University of Novi Sad, Department of Mathematics and PhD from the University of Novi Sad, Department of Mathematics, PhD thesis title: Approximate reasoning in fuzzy system based on pseudo-analysis. Actually she serves as Deputy-manager of the Institute of Intelligent Engineering Systems, Budapest Tech, Department of Informatics Neumann János, Budapest, Bécsi út 96/b, Hungary. She is member of Neumann János Society, Hungarian Fuzzy Association and IEEE Society. She has several research papers in different international journals and proceeding of interantional conferences.

1. Introduction

Soft computing technologies have definitely brought real world models closer to direct human thought. They often use combined models where fuzzy systems combine genetic algorithms and neural network models, and partly solve the above-described problems with certain models. Genetic algorithms often intensify the adaptive character of the algorithm; neural networks intensify the efficiency and velocity. Also, these solutions require new hardware and software resources, and make the system more complicated.

Fuzzy models are user-friendly, the rule base system used in Fuzzy logic control (FLC), and approximate reasoning methods applied in decision making have excepted and schematically applied models [12], [14].The complexities described in the previous paragraph result in more and more researches [15].

One of these novel research areas, also related to in this article is the choice of operators used on fuzzy sets [5], [13], [8] . Uninorm groups, researched in the past decade, have yielded exceptionally good results [9].

The mathematical background of uninorm researches is given, but it must be born in mind that the underlying notions of soft-computing systems are flexibility and the human mind. The choice of the fuzzy environment must support the efficiency of the system, it must comply to the real world. This is more important than trying to fit the real world into the inflexible models. [1], [10], [11].

One of the other research areas is the hierarchical fuzzy control system [4]. The application of the tree-structure in decision-making in a given moment enables us to choose the most efficient system parameters and environment factors and by this achieve the desired state as soon as possible.

This article outlines the foundations of a future adaptive system, which is based on earlier research results. In this article, the distance based operators are used in approximate reasoning systems. These are parameter dependent operators, and by changing this parameter, the output in an otherwise fix systems changes drastically, as has been shown in experimental research.

The second section presents the analyzed system. The system to be controlled is modelled by a first order differential equation, $q' = k_1(y + k_2 q)$. The principles of the applied approximate reasoning system in FLC is presented.

In the next section the simulation result are analysed, depending on the efficacy of the operator choice in approximate reasoning model. A general description of a graphical interface was founded, which supports the choosing of suitable fuzzy operators and their parameters. In the next section there is also an outline on future direction of the current fuzzy control system: building a hierarchical FLC system in which other environment parameters can be adaptively changed.

2. Presentation of the Simulation System

The simulation system will be presented, in which system behavior is analyised depending on change in FLC by parameter choosing, using distance based operators.

The system was built in MATLAB-SIMULINK environment, and the programs, that substitute the FLC-s, were written in MATLAB. The SOURS is a step function (*Step Input*), with the time step 0.1 sec, with the starting value 0, and the final value 1.*e* and *y* were transformed into the interval [-1,1]. The system to be controlled is modelled by a first order differential equation, $q' = k_1\left(y + k_2 q\right)$. During the simulation all of the components of the system were fixed except the FLC. The goal is, achieving the desired (input) step function as fast is it possible. The questions are: does this function reaches 1, as well as how stable this system is.

The detailed structure of the function is as follows, shown in Figure 1.

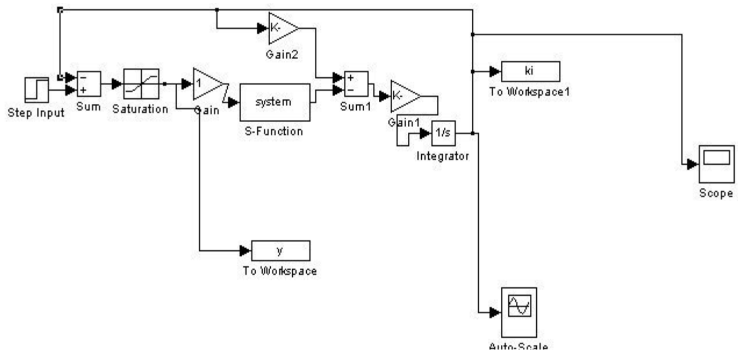

Figure 1: The SIMULINK simulation system

The S*um* element is an operator which calculates the difference between the desired step function and the system output from the previous cycle.

The task of the *Saturation* element is to slide the input value in the interval [0,1].

The *Gain* element multiplies the input as it was foreseen in the first order differential equation. The system contains two more gain elements (*Gain1, Gain2*).

The rule of the *S-function* is the most important. The S-function is a computer program written in *C* programming environment to model FLC. The program contains global variables: the operators used in approximate reasoning, and the parameter of the operators.

The *Sum1* element calculates the error for the feedback.

The *Integrator* element performs time-continuous integration of the input. The results are represented by two scopes (*Scop*e), one for system output, while the other the error. The system also includes two graphical outputs for the results of the scopes: *Auto-Scale Graph* and *Auto-Scale Graph1.*

2.1. The FLC Model

In the theory of approximate reasoning introduced by Zadeh in 1979, the knowledge of system behavior and system control can be stated in the form of if-then rules. In Mamadani-based FLC sources it was suggested to represent the i^{th} rule

$$\text{if } x \text{ is } A_i \text{ then } y \text{ is } B_i$$

simply as a connection (for example as a t-norm, $T(A_i,B_i)$ or as $min(A_i,B_i)$) between the so-called rule premise: x is A and rule consequence: y is B. The most significant differences between the models of FLC-s lie in the definition of this connection, relation or implication.

The strict modus ponens is replaced with the expectation: let be $B' \supset B$, where B' is a cut of B. That is the Generalized Modus Ponens (GMP), in which the main point is, that the inference y is B' is obtained when the propositions are:

- the i^{th} rule from the rule system of n rules: if x is A_i then y is B_i

- and the system input x is A'.

GMP sees the real influences of the implication or connection choice on the inference mechanisms in fuzzy systems. Usually the general rule consequence for one rule from the *i*-th rule base system is obtained by

$$Bi'(y)=\sup_{x\in X}(OPDis2(A'(x),OPDis2(Ai(x),Bi(y))).$$

The connection *OPDis1* and *OPDis2* are generally defined, and they can be some type of fuzzy disjunctive operators [2], [3].

However, in engineering applications the Mamdani approach is widely used, which cannot be considered as a special case of GMP, but generally satisfies conditions which are usually supposed by *approximate reasoning*.

The Mamdani inference rule states that the membership function of the consequence in the *i*-th rule B_i' is defined by

$$Bi'(y)=\sup_{x\in X}(OPDis\ (A'(x),\ OPDis\ (Ai(x),Bi(y)))$$

where *OPDis* is a fuzzy disjunctive operator.

Using the operator properties, from the above expression follows

$$Bi'(y)=OPDis\ (\sup_{x\in X}(OPDis\ (A'(x),Ai(x))),Bi(y)).$$

Generally speaking, the consequence (rule output) is given with a fuzzy set $B'(y)$, which is derived from rule consequence $B(y)$, as a cut of the $B(y)$. This cut,

$$DOF=\sup_{x\in X}(OPDis\ (A'(x),A(x))),$$

is the generalized degree of firing level of the rule, considering actual rule base input $A'(x)$, and usually depends on the covering over $A(x)$ and $A'(x)$. But first of all it depends on the *sup* of the membership function of *OPDis* $(A'(x),A(x))$.

Rule base output B'_{out} is an aggregation of all rule consequences $B_i'(y)$ from the rule base. As aggregation operator a conjunctive fuzzy operator is usually used.

$$B'_{out}(y)=$$
$$OPCon(B_n'(y), OPCon(B_{n-1}'(y), OPCon(...., OPConS(B_2'(y),\ B_1'(y))))).$$

The crisp FLC output y_{out} is constructed as a crisp value calculated with a defuzzification method, from rule base output, for example with the center of gravity method, given by

$$y_{out} = \frac{\int_Y B'_{out}(y)\cdot y dy}{\int_Y B'_{out}(y)\cdot dy}.$$

It can be concluded, that in approximate reasoning the (*OPDis, OPCon*) pair of operators are used.

2.2. The Investigated System

The rule base of the FLC, analysed in this case contains 5 rules, well-known from fuzzy applications [Yager].

The operators *OPDis* and *OPCon* are chosen from the group of distance based operators.

The distance-based operators ([6], [7]) can be expressed by means of the min and max operators as follows:

the *maximum distance minimum operator with respect* to $e \in [0,1]$ is defined as

$$\max_e^{\min} = \begin{cases} \max(x,y), & \text{if } y > 2e - x \\ \min(x,y), & \text{if } y < 2e - x \\ \min(x,y), & \text{if } y = 2e\text{-}x \end{cases}$$

the *minimum distance minimum operator* with respect to $e \in [0,1]$ is defined as

$$\min_e^{\min} = \begin{cases} \min(x,y), & \text{if } y > 2e - x \\ \max(x,y), & \text{if } y < 2e - x \\ \min(x,y), & \text{if } y = 2e\text{-}x \end{cases}$$

the *maximum distance maximum operator with respect to* $e \in [0,1]$ is defined as

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The maximum distance minimum operators are from disjunctive operators group, the minimum distance maximum operators are from conjunctive operators group.

Considering the structure of distance based operators, namely that they are constructed by the min and max; it was worth trying to move away from the strictly applied max (disjunctive) and min (conjunctive) operators pair in approximate reasoning. Therefore, in the simulation system different operators from the group of distance based operators were applied as disjunctive and conjunctive. Moreover, the distance based operators are parametrized by the parameter *e*, therefore the program (*S* -function), which performs the task of FLC in the simulation system, has global, optional, variables (*OPDis, OPCon*, *e*), where *Opdis* is the operator applied by GMP, and the *OPCon* is the aggregation operator for the calculation of the B'_{out}. The neutral element of the *OPDis* operator is parameter *e,* and the neutral element of the *OPCon* operator is parameter 1-*e.*

3. The System Behavior with Several (OPDis, OPCon, e) Triples in FLC

The simulation system was built in MATLAB-SIMULINK environment, and the program (S-function) of the FLC model in C programming language. This program runs over in every simulation step, get one crisp number from the simulation system and gives back a crisp number to the system. The possibilities of the programm are:

- choosing of the OPDis and OPCon operators from the group of the distance based operators,

- sliding of the parameter *e* of the distance based operators (in the interval [0,1]),

- sliding of the center of the fuzzy sets of rule premises and rule consequences in rules of the fuzzy rule base. The rule bases contains 5 rules.

The parameter changing program uses grafical interface and it is written in Delphi environment (Figure 2).

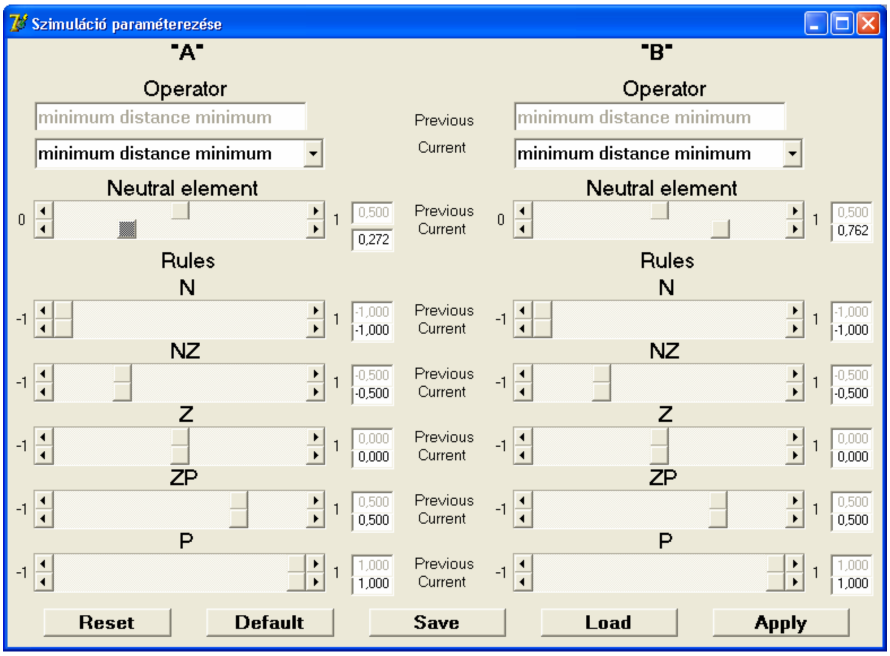

Figure 2: The grafical interface

In the grafical interface the upper scrollbars show the default values and the downer scrollbars can be changed. The Apply button gives the actual parameters to the simulation system in the S-function, and we can run the simulation with the new parameters. This program can save and load the tuned parameters and reset the parameters as the default value for the next state. This program let see the effect of the different parameter-choosing to the output and let the user to make experiments with the rules and operators.

3.1. The Simulation Results

The criteria for comparison of the simulation results are the following:

-How fast does it reach the intensity of 1?

-How precisely does it reach the intensity 1?

-How significant is the dispersion around intensity 1?

-Does the irregular behaviour repeat periodically?

If

$$(OPDis, OPCon, e) = \left(\max_e^{\min}, \min_{1-e}^{\max}, e\right),$$

$(e \neq 0{,}5)$, (case (M2.8.)) or

$$(OPDis, OPCon, e) = \left(\max_e^{\min}, \min_{1-e}^{\min}, e\right),$$

case (M2.5.), the conclusions are:

the step function does not achieve the intensity 1, but the system is stable. The time from the start to stability is cca 0.8 seconds.

If

$$(OPDis, OPCon, e) = \left(\min_e^{\max}, \min_{1-e}^{\min}, e\right),$$

$(e \neq 0{,}5)$, (case (M2.9.)) or

$$(OPDis, OPCon, e) = \left(\min_e^{\min}, \min_{1-e}^{\min}, e\right),$$

case (M2.13.), the conclusions are:

the step function from FLC output fails to reach intensity 1 again (it is cca. 0,5), yet the system is stable. The time from the start to stability is cca 0.2 seconds, the simulation process is fast.

If

$$(OPDis, OPCon, e) = \left(\min_{e}^{\min}, \max_{1-e}^{\max}, e\right),$$

$(e \neq 0{,}5)$, (case (M2.16.)) or

$$(OPDis, OPCon, e) = \left(\min_{e}^{\min}, \max_{1-e}^{\min}, e\right),$$

case (M2.11.), the conclusions are:

the step function from FLC output reaches the intensity 1 in under 0.3 seconds, following that however, the system is shows great differences. It contains such sections, where these irregular behaviours repeated.

If

$$(OPDis, OPCon, e) = \left(\max_{e}^{\max}, \max_{1-e}^{\max}, e\right),$$

$(e \neq 0{,}5)$, (case (M2.1.)) or

$$(OPDis, OPCon, e) = \left(\max_{e}^{\min}, \max_{1-e}^{\max}, e\right),$$

case (M2.7.), the conclusions are:

the step function from FLC output reaches the intensity 1, but following that the system portrays positive and negative irregularities.

If

$$(OPDis, OPCon, e) = \left(\max_{e}^{\max}, \min_{1-e}^{\min}, e\right),$$

$(e \neq 0{,}5)$, (case (M2.4.)) or

$$(OPDis, OPCon, e) = \left(\min_{e}^{\max}, \max_{1-e}^{\max}, e\right),$$

case (M2.12.), the conclusions are:

the step function from FLC output reaches the intensity 1, and the system portrays positive and negative irregularities periodically. The time from the start to stability is cca 0.3 seconds, the simulation process is fast.

If

$$(OPDis, OPCon, e) = \left(\min_{e}^{\max}, \min_{1-e}^{\max}, e\right),$$

$(e \neq 0{,}5)$, (case (M2.10.)) or

$$(OPDis, OPCon, e) = \left(\min_{e}^{\min}, \min_{1-e}^{\max}, e\right),$$

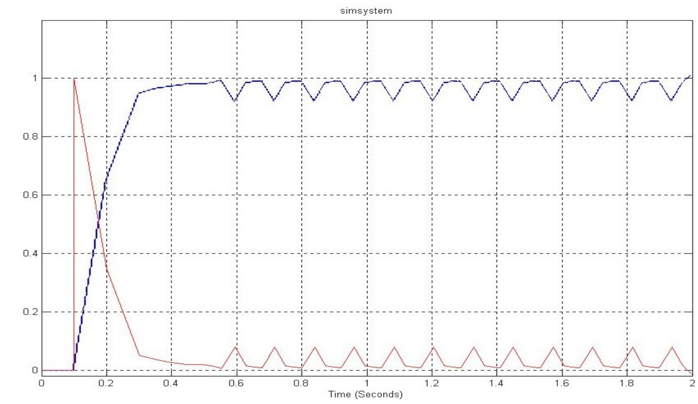

Figure 3: Case M2.3.

case (M2.14.), the conclusions are:

the step function from FLC output fails to reach intensity 1, and it is instable.

If

$$(OPDis, OPCon, e) = \left(\max_e^{\max}, \min_{1-e}^{\max}, e\right),$$

$(e \neq 0{,}5)$, (case (M2.3.)), the conclusions are:

the step function from FLC output reaches the intensity 1, and the system portrays urregularities periodically (Figure 3).

If

$$(OPDis, OPCon, e) = \left(\max_e^{\min}, \max_{1-e}^{\min}, e\right),$$

$(e = 0{,}5)$, (case (M2.6.)), the conclusions are:

the step function from FLC output reaches the intensity 1, and the system stay stable after 0,5 seconds. This choice of the parameter and operators is the best for the investigated system (Figure 4).

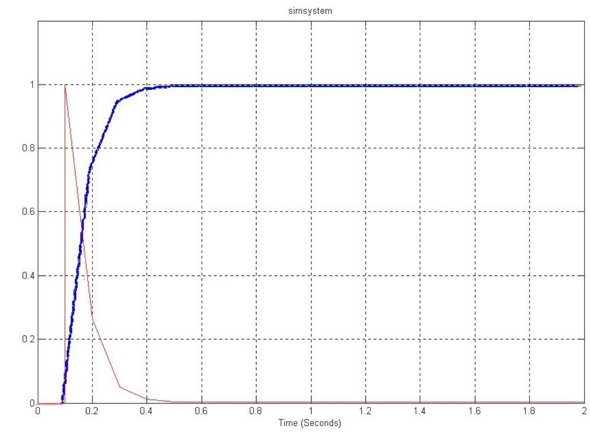

Figure 4: Case M2.6.

This shows that the output is sometimes stable, but does not have the sufficient intensity, at other times, it does have the sufficient intensity, but has a periodical irregularity. From this it can be concluded that the other elements (gains, coeficients) of the simulation system (and of the real system) can be changed to achieve the desired state in a short period of time.

4. Conclusion and the Future Direction of Building a Hierarchical FLC System

Hence and because by the simulation the triple (*OPDis, OPCon*, *e*) can be chosen by even running of the simulation system, it enables the parameters to be set at every running of the system in order to achieve greater efficiency.

In reality the other elements of the system (gains, product elements) are also system dependent and changeable and it can be expected that the operators used in FLC be tuned to these elements for greater efficiency.

In the future it must be analysed experimentally which parameters with which parametrical operators in FLC achieve the greatest effectiveness. All this could be implemented in a Fuzzy rule system which is of such type:

IF *the system elements(gains,…)* ARE …. ,

THEN *the chosen triple of operators and its parameters* IS (*OPDis, OPCon*, *e*) .

The system presented in the Section 3, from the input to the output will be the lower level of the hierarchical system, while on the upper level decisions will be made about the choice of operators in FLC depending on the temporary state of other system elements, (gains, etc.).

Based on the experimental results, it can be conclude, that in a dynamic system it is reasonable to build a hierarchical fuzzy control system. If the dynamical system has fixed construction, than depending on the different intensity of the system element (gains, multiplicators), it is possible on an upper level choose the operators, and its parameters for FLC, achieving sufficient result based on this principle.

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