FUZZY MODEL BASED CONTROL OF DYNAMIC SYSTEM

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Abstract: The paper deals with the relatively universal method of ivestigation and fuzzy description of the basic qualitative characteristics of dynamic systems. A relatively simple universal fuzzy model of a dynamic system has a firmly defined dynamic section of dynamic system, covers the whole operational area of the dynamic system and does not require a complicated procedure for determining the rules of the static fuzzy section of the fuzzy system model. This approximation can then be used as the basis for the design of simple robust adaptive regulation structures suitable for systems characterized by imprecisely defined parameters and possibly also structure. The intention of the adaptive control algorithm introduced was to enable control a dynamic system with a little previous knowledge as possible and to avoid the heuristic search for a rule-based fuzzy controller.

Key words*: dynamic system, controlled system, fuzzy model, simple fuzzy controller structure, dynamic properties, human language description*

1 Introduction

In technical practice, the systems which analytical description is very complicated and it is very hard to build up and also to determine its parameters, can occur very often. It is most often an area suitable for the application of fuzzy techniques in the modeling and control of dynamic systems, which are not based on analytical knowledge of the system being investigated, but require knowledge of its quality characteristics. These can essentially be obtained in two ways – from experts or from a database of suitably measured data of the investigated object. The latter of the two (if applicable) is much more convenient, because it does not require any experts and it can be automated. However, in the course of its application several serious problems may be encountered – the consistency of the measured data database, insufficient coverage of the whole working /operating range of the investigated equipment, requirement for a large number of rules for achieving sufficient quality of the fuzzy system, difficulties in defining the dynamic part of the fuzzy system, etc.

This paper presents a method of modeling the basic quality characteristics of common dynamic systems and its application in their control.

2 Methodics of investigating the qualitative characteristics of a dynamic system

Consider a system with a single output and **p** inputs in the form

$$\mathbf{y} = \mathbf{f}(\underline{\mathbf{x}}, \underline{\mathbf{u}}) \qquad (1)$$

Consider further that it is a stable system, i.e. that to each constant input vector $\underline{\boldsymbol{u}}$ and initial state $\mathbf{x_0}$ there relates a stabilised state of output **y**. In case of a change in the input vector $\underline{\boldsymbol{u}}$ from one constant value $\mathbf{u_1}$ to another constant value $\mathbf{u_2}$ (or, in non-linear systems, also taking into account the initial state of vector $\mathbf{x_0}$) the output value of the system will be stabilized following a transition characteristic which can essentially have an aperiodic or oscillating damped character as demonstrated in Fig.1.

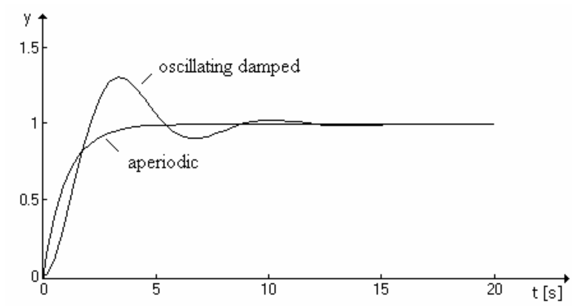

Fig. 1 Typical responses of a dynamic system to input value step

The quality of these responses is expressed in just a few parameters, such as response time, overshoot and oscillating frequency of the characteristic. Based on these simple assumptions we can model the dynamic system by a fuzzy system in accordance with Fig. 2. The dynamic part of the DS will be formed by a simple *n-th* order linear system (by transfer in the form of a rational fractional function) with variable parameters $\underline{\boldsymbol{K}}$. We will choose this subsystem in a way that it will approximate the responses of the system being modeled as closely as possible. The FS subsystem will be a static fuzzy system which will set actual parameter values of the dynamic part $\underline{\boldsymbol{K}}$ on basis of inputs $\underline{\boldsymbol{u}}$ or states $\underline{\boldsymbol{x}}$.

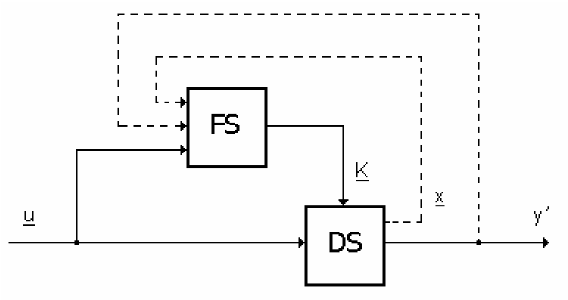

Fig. 2 Fuzzy model of dynamic system

3 Setting up a fuzzy model of a dynamic system

Let us assume that the dynamic system we want to describe using fuzzy techniques has the structure shown in Fig.3.

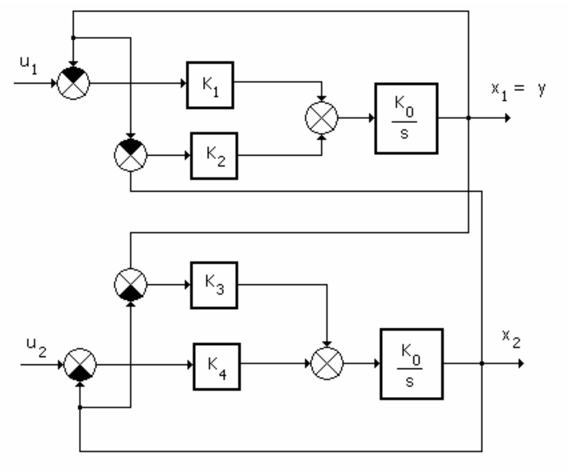

Fig. 3 Structure of a dymanic system

Let us further assume that for selected pairs of inputs of vector $\underline{\boldsymbol{u}}$ the following typical responses have been measured (Fig. 4).

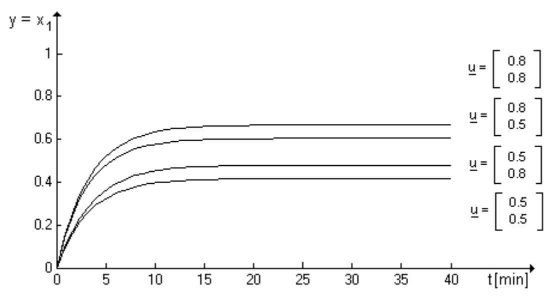

Fig. 4 Responses of the dynamic system to various values of input **u**

In terms of dynamics, a system with the responses specified in Fig. 4 can be approximated by a first order system with transfer function:

$$\mathbf{F(s)} = \frac{\mathbf{K}}{\mathbf{1 + sT}} \tag{2}$$

where **K** is the amplification of the system and **T** is the time constant of the system.

For each of these responses it is possible to determine the concrete values of parameters **K**, **T** and hence set up a table with a database of rules that describe the static part FS of the system´s fuzzy model. The values of parameters **K**, **T** are shown in Tab. 1

The rules for the FS part of the fuzzy model result directly from this table.

Tab. 1 Database for FS rules development

$\mathbf{u_1}$	$\mathbf{u_2}$	**K**	**T**
0,5	0,5	0,416	3,33
0,5	0,80	0,479	3,59
0,8	0,5	0,603	3,13
0,8	0,8	0,666	3,33

A graphic presentation of the fuzzy model areas is given in Fig. 5.

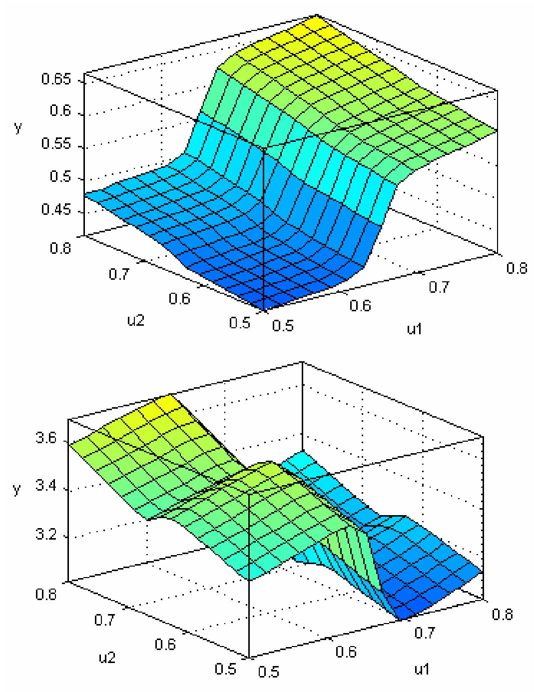

Fig. 5 Characteristic areas of the fuzzy model for the dynamic system

The structure of the fuzzy model for the dynamic system under consideration is then shown in Fig. 6.

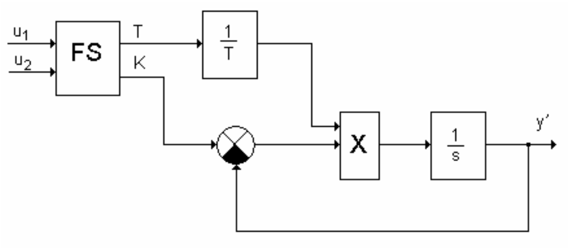

Fig. 6 Fuzzy model structure of dynamic system

The response of this model to step **u**=[0.6, 0.6] is presented in Fig. 7.

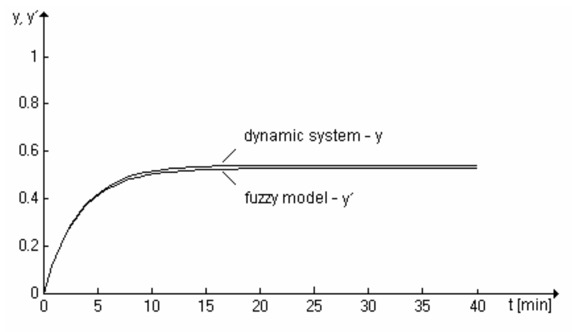

Fig. 7 Comparison of responses of dynamic system and its fuzzy model

4 Controller design based on fuzzy model

Let us assume the desired transfer function of enclosed control circuit for considered dynamic system has the form:

$$F_u(s) = \frac{1}{1 + sT_Z} \quad (3)$$

where $\mathbf{T_Z}$ is the time constant determining the control dynamics. Transfer function of dynamic system has the form (2).

The controller is of the PI type with transfer function in the form:

$$F_R(s) = K_P + \frac{K_I}{s} \quad (4)$$

where $\mathbf{K_P}$ is the amplification of the proportional part and $\mathbf{K_I}$ the amplification of the integrating part of the controller. Hence it is possible to derive relationships that describe the dependence of its parameters $\mathbf{K_P}$ and $\mathbf{K_I}$ on the actually estimated dynamic system parameters:

$$F_0 = \frac{1}{T_Z s} \quad (5)$$

$$\frac{((K_P s) + K_I).K}{s.(1 + sT)} = \frac{1}{T_Z s} \quad (6)$$

$$\frac{(\frac{K_P}{K_I} s + 1).K_I K}{s.T + 1} = \frac{1}{T_Z} \quad (7)$$

$$T = \frac{K_P}{K_I} \Rightarrow K_P = K_I.T \quad (8)$$

$$K_I K = \frac{1}{T_Z} \Rightarrow K_I = \frac{1}{T_Z K} \quad (9)$$

$$K_I = \frac{1}{T_Z.K}$$

$$K_P = K_I.T \quad (10)$$

where **K** and **T** are fuzzy estimated actual parameters of the controlled system. Fig. 8 shows a block diagram of the enclosed control circuit.

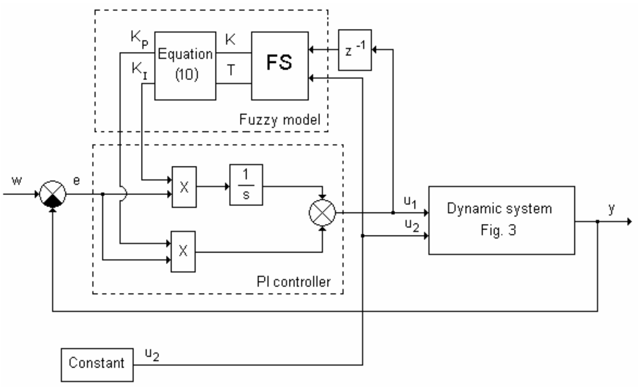

Fig. 8 Block diagram showing enclosed control circuit of dynamic system

The resulting control dynamics, assuming that $\mathbf{u_2} = 0.5$ (constant value of the second input) for selected desired values **w** and $\mathbf{T_z}$=0.5 , is shown in Fig.9

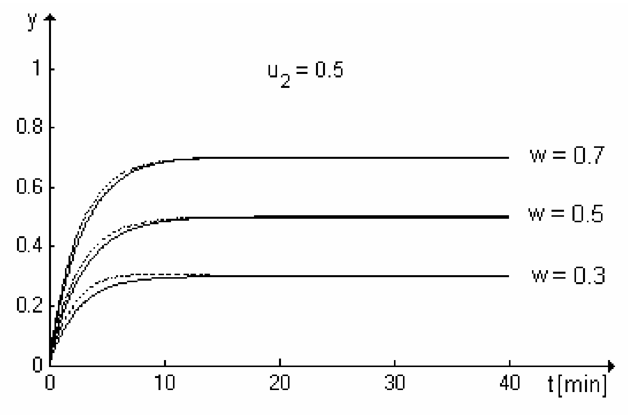

Fig. 9 Control dynamics of dynamic system

Note 1: For purpose of simplification, in the given examples we consider all values of the control circuit normalized into the range < -1,1 >, e.g. for example $y=Y/Y_N$ etc., where **Y** indicates output of the system and Y_N its nominal value.

Note 2: For comparison, the broken lines in Fig. 9 show the ideal courses of system output.

5 Evaluation and Conclusion

The paper presents a possible procedure of building a relatively universal dynamic system fuzzy model having a firmly defined DS dynamic part and covering the entire working area of the DS, which does not require the complicated procedure of determining rules for the static fuzzy part of the FS model. This approximation enables the design of simple robust adaptive control structures suitable for systems with inaccurately defined parameteres and structure. The quality of the proposed adaptive control structure was verified through simulation in examples.

Comparing fuzzy to conventional control it must be stressed that in some cases the achieved results are better and in other cases not. We cannot say that one method is superior to another at all. It depends on dynamic system or the problem to be solved which method fits best. In this spirit the algorithm presented has to be understood as an enlargement of the wide range of adaptive fuzzy control algorithms.

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