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Analysis of approaches to modelling the fuzzy control systems with extension of their functional capabilities

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Abstract

The research covers the issues of complexity in formalization of complex control objects using conventional methods and algorithms, considers different approaches to modeling of these objects, as well as reviews the features of different methods for synthesis of intelligent control systems using multi-cascade fuzzy control. It also represents a tracking drive model based on two-stage system. The structural solution for such an intelligent system includes four fuzzy controllers, three of which use Mamdani inference algorithms, and the fourth one represents an intelligent switching device with Sugeno inference algorithm. The article demonstrates the use of multi-cascade control technology for implementation of spacial membership functions.

Keywords: intelligent control system, spacial membership functions, multi-cascade fuzzy controller.

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1. Introduction

The modern automatic control systems represent the complexes of interacting technical devices and elements which operate based on different physical principles. Their design and technical characteristics are different as well. Though the individual automatic control systems and their elements are various, the latter can be divided into several basic types which differ in their purpose and interaction within the control system. Modeling can significantly help during resolution of many complicated scientific and technical tasks.

Methods of search of the object control procedure, when both the object itself and its control criterion are described with accurate terms, is outdated and irrelevant. The control objects developed as time goes by, and became more complex. So the best standard practices cannot be applied to the non-conventional control objects [1].

Since the increasingly high requirements are applied to the control processes in different fields of technologies, the identification problem becomes critically important. The qualitative control of the system cannot be ensured if its mathematical model is not studied with sufficient accuracy and the set of constraints is not explicitly stated.

The control systems developed and extended with fuzzy logic elements advance with a rapid rate. It is related to the fact that the control systems which include the fuzzy logic elements may succeed where the computational algorithms cannot. Considering the varying approaches to formalization of control objects, i.e. increasing requirements for accuracy, quality of mathematical description, reduction of constraining factors, presence of a number of optimization criteria, the approaches to synthesis of fuzzy systems shall be modified in a certain way. The possible ways to extend their capabilities are structural solutions - implementation of nesting, as well as parametric solutions - modeling of spacial membership functions [2].

Therefore, the control system based on fuzzy logic is capable to take decisions which are close to the actions of an engineer, i.e. to learn and adapt to changing environment [3].

2. Fuzzy model synthesis

For development of a control system which would allow for speed control, a subordinate control DC drive model will be used as shown in Figure 1.

This automatic drive control system will comprise two control loops: an internal loop, i.e. current control loop, and an external loop - speed control loop. Both loops are tuned for module optimum.Figures 2 and 3 show graphs of the system transients in current and speed, respectively.

There are contemporary approaches to eliminate all modeling disadvantages. The primary trend of developmentofcontrolmethodsistheir intellectualization. Themain areasof research in the field of artificial intellect are:

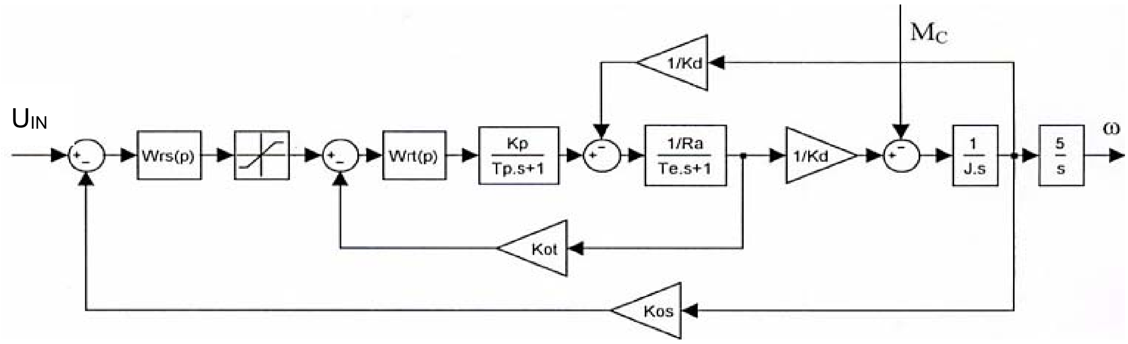

Figure 1. Structural diagram of a drive with subordinate current and speed control

At the moment the complex control systems are subject to the requirements which are different from conventional and mathematical approaches. They are subject to the properties which are defined by responsiveness of a control system, lack of formalized object existence purpose, lack of desired characteristics and optimality, incomplete information about the object. This is why the issue of identification and mathematical description of these systems takes place.

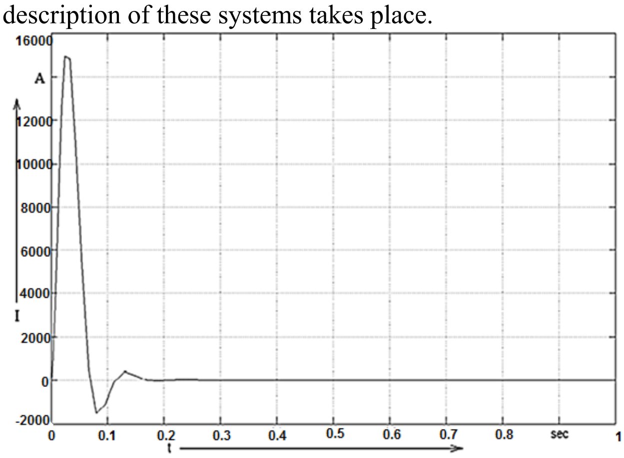

Figure 2. Motor current transient process

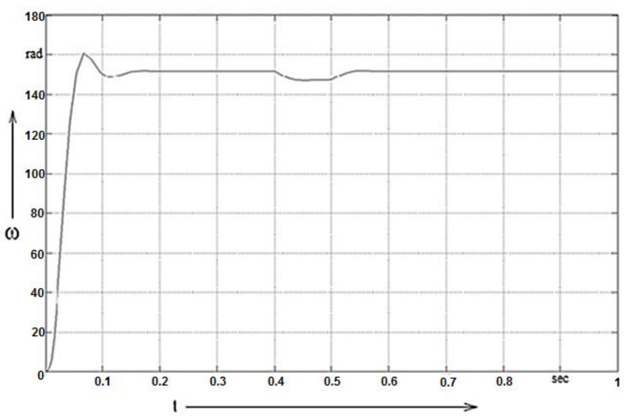

Figure 3. Motor speed transient process

– artificial neural networks,
– fuzzy logic systems,
– genetic algorithms and evolutionary programming.

The conventional methods during modeling are often inadequate. At the moment, fuzzy control is one of the most promising intellectual technologies which allows creation of high-quality control systems. A fuzzy controller itself creates a control action which goes to the object input, or fuzzy logic inference signals control the parameters of the controller within the conventional control system [2].

The application of the approach proposed makes it possible to combine the intuitively simple tuning of fuzzy systems with widest opportunities and flexibility of neural networks without the need to use their cumbersome mathematics.

As an example, we will consider the simulated drive control system using fuzzy logic. A fuzzy control algorithm in the controlled drives is implemented using a fuzzy controller (Figure 4).

Functioning of this controller can be performed using the Sugeno-Mamdani inference algorithms. In our case, the tuning is based on simplified Sugeno inference algorithm. A fuzzy knowledge base will be tuned after tuning the fuzzy controller input and output [3]. Thereafter the modeling process is started. As a result, we obtain a graph of the transient process of intelligent control system with a fuzzy controller (Figure 5).

The graph shows that the main advantage of systems with a fuzzy logical controller is the lack of overshoot, while in the classical control system it is 5%; and there is also a slight increase in the speed of the control system tuned using the theory of soft computing.

It can be observed that the main advantage of the systems with fuzzy logic controller is lack of overshoot and insignificant response speed improvement.

More complex control objects require implementation of complex control procedures, as well as implementation of the approaches during synthesis of these procedures considering the requirements and constraints applied to these objects during formalization. We will show the implementation of the complex control laws using a multi-cascade fuzzy controller in the context of tracking drive system [4].

The application of multi-cascade fuzzy control technology not only provides solution of the conventional control task for drive systems, but also offers the opportunities for control procedures in the context of multicriteriality, improves adaptivity and universality, as well as resolves this task for the entire classes of these systems.

For synthesis of the fuzzy control system with Mamdani inference algorithm the designed model of a tracking drive is taken as a basis. The conventional position controller is replaced by the fuzzy controller with Mamdani inference algorithm (Figure 6).

A fuzzy logic controller (FLC) analyzes an error signal and has a linguistic variable “input1” at the input; the output of controller is formalized by one linguistic variable “output1”. Functioning of this controller is performed using the Mamdani inference algorithm [5-7].

The linguistic variable “input1” formalizes the values of the first input signal of the fuzzy controller - a position error signal. Selection of a domain of linguistic variables shall be based on the transient process of a system with the conventionalcontroller. Five approximated triangle membership functions of fuzzy variables are distributed within the domain of linguistic variable term set [8-11].

The linguistic variable “output1” formalizes the values of the first input signal of the fuzzy controller - a position error signal. Selection of a domain of linguistic variables shall be based on the transient process of a system with

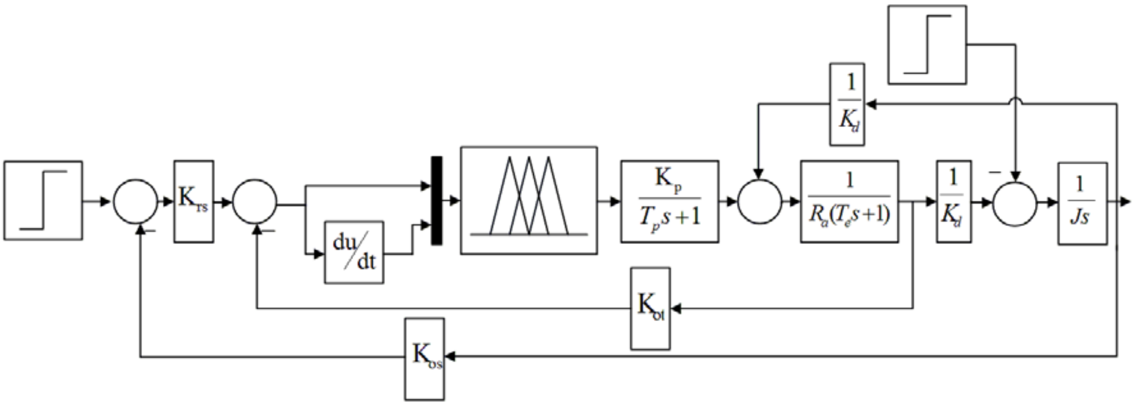

Figure 4. DC drive model with fuzzy controller

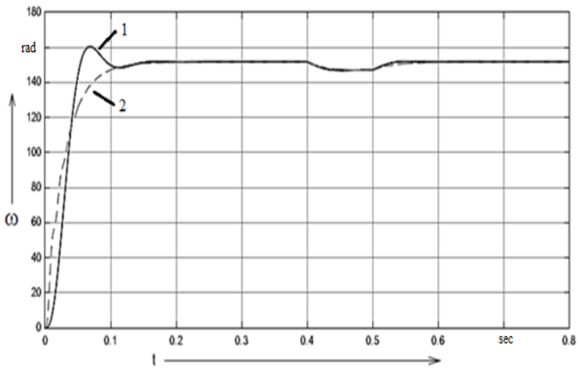

Figure 5. Transient process of system with conventional and fuzzy controllers (1 - system with conventional controller, 2- system with fuzzy controller)

the conventional controller. Five approximated triangle membership functions of fuzzy variables are distributed within the domain of linguistic variable term set.

In order to create a model of the fuzzy controller with membership functions, a complex multi-cascade intelligent system shall be implemented which includes a number of the simplest Mamdani controllers with the only membership function at the input and the output, and intelligent switching device with Sugeno inference algorithmwiththe only linguistic variable at the input and three information outputs [12, 13].

Conceptually, development of this approach will essentially extend the opportunities of fuzzy systems by means of building the fuzzy controllers with spacial membership function for input linguistic variables.

In order to form an internal cascade of the intelligent

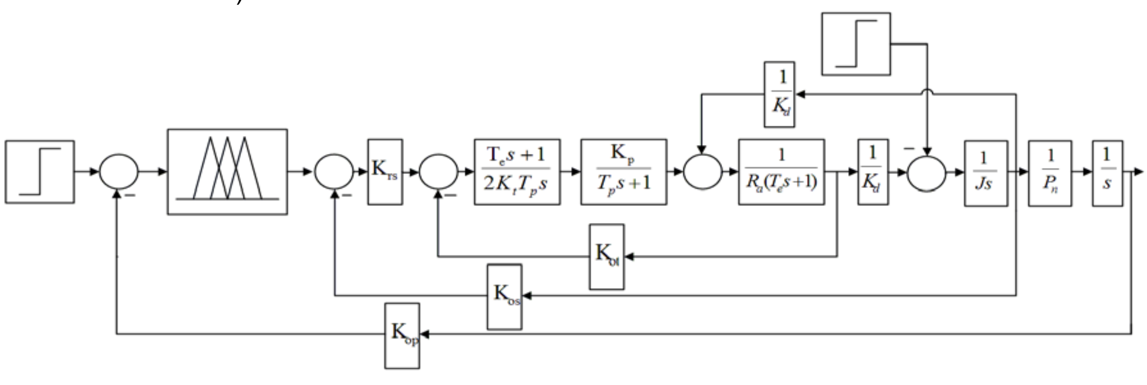

Figure 6. Model of a DC drive with a fuzzy controller

system it is required to reduce the control range of Mamdani fuzzy controller by 30%, and to form a similar controller with the control range extended by 30%.

The knowledge base comprises a set of production rules, remains unchanged for all the above mentioned controllers, and will be as follows:

1. If «input1» is Z, then «output1» is Z,
2. If «input1» is MP, then «output1» is MP,
3. If «input1» is P, then «output1» is P,
4. If «input1» is O, then «output1» is O.

We will introduce the intelligent switching device to the system. The main function of it will be to model the spacial membership function. It is a fuzzy logic controller with Sugeno inference algorithm and three multiplication elements. FLC analyzes an error signal and has a linguistic variable “input1” at the input; the output of controller is formalized by three linguistic variables “output1”, “output2” and “output3”. Functioning of this controller is performed using triangle membership functions in fuzzification block [14].

The linguistic variable “input1” formalizes the values of the first input signal of the fuzzy controller - position error signal. The domain is a range [0; 10.4]. Three approximated trapezoidal membership functions of fuzzy variables are distributed within the domain of linguistic variable term set [8-11]. The linguistic variable “output1” formalizes the value the output signal of the fuzzy controller. The domain is a range [0;1]. A ground term-set – T of the linguistic variables - consists of the following elements: $T = \{Z, P\}$, where Z is a constant value, equal to 0; P is a constant value, equal to 1; values of fuzzy variables of the linguistic variable “output1” [15].

The fuzzy production rule knowledge base of the fuzzy controller represents a list of three rules and looks as follows:

1. If «input1» is Z, then «output1» = 0, «output2» = 1, «output3» = 0;
2. If «input1» is P, then «output1» = 1, «output2» = 0, «output3» = 0;
3. If «input1» is MP, then «output1» = 0, «output2» = 0, «output3» = 1.

When applying the above mentioned structural solution, it is possible to obtain the following model of the intelligent control system with the fuzzy controller forming the spacial membership functions (Figure 7).

Functional ability of the system can be checked by means of changing the drive signal value by 30% from the initial value, so three signals are formed with the values of 5.6 (-30% from the initial signal), 8 (initial signal), 10.4 (+30% from the initial signal). The equivalent drive signals are given to the conventional system. Analyzing the obtained graphs of the system’s transient processes (Figure 8), we can conclude that a system configured using an intelligent approach has better transient quality indicators than the classical automatic control system. The advantages of an intelligent control system are the absence of overshoot compared to the classical system, where it is 6%, and the maximum response speed of these systems will be to a considerable extent defined by the minimum set of production rules and approximated membership function. The control strategy while using the multi-cascade fuzzy controller will be defined by the knowledge base of the external cascade, which is the base for selection of the elements in the internal cascade.

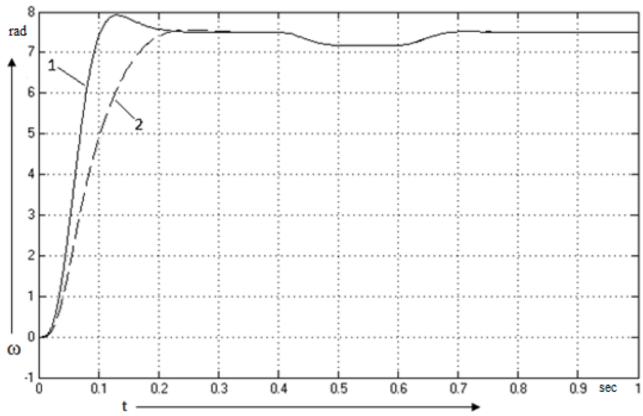

Figure 8. Transient process of system with conventional and fuzzy controllers with reference control signal (1 - system with conventional controller, 2 - system with fuzzy controller)

Therefore, we obtain the intelligent controller for implementation of spacial membership function, as shown in Figure 9.

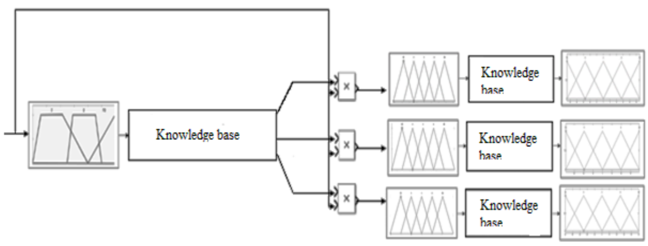

Figure 9. Intelligent controller with spacial membership functions

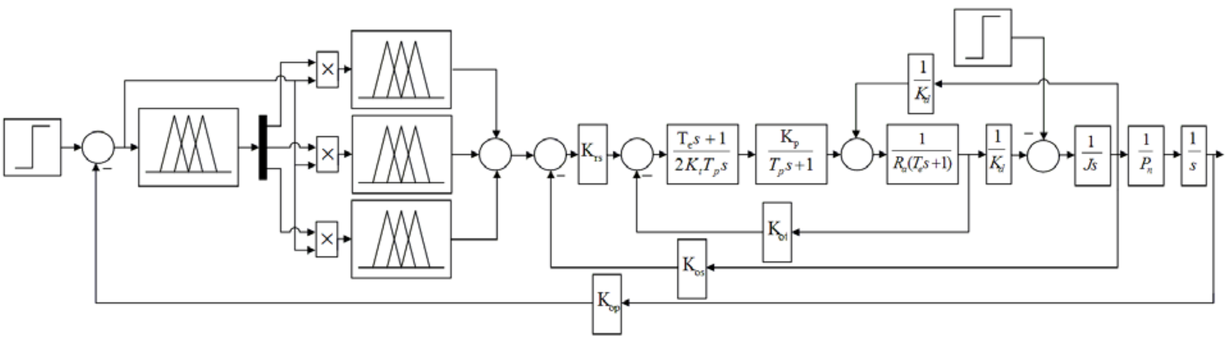

Figure 7. Model of a fuzzy control system

This intelligent system comprising a two-stage fuzzy controllers set forms the spacial membership functions as shown in Figure 10.

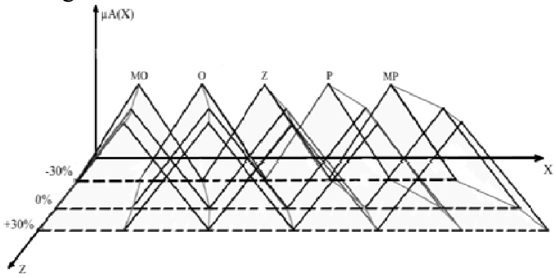

Figure 10. Spacial membership functions

The variations of signals shown in the article do not restrict the capabilities of controller, and it remains sensitive to changing environment, which includes the extremes of the control range. Such an approach to implementation of fuzzy systems helps to enhance universality of the intelligent controller, to extend its adaptive properties and simplify tuning and retuning processes, as well as to reduce information redundancy and algorithmic complexity of these controllers, if implemented as a single module.

The response speed of the system will be primarily based on the following parameters of fuzzy multi-cascade controller model: membership function form, fuzzy inference algorithm in the external cascade - to a greater extent, and number of elements within the internal cascade and fuzzy inference algorithms - to a lesser extent. It shall be also emphasized that such construction of the fuzzy control system will not result in significant extension of the controller's knowledge base. This has to do with the fact that the elements within the internal cascade have the similar rule bases, which assign the unique input to the unique output. The approach proposed will make it possible to fill the gaps of fuzzy controllers synthesized with use of standard methods and comprising a big number of input and output linguistic variables, such as big number of production rules, big number of connections within these rules and hyper-spacial form of a knowledge base as a whole.

Conclusions and outlines

The fuzzy control does not require knowledge of accurate object model; it implements an approximated control strategy by means of modeling the human thinking. It can express any algorithm both non-linear and linear required for control task in simple linguistic terms. This algorithm shall be preliminary developed by an expert. The special feature of the fuzzy control is its capability to impart the robustness property to the non-linear systems [15].

In addition to the advantagesthe system presents a number of disadvantages related to technical implementation of this kind of controller models. Particularly, there is a problem related to selection of combinations of fuzzy inference algorithms that defines possible structural solutions while synthesis of cascading. In addition, the application of Mamdani algorithm in implementation of a module in the external cascade causes a number of problems related to quality of selection of one or another element from the internal cascade.

But despite this fuzzy logic ensures the effective presentation of real object uncertainties and incompleteness of their formal description. Mathematical means which reflect fuzziness of original information allow construction of reality-relevant model without use of lengthy computational procedures which are typical for the conventional control method. Fuzzy control provides more flexible mechanism comparing to capabilities of widely used conventional control algorithms [4].

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