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FUZZY PID CONTROLLER FOR NONLINEAR PLANT

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ABSTRACT

This paper deals with a design of fuzzy PID controllers for nonlinear dynamic system. An important feature of decomposed fuzzy PID controller is their simple structure. In its simplest version, it uses three one-input one-output fuzzy inferences with three separate bases with simple rules. The fuzzy PID controller parameters are optimized by using genetic algorithm. The performance of the proposed method is compared with the conventional PID methods for a coupled pendulums systems using MATLAB/Simulink software package. The experiment results show that in contrast to traditional PID controller, the developed approach can achieve better rapidity.

Keywords: fuzzy PID controller, genetic algorithm, coupled pendulum.

1. INTRODUCTION

The concept of "intelligent regulators" is usually associated with fuzzy or neural controllers. For implementation of the law of control, Fuzzy Logic Controllers (FLC) use the rules connecting the fuzzy description of a situation and a signal of control ([1, 2] and others). FLC can be used for the organization of a contour of adaptation in a system, operating the parameters of the regulator of the lower level [3, 4], but usually they, being nonlinear correcting link, join consistently with the object of control. The main problem of the use of FLC is in lack of simple techniques of their adjustment, that doesn't allow regulators of this type reaching the same distribution as PID controllers.

In the paper [5], it was shown that a nonlinear PID controller can be carried into effect on the basis of artificial neural network (NN), where nonlinear activation functions are setup. Thus, a substantial increase of quality of control is reached. However, NN is a "blackbox" which behavior is difficult to analyze. In this paper, a similar approach is used towards the problem of synthesis of FLC, which is regarded as a nonlinear addition to a PID controller. A simple synthesis algorithm of FLC of PID-type using a stochastic optimization is offered.
The results of the experiments on control over a nonlinear dynamic object executed in *MatLab Simulink* are given.

2. FUZZY PID CONTROLLER AND ITS ADJUSTMENT

The main component of FLC is a rule database connecting the situation observed on plant and necessary control. There are various approaches to synthesis of rule database of FLC. Historically, the options connected with formalization of the knowledge of an expert operating an object manually [6] were the first. Knowledge can be formalized directly by interviewing an expert or by supervision over their control actions. In the absence of an expert, FLC can be adjusted in the course of experiments with an object.

If there is rather reliable computer model of an object of control, with its help it is possible to perform a set of options of FLC adjustment, including – on the basis of identification, adaptation, evolutionary self-organization. However, computing expenses quickly grow at increase in number of the adjusted parameters, which can make a problem of control troublesome. Therefore, in practice, it is desirable to have a regulator with a simple structure and a small number of adjusted parameters.

Fuzzy PID controller receives the same input signals, as the ordinary PID controller, but can it realize a more difficult nonlinear algorithm of control. In other words, the law of control over fuzzy PID represents a hyper-surface unlike a hyper-plane which is realized by a PID controller.

As fuzzy PID has three ins, three linguistic variables (LV) are necessary for the description of the law of control. The rules of control should be of the form of:

$$\text{If } (e = e^*)\,\&\,(\dot{e} = \dot{e}^*)\,\&\,(\textstyle\int e = \int e^*), \;\; \text{then } u = u^*,$$

where $e, e^*, \dot{e}, \dot{e}^*, \int e, \int e^*, u, u^*$ – an error of control, its derivative, an error integral, a signal of control, and linguistic values corresponding to them.

The structure of fuzzy PID using the rules with three premises is shown in fig. 1, where *N* and *DN* designate the operations of normalization and a denormalization. The blocks of normalization serve to reduce an input signal to a range [-1, 1]. The block of a denormalization scales an output signal of the controller.

For example, if we choose a LV with identical quantity of terms of $n = 7$ for each in, the number of potential fuzzy rules with three premises of $N = n^3 = 343$. The adjustment of such a difficult design causes big problems.

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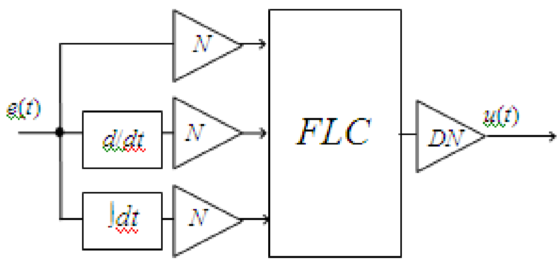

Figure-1. FLC of PID-type.

For justification of algorithm of designing of fuzzy PID, we will consider the law of control over the linear PID controller:

$$u(t) = k_{\mathrm{p}} e(t) + k_{\mathrm{i}} \int_{0}^{t} e(\tau) d\tau + k_{\mathrm{d}} \frac{de(t)}{dt}, \quad (1)$$

where$e(t)$ – an error of control, k_{P}, k_{i},k_{d} – coefficients chosen in the course of design.

The formula (1) contains three independent summands; therefore, the problem of synthesis of fuzzy PID can be considerably simplified, if we realize the controller as a sum of output signals of three independent FLC: P-type, D-type, and I-type (Figure-2).

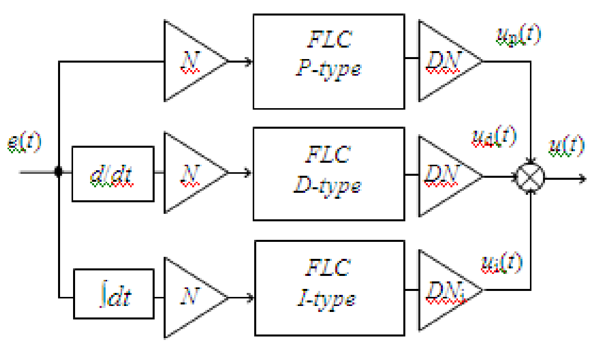

Figure-2. Decomposition of the law of control.

Each of controllers in this structure uses simple rules with one premise. For example, for a FLC of P-type they will be of the form of:

If $e = e^*$, then $u = u^*$.

When using, for example, 7 terms for the description of an error, the controller will demand only 7 rules which conclusions are required to be optimized. Here, the law of control is possible to describe by means of some nonlinear function; such example is shown in Figure-3. The symmetry of function demands only two points (highlighted in white) to be adjusted.

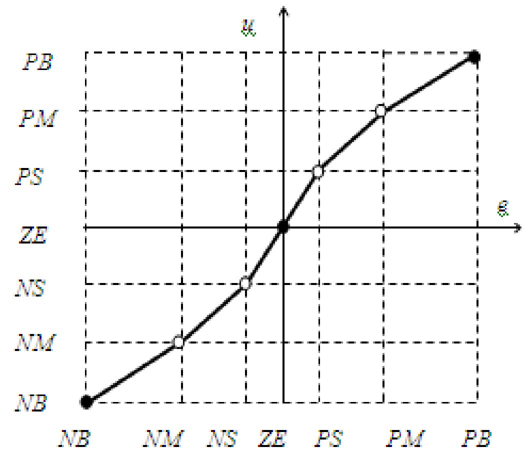

Figure-3. Nonlinear law of control by error.

The PID controller coefficients in (1) correspond to a “weight” which is brought to the law of control by proportional, differential and integrated components of the law of control. Respectively, in the structure of FLC of PID-type, such weights are coefficients of denormalization of DN_{p}, DN_{d} and DN_{i}.

Considering the problem of synthesis of fuzzy PID as a problem of improvement of quality of PID controller, it is possible to suggest the following algorithm from the sequence of two steps:

1. A linear PID controller, which parameters k_{P}, k_{i},k_{d} will play a role of coefficients of a denormalization, is synthesized.

2. Nonlinear functional dependences describing the fuzzy law of control on each of input variables are adjusted.

Thus, on the first step, basic coefficients of strengthening, and on the second step - additional coefficients of strengthening, which nonlinearly depend on an input signal, are obtained.

Considering various combinations of summands (1), it is possible to obtain PD-and PI-controllers. Respectively, it is possible to consider FLC of PD- and PI-type.

3. MODELING EXAMPLE

The problems of control over oscillatory mechanical systems are of considerable theoretical interest and great practical value. We will consider, as an example, a problem of control over an oscillator, which can arise at the description of various physical and mechanical systems [6, 7].

An oscillator consists of two pendulums - uniform metal cores of same length - connected by a spring. At disturbing the balance of a system, pendulums perform complex flat movements, which need to be operated. An oscillator has the only control device installed in the point of subweight A of the first pendulum (Figure-4).

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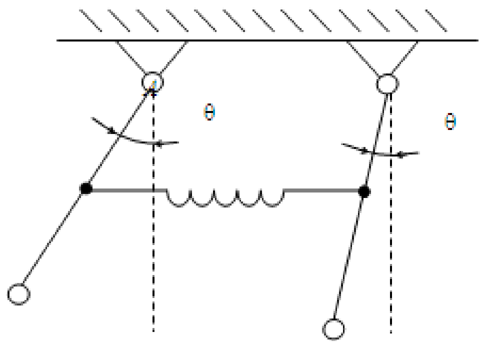

Figure-4. Two pendulums connected by a spring.

Let us suggest designations: θ_1 and θ_2 – angles of rotation of pendulums, *u (t)* –external operating moment attached to the first pendulum, m_1 and m_2 – masses of pendulums, *L* – length of pendulums, *k* – parameter of a spring, *h* – distance from subweight to a point of fastening of a spring.

The equation of the moments for pendulums is of the form of:

$$\begin{cases} \dfrac{m_1L^2}{2}\ddot{\theta}_1(t)+Lm_1g\sin\theta_1(t)= \\ =k\left(\sin\theta_2(t)-\sin\theta_1(t)\right)h\cos\theta_1(t)+u(t), \\ \dfrac{m_2L^2}{2}\ddot{\theta}_2(t)+Lm_2g\sin\theta_2(t)= \\ =k\left(\sin\theta_1(t)-\sin\theta_2(t)\right)h\cos\theta_2(t). \end{cases}$$

In Figure-5, the example of free movement of pendulums at a set initial deviation is shown.

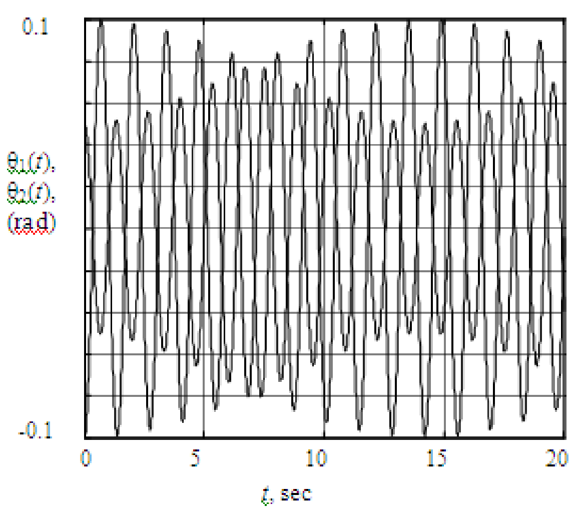

Figure-5. Free movement of oscillator at the initial deviation φ_1 = 0,05; φ_2 = –0,1.

At the first stage of the synthesis of a controller, the linear law of control was considered:

$$u(t)=k_1\theta_1(t)+k_2\dot{\theta}_1(t)+k_3\theta_2(t)+k_4\dot{\theta}_2(t).$$

The search of the coefficients k_1, k_2, k_3, k_4 was carried out for the purpose of minimization of objective function

$$\Delta=\sum_{i=1}^{N}\left(\theta_1^{i}(t)+\theta_2^{i}(t)\right), \tag{2}$$

In Figure-6, the transition process for a linear controller is shown.

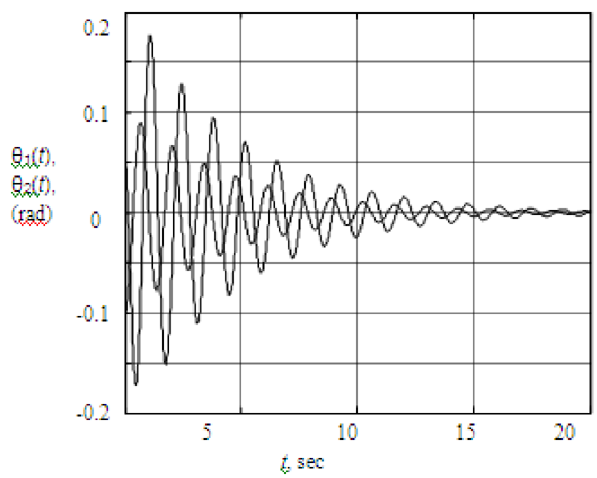

Figure-6. Dynamics of oscillator with linear controller.

At the second stage, FLC of PD-type, in which the obtained coefficients k_1, k_2, k_3, k_4 were used for denormalization of signals from FLC, was considered.

In Figure-7, the final structure of the controller where four nonlinear blocks correspond to FLC with one input variable is shown. The optimization of nonlinearities was carried out by means of genetic algorithm [5, 8]. As an objective function, (2) was used.

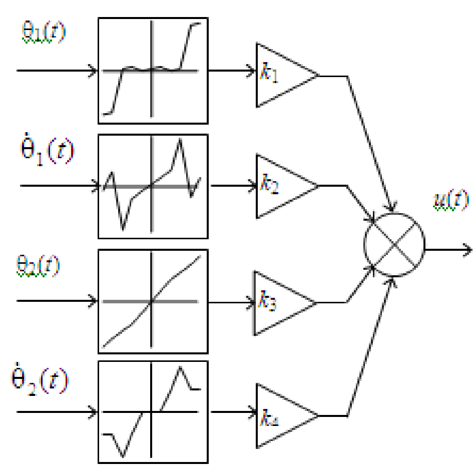

Figure-7. Structure of nonlinear controller.

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In Figure-8, the transition process for a nonlinear controller is shown.

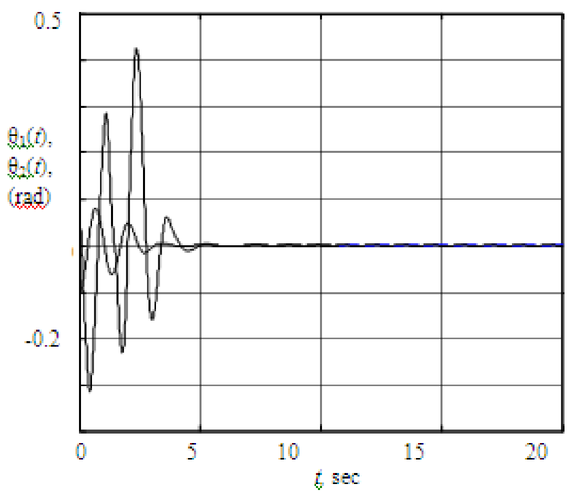

Figure-8. Dynamics of the oscillator with FLC.

When comparing Figures 7 and 8, we see that the time of control is approximately reduced by 3 times. However, at that, re-control (Figure-8) grew. If necessary, it is possible to decrease re-control through more difficult objective function upon optimization.

4. CONCLUSIONS

The approach to design of FLC of PID-type considered in this paper is simple and consists of two steps. At the first step, the parameters of the linear PID controller are optimized, and at the second step, the behavior of the controller is improved by introduction of consecutive nonlinear correcting links on each of the channels.

The given example of modeling of a control system of nonlinear dynamic object (the connected pendulums) showed that the use of FLC of PID-type can provide considerable reduction of time of transition processes which is unattainable through the linear law of control.

Thus, the suggested approach can be useful for modernization of control systems of a wide class of dynamic objects where linear PID controllers are used.

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