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ALGORITHM FOR SYNTHESIS OF A NEURO-FUZZY DISCRETE REGULATOR IN TASKS OF CONTROL OF A DYNAMIC OBJECT

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The article presents the results of a study of the properties of an automatic control system with a proportional-integral-differential-controller and a sequential adaptive corrective device for the dynamic characteristics of automatic control systems. To adjust the parameters of the proportional-integral-differential-controller, a two-layer artificial neural network is proposed, which is distinguished by the simplicity of implementation on microcontrollers. To give the adaptation property to the digital proportional-integral-differential-controller, the method of interactive adaptation based on the Frechet method is used. The results of the study of the properties of an automatic control system with a proportional-integral-differential-controller and a serial adaptive corrective device for the dynamic characteristics of automatic control systems are presented. A distinctive feature of adaptation lies in the fact that during the operation of the system the regulator parameters do not change and correspond to the setting preceding the start of the system. In this case, depending on the change in the parameters of the control object, the transfer coefficient of the corrector or the phase shift created by it changes. Changes that occur only in cases where the quality of the automatic control system becomes unsatisfactory due to changes in the properties of the control object or due to the impact of disturbances on the control object. To give the desired property to control systems, a non-linearity of the “saturation” type is included in the control loop. The use of nonlinear correctors is associated with the problem of taking into account the dependence of the frequency characteristics on the amplitude of harmonic oscillations of the input signal, which allows one to obtain the required amplitude and phase frequency characteristics, which ensures the stability of the system and improves the quality of the transition process. A comparative analysis of the results obtained by conducting a simulation experiment on the environment «MATLAB». The results of the study, an automatic control system with linear corrective devices showed that the adaptation of linear correctors even using modern mathematical apparatus, such as fuzzy logic, is possible only with limited range and nature of changes in the parameters of the control object. The results can be implemented on a production system, i.e. to maintain the given mode of the boiler units in the power system.

Key words: ATS, PID-regulator, PID-law, nonlinear, linear, neuro-fuzzy, algorithm, hypersurface, procedure, system, dynamic object.

В статье приводятся результаты исследования свойств систем автоматического регулирования с пропорционально-интегрально-дифференциальном-регулятором и последовательным адаптивным корректирующим устройством динамических характеристик систем автоматического регулирования. Для настройки параметров пропорционально-интегрально-дифференциального регулятора предложена двухслойная искусственная нейронная сеть, отличающаяся простотой реализации на микроконтроллерах. Для придания свойства адаптации цифровому пропорционально-интегрально-дифференциальному регулятору использован метод интерактивной адаптации, основанный на методе Фреше.

Приведены результаты исследования свойств системы автоматического регулирования с пропорционально-интегрально-дифференциальным регулятором и последовательным адаптивным корректирующим устройством динамических характеристик систем автоматического регулирования.

Ключевые слова: САР, ПИД-регулятор, ПИД-закон, нелинейный, линейный, нейро-нечеткий, алгоритм, гиперповерхность, процедура, система, динамический объект.

Мақолада пропорционал-интеграл-дифференциал-регулятор ва автоматик бошқариш тизимларининг динамик характеристикаларини кетма-кет мослаштирадиган динамик автоматик бошқарув тизимининг хусусиятларини ўрганиш натижалари берилган. Пропорционал-интеграл-дифференциал-регулятор параметрларини созлаш учун микроконтроллерларда амалга оширишнинг соддалиги билан ажралиб турадиган икки қаватли сунъий нейрон тармоқ таклиф этилади. Мослашув хусусиятини рақамли пропорционал-интеграл-дифференциал-регуляторга бериш учун Фреше усулига асосланган интерфаол мослашув усули қўлланилади. ПИД-регулятор ва автоматик бошқарув тизимларининг динамик характеристикаларини кетма-кет мослаштирувчи тузатувчи мосламали автоматик бошқарув тизимининг хусусиятларини ўрганиш натижалари берилган.

Таянч иборалар: АБТ, ПИД-регулятор, ПИД-қонун, ночизиқли, чизиқли, нейро-норавшан, алгоритм, гиперюза, процедура, тизим, динамик объект.

I. INTRODUCTION

Today, one of the urgent problems of modern control theory is the development of ways to ensure the required quality of automatic control systems (ATS) by objects with non-stationary parameters [2].

Currently used in industry proportional-integral-differential (PID) -regulators are the most common type of regulators. About 90-95% of the regulators currently in operation use the PID algorithm. The reasons for such a high popularity are the simplicity of construction and industrial use, clarity of operation, suitability for solving most practical problems, and low cost [1].

The use of the PID law in the power industry leads to an increase in the quality of regulation. As applied to steam temperature ATS, the use of the PID control law makes it possible to maintain temperature fluctuations more precisely in the entire steam production range of the boiler, which is a top priority. The use of the PID algorithm is limited by the complexity of its configuration. This is explained by the peculiarity of the operation of ATS with PID controllers: high sensitivity to deviation of the optimum of their settings and the inability to use the step method to obtain the type of transient process.Для получения:

• the greatest gain from the PID law of regulation;

• reduction of labor costs for commissioning of ATS with a PID controller;

• evaluating the effectiveness of the PID control law at the design stage, including more complex ATS circuits (three or more temperature ATS circuits, circuits with a complex differentiator), a comparative analysis of ATS tuning procedures with a PID controller is carried out, based on which the most suitable for practical use. To determine the capabilities of the PID law, the settings of the PID controller were calculated taking into account the criteria for the quality of the transition process adopted in the power system, and the dependences of the settings of the PID controller were obtained.

To give the desired properties of a managed object, adaptive control methods are widely used.

II. MAIN PART

Adaptive control is currently implemented in most cases based on the identification of the control object with the subsequent solution of the problem of determining the parameters of the PID controller.The main disadvantages of this approach are the complexity of the identification procedure and the limited ability to change the dynamic properties of the ATS by changing the parameters of the PID controller.This work presents the results of a study of the properties of ATS with a PID controller and a sequential adaptive corrective device for the dynamic characteristics of automatic control systems. The adaptation method is characterized by the fact that during the system operation the regulator parameters do not change and correspond to the setting preceding the system startup. During the operation of the control system, depending on the change in the parameters of the control object, the transfer coefficient of the corrector or the phase shift created by it changes. These changes occur only in cases when the quality of the ATS becomes unsatisfactory due to changes in the properties of the control object or due to the impact of disturbances on the control object. This allows you to ensure system stability and improve the quality of transients.The results of the study of ATS with linear corrective devices showed that the adaptation of linear correctors even using modern mathematical apparatus, such as fuzzy logic, is possible only with limited range and nature of changes in the parameters of the control object. The use of nonlinear correctors is associated with the problem of taking into account the dependence of the frequency characteristics on the amplitude of harmonic oscillations of the input signal. The use of an adaptive pseudo-linear corrector of dynamic characteristics allows to obtain the required amplitude and phase frequency characteristics. Typically, these devices have two channels, amplitude and phase, adjustable independently of each other. In this case, the frequency characteristics of pseudo-linear corrective devices are independent of the amplitude of harmonic oscillations of the input signal.

If the control object is essentially non-linear, then it is difficult to achieve a good quality of management. The use of nonlinear regulators (for example, fuzzy or neural regulators [3, 4]) allows, in principle, to achieve higher quality indicators of the transition process. However, the simplicity and clarity of the structure of PID controllers stimulates research related to the improvement of their design ([5–8] and others). So in [5] it is proposed to supplement the PID controller with a neural network controller trained using the back propagation error algorithm. The signals of both controllers add up, which allows to obtain a nonlinear control law. In [6], an RBF network is used, which serves to change the coefficients of the PID controller. Tuning is done using a genetic algorithm (GA). In [7], an artificial neural network approximates a PID controller, and a differential evolution algorithm is used for training. In [8], a neural supervisor based on NS of direct propagation controls the coefficients of the PID controller. In this paper, we study a simple modification of a digital PID controller based on an equivalent representation based on a neural network (NS) with the subsequent introduction of nonlinearities that improve the quality of transients.

In this case, the PID controller can be represented as a simple NS, containing only one neuron with three inputs and a linear activation function (Fig. 1). The control law is a hyperplane in 4-dimensional space. It can be assumed that the improvement of control quality is ensured by replacing the hyperplane

$$(x+a)^n = \sum_{k=0}^{n} \binom{n}{k} x^k a^{n-k}$$

some hypersurface, for the description of which one can go from the structure of Fig. 1 to a more complex structure containing nonlinearities.

To solve this problem, we consider the discrete representation of the PID controller, replacing the derivative and the integral by the relations of finite differences:

$$u(n) = kx_{p^e}(n)ki \ \ \Delta t\sum_{k=0}^{n} \ e(k) + \frac{kd}{\Delta t}(e(n) - e(n-1) \ ),$$

where n is the point in time. Restricting ourselves to two terms in the formula for the integral, we have:

$$u(n) = kx_{p^e}(n) + si(e(n) + e(n-1) \ ) + sd(e(n) - e(n-1) \ ),$$

where $si = ki\Delta t, sd = kd/\Delta t, \Delta t$ – time sampling step.

To implement a discrete PID controller, we can consider a two-layer NS, in which only the activation function of the 2nd layer is linear, and the activation functions of the 1st layer are generally non-linear (Fig. 2, where Δ is the delay by one clock cycle).

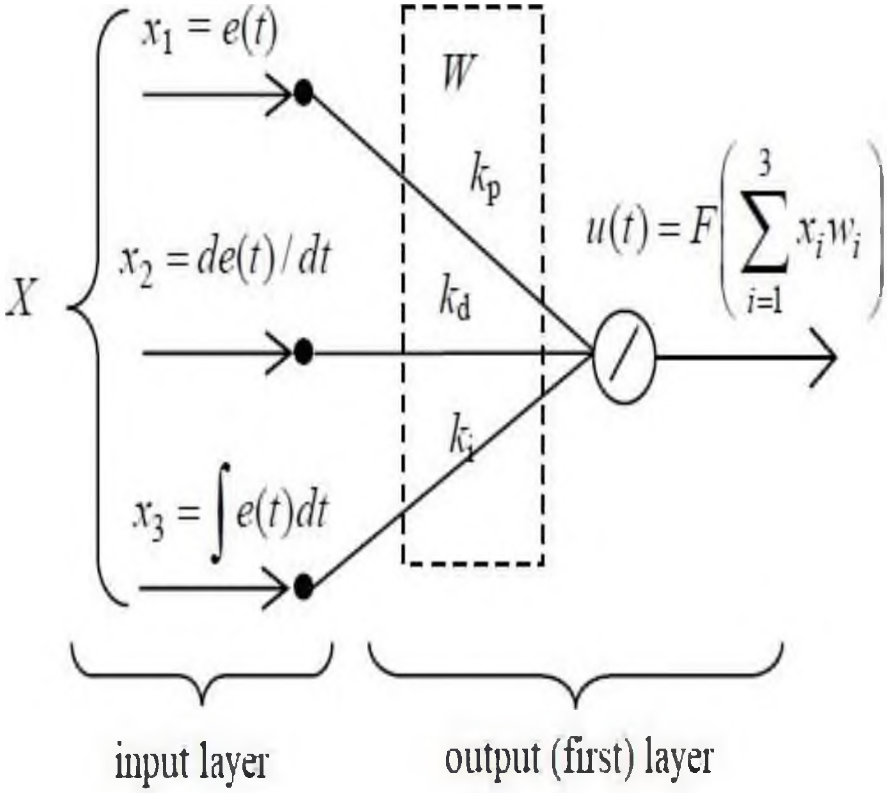

Fig.1. Discrete PID controller structure

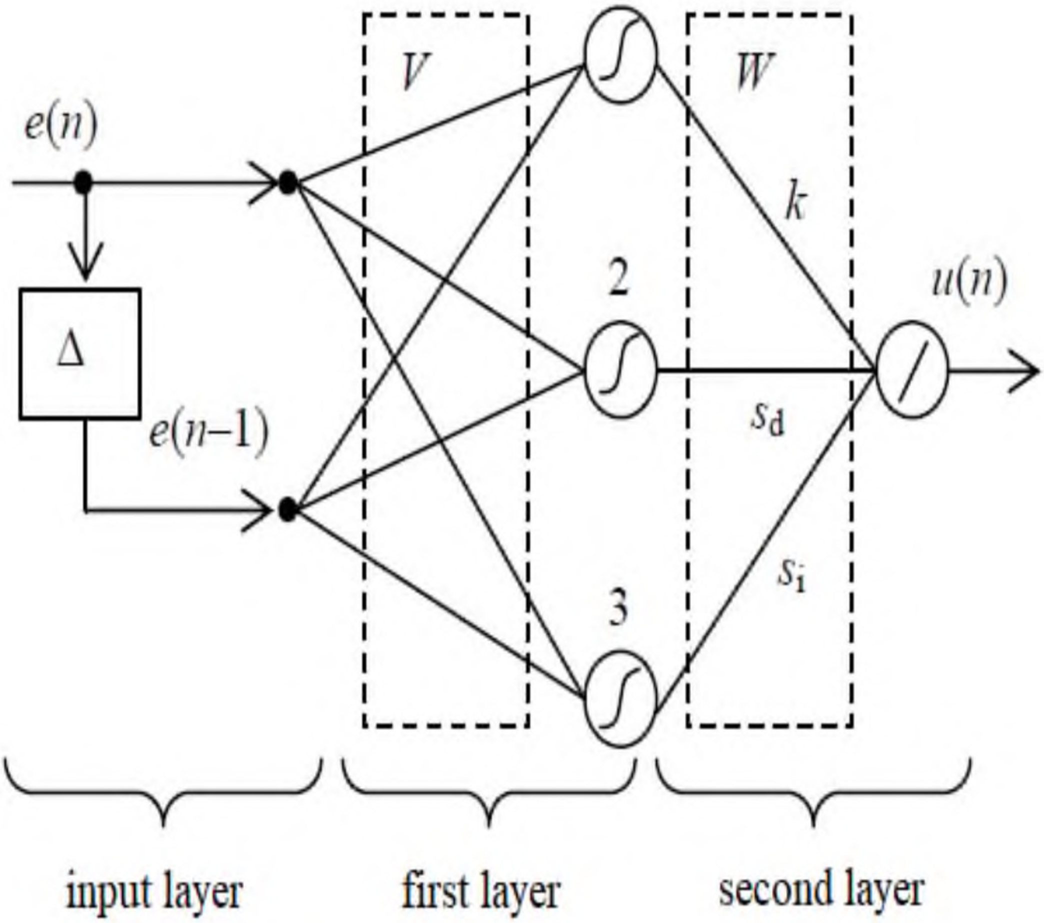

Fig. 2. One beat delay

Thus, in the structure of a nonlinear PID controller (neuro-PID), only the parameters of the activation functions of neurons of the 1st layer are unknown.

It is proposed to configure a nonlinear digital PID controller in two stages:

1. Synthesis of a linear digital PID controller, during which a weight matrix of the 2nd layer W. is formed.

2. Optimization of the parameters of the nonlinear activation functions of neurons of the 1st layer, forming a nonlinear control law that satisfies the specified quality indicators.

Consider the problem of controlling a nonlinear dynamic object containing sequentially included linear and nonlinear parts. Static nonlinearity of the "saturation" type is considered. The linear part is described by the transfer function

At the first step, the coefficients of the linear PID controller are optimized (Fig. 1). The transition process (reaction to a single jump) after optimization is described by curve a in Fig. 3.

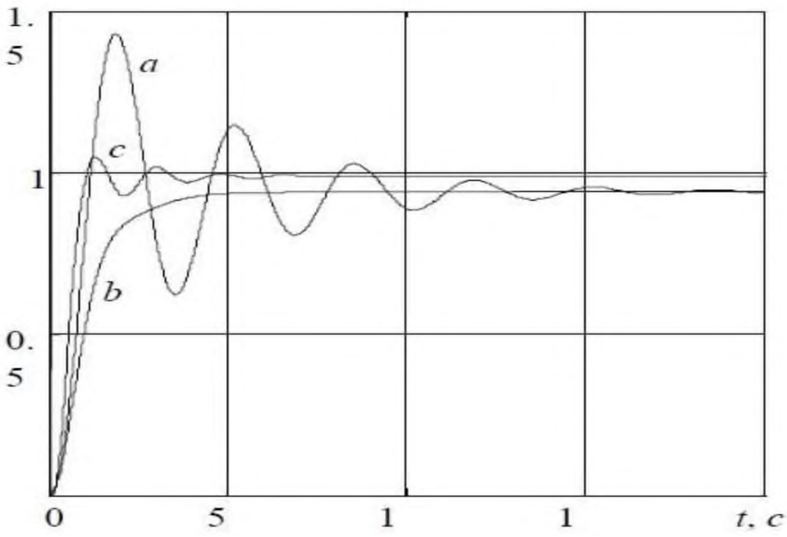

Fig. 3. Transient process (reaction to a single jump) after optimization

The linear control law here leads to significant overshoot and large static error. At the second step, the parameters of the activation function of neuron 2 are optimized (Fig. 2), which corresponds to the differential component of the PID controller. The result is shown in fig. 4 (left).

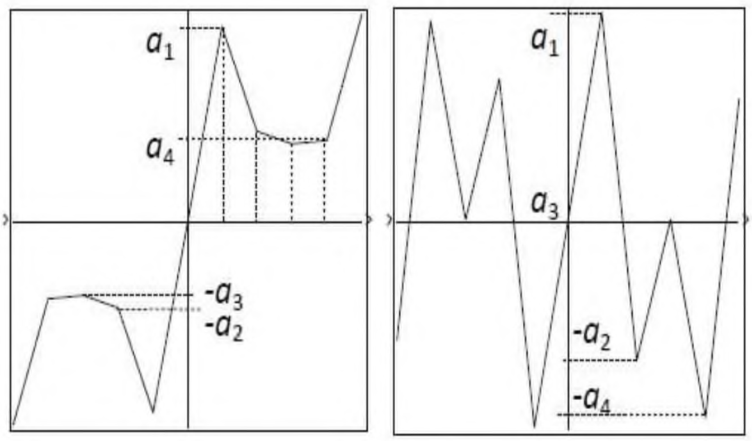

Fig. 4. The differential component of the PID controller

The transition process corresponds to curve b in Fig. 3. The transition process acquired an aperiodic character, but the static error did not decrease, and the rise time increased slightly.

At the third step, the parameters of the activation function of neuron 3 are optimized (Fig. 2), which corresponds to the integral component of the PID controller. The final form of the activation function is shown in Fig. 4 (right). The transition process corresponds to curve c in Fig. 3. The transition process has again become oscillatory, but the overshoot is insignificant, the rise time has been significantly reduced, and the static error has become insignificant. Note that the activation function of neuron 1 (Fig. 2) in the considered example remained linear, i.e. the base gain here remains constant. For other dynamic objects, this situation may change during the optimization process.

III. CONCLUSION

The considered approach to the design of a nonlinear PID controller (or neuro-PID) is simple and based on the representation of a two-layer NS controller, in which three neurons of the 1st layer can have nonlinear activation functions, and the neuron of the 2nd layer has a linear activation function.

The design process includes two stages:

- Optimization of the linear PID controller coefficients, which form the weights of the 2nd layer of the NS.
- Transition to a discrete representation, and optimization of parameters of nonlinear activation functions of neurons of the 1st layer in order to improve the quality of transients.

Optimization can be performed in just three parameters, but the objective function is multi-model, which requires the use of global optimization methods, such as a genetic algorithm.

The given simulation example showed that replacing a PID controller with a neuro-PID controller can provide a significant improvement in the quality of control, which is unattainable with a linear control law.

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

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