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Analysis of hybrid controllers in control models of technical objects operating in changing conditions

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Abstract :The paper analyzes hybrid controllers for control models of technical objects operating in changing conditions. It also considers the models which involve control based on hybrid controllers imple-mented on the basis of sequential interaction between PI- and IPI-FUZZY-controllers and PID- and IPD-FUZZY-controllers with the generated structure of the Sugeno-type fuzzy inference system and the developed ANFIS model. In hybrid controllers, the fuzzy controller rule base is formed automatically using a specially developed algorithm based on data obtained from a classical controller with subsequent training us-ing a neural network. The ANFIS design principle in the form of a hybrid network for PI and IPI-FUZZY controllers is the use of the output signal error indicators, its integral (differential for PID and IPD-FUZZY controllers) and control action. The following aspects have become the development-ment features. In order to test the hybrid network efficiency to identify the fact of its retraining, the authors used the data obtained as a result of the classical regulator operation; to form a training sample for building a hybrid network they used the data obtained as a result of the fuzzy regulator operation. This makes it possible to exclude expert's participation in the synthesis of the fuzzy controller rule base and to ensure efficient and robust control of an object functioning in unforeseen external situations. The IPI-FUZZY-controller and the IPD-FUZZY-controller have shown better quality indicators comparing to the corresponding classical ones, which makes it possible to recommend using in real control systems.

Keywords: control management , hybrid model , rule base , intelligent controller , training .

Introduction

The rapid development of modern automated process control systems is determined by the need to solve complex problems related to ensuring reliable control under conditions of uncertainty. To solve such problems, intelligent technologies are used to ensure the reliability and efficiency of control, including in emergency situations.

However, in almost all existing automated process control systems in control loops, preference is given to traditional control methods based on the use of classical controllers, despite their limited capabilities or inapplicability for controlling technical objects with a poorly formalized structure, dynamic behavior, in case of changing object parameters, during operation in unforeseen external situations.

This is due to a certain reliability of classical controllers in the management of stationary objects and distrust of intelligent ones due to their limited applicability in real industries, including modern ones, and lack of operating experience.

To implement intelligent control systems in real industries, it is necessary to obtain sufficient theoretical and applied evidence of their reliability, the ability to guarantee the desired control with maximum quality in case of changing control situations.

This work is devoted to the analysis of the results of research carried out by the authors on the development of control systems for technical objects that operate under uncertainty based on intelligent hybrid controllers - classical (PI, PID) and fuzzy (IPI-FUZZY, IPD-FUZZY) and allow to provide the desired control with maximum quality, including in cases of changing control situations.

The task is to analyze the control signals obtained in hybrid controllers based on a comparison of the results of the operation of a classical PI controller with an IPI-FUZZY controller and a classical PID controller with an IPD-FUZZY controller.

Analysis of research on a scientific problem

The problem of developing control systems using intelligent controllers is given special attention by the world scientific community and many scientific works are devoted to it.

Thus, in the study [1], the tuning rules for reliable FOPID controllers are considered based on multi-objective optimization using FOPDT models. A set of optimally balanced tuning rules for fractional-order PID controllers with minimization of the integrated absolute error both for the setpoint and for the response to a load disturbance is proposed.

The work [2] is devoted to the development of a hybrid system in which the optimality of the PID controller parameters obtained using a genetic algorithm is achieved by means of a neural network, and then the fuzzy model rule base is also built with its help.

The development of a fuzzy controller based on an improved genetic optimization algorithm for controlling an unmanned helicopter is discussed in [3]. The genetic algorithm improved by the authors is used to optimize the initial expert empirical rules of fuzziness, which avoids the use of traditional methods for local solutions in the optimization process. The simulation results of the synthesized adaptive fuzzy PID controller showed that it has a better control effect and noise protection than the classical PID controller. However, the developed genetic algorithm is used to optimize the initial expert empirical fuzzy rules, which initially depend on the knowledge of experts, which is not an advantage over control systems in which fuzzy inference rules are generated automatically.

Logic based on hybrid control for fuzzy PID control is presented in [4]. The fuzzy controller parameters are tuned in real time based on the Mamdani algorithm, taking into account the identification performed when an unmeasured stepwise disturbance of any form influences the behavior of the control process.

The work [5] describes an effective method for determining the optimal parameters for tuning a fuzzy PID controller. The disadvantage of the method is the lack of training or adaptation of the controller in case of changing the parameters of the control object.

The article [6] is devoted to the implementation of a hybrid approach to the problem of controlling a technical object based on classical and fuzzy PID controllers for adjusting the power of the active zone of a liquid-salt reactor. In order to take advantage of fuzzy and traditional PID controllers at the same time, a combined controller has been developed that automatically switches between fuzzy control and PID control according to the error range. As a result of the simulation, it was determined that the transient performance of the combined controller is higher than that of a conventional PID controller or a fuzzy controller.

In [7], a fuzzy controller was synthesized based on a traditional PID controller. Closed-loop data, including error and control signals, are analyzed to obtain the most appropriate input and output linguistic variables and a fuzzy controller rule base that describe the behavior, more specifically the dynamics of the system. The proposed method determines the main parameters of the fuzzy controller and helps to avoid the difficulties associated with the representation of expert knowledge. Next, a fuzzy controller is developed, which should support the performance of a traditional PID controller and be immune to the uncertainty of the model coefficients.

The control system for an asynchronous AC drive based on an adaptive fuzzy identifier and a neurofuzzy controller is presented in [8]. The system is able to adapt to changes in the load of the power line by changing the rules of the neuro-fuzzy controller.

The authors of [9] proposed a genetic approach for automatic tuning of the adaptive fuzzy PID controller of the telescope tracking system. A fuzzy adaptive PID controller for the position of the telescope axis servo has been developed. An automatic tuning of membership functions and fuzzy controller rules using an evolutionary algorithm is presented. This regulator is effective for high-precision control by eliminating the step mode that occurs in a multi-mass system with a non-linear torque at a very low speed of tracking space objects.

An analysis of scientific research in the field of designing intelligent control systems, automatic procedures for their synthesis allows us to conclude that one of the main directions in the development of hybrid systems are combinations of classical and fuzzy controllers, the use of a neural network, and genetic algorithms.

This paper considers hybrid controllers built on the integration of classical and fuzzy controllers using a neural network, which determines the relevance of the research.

Method for solving the problem of control of technical objects under conditions of uncertainty

This work is a continuation of the research carried out by the authors on the development of effective control methods based on a hybrid approach [10], intelligent controllers [11, 12], and methods for their optimization [13].

The method that allows to provide the desired control of a technical object operating in changing conditions is determined by the following steps.

1. Development of a hybrid model for managing technical objects using PI- and IPI-FUZZY controllers, PID- and IPD-FUZZY controllers. In hybrid models, rule bases for fuzzy controllers are formed automatically using the developed algorithm [14] based on reference systems, which are understood as control loops using classical PI and PID controllers, respectively. Next, the models are launched to save the performance indicators of the classical and fuzzy controllers (the indicators are recorded in special program files).

2. Development of the ANFIS model in the form of a hybrid network based on PI and IPI-FUZZY controllers, as well as PID and IPD-FUZZY controllers.

When implementing a model based on PI- and IPI-FUZZY-controllers, the error indicators of the output signal, its integral and control action, obtained as a result of the operation of the classical controller, are the data used to test the efficiency of the hybrid network in order to identify the fact of its retraining, and the error indicators output signal, its integral and control action, obtained as a result of the operation of the fuzzy controller, form a training sample for building a hybrid network.

In the case of developing an ANFIS model in the form of a hybrid network based on PID and IPD-FUZZY controllers, the indicators of the error of the output signal, its differential and the control action obtained as a result of the operation of the classical controller are data used to test the efficiency of the hybrid network in order to identify the fact its retraining, and the indicators of the error of the output signal, its differential and control action, obtained as a result of the operation of the fuzzy controller, form a training sample for building a hybrid network.

3. Generating the structure of fuzzy inference systems of the Cygeno type, which are models of hybrid networks.

4. Training of hybrid networks in the MATLAB system.

5. Integration of the generated Cygeno-type fuzzy inference systems into the Simulink interactive system for simulation.

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6. Performing research on the operation of hybrid models in the event of the following changes in control situations:

- for a hybrid control model of a technical object using PI- and IPI-FUZZY-regulators, a disturbing action is introduced, the parameters of the control object are changed;

- for a hybrid control model of a technical object using PID- and IPD-FUZZY controllers, a perturbing action is introduced.

The models considered in this paper, in which control is carried out using hybrid controllers implemented on the basis of the sequential interaction of PI- and IPI-FUZZY controllers and PID- and IPD-FUZZY controllers, are shown in Figures 1 and 2, respectively.

In the simulation scheme in Figure 1 and its individual subsystems, the area of change in the control situation in the form of a perturbing action is marked with a dotted rectangle. For the control object in the form of an engine (DPT NV), the parameters Kdv were changed. (from 0.2210 to 0.0128), as well as Kreg. (from 3.7 to 63.63).

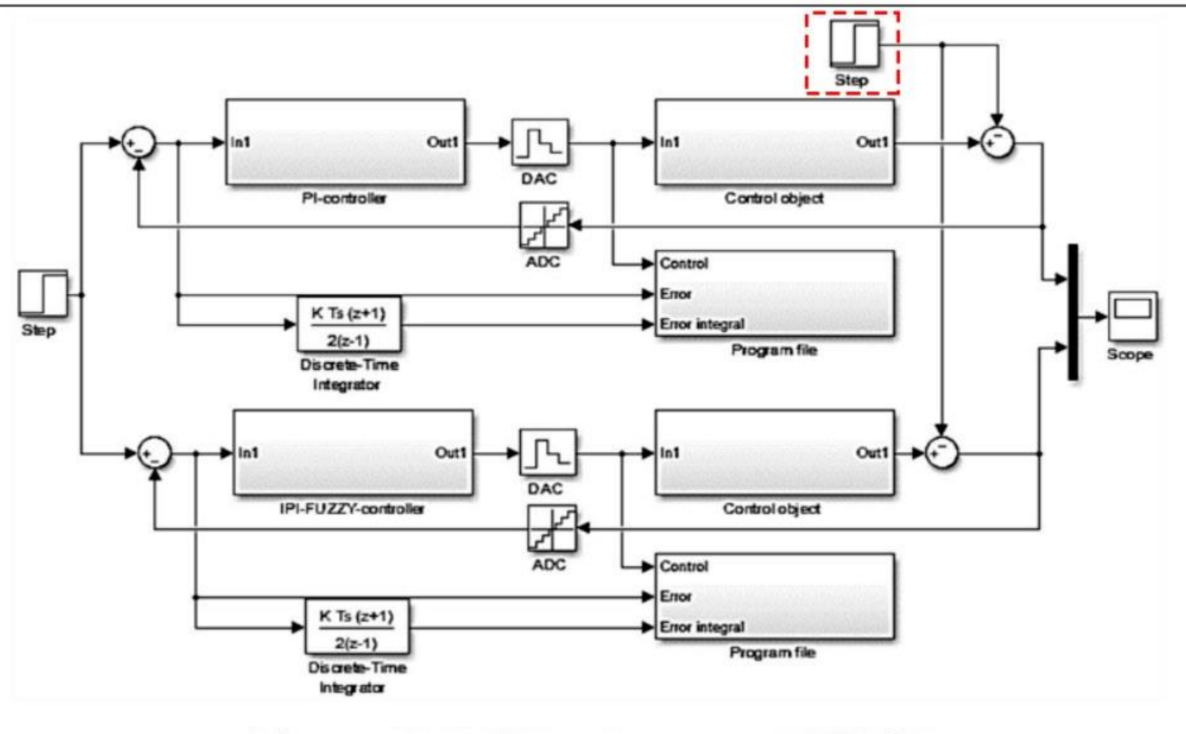

Fig. 1. A model based on PI and IPI FUZZY controllers

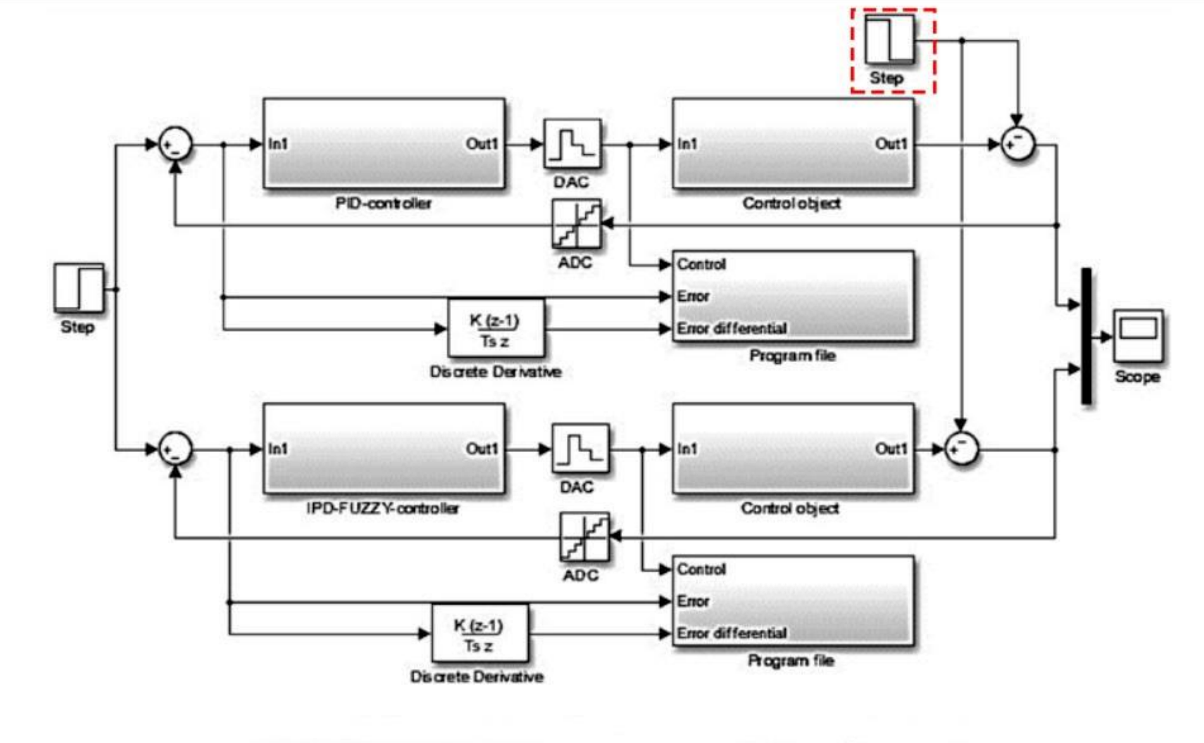

Fig. 2. A model based on PID and IPD FUZZY controllers

In the simulation scheme (regulation of the concentration of the output flow in the mixer) in Figure 2, the area of change in the control situation in the form of a perturbing action (10% of the value of the input action at the start) is marked with a dotted rectangle. As a result of the simulation, transient graphs were obtained and a fuzzy inference surface was constructed

Digital analysis of the quality of transient processes, performed in [10] in terms of the main indicators (overshoot value (s, %), regulation time (treg., s), number of oscillations (n), time to reach the first maximum (t1max, s)), showed that the use of hybrid controllers implemented on the basis of the sequential interaction of PI- and IPI-FUZZY-controllers, as well as PID- and IPD-FUZZY-controllers with the generated structure of the Cygeno-type fuzzy inference system and the developed ANFIS model and with the automatic formation of the rule base of the fuzzy controller , obtained from the classical controller with subsequent training, allows you to increase the efficiency of managing a technical object in conditions of incomplete data.

The quality indicators of transient processes obtained when the object is controlled using IPI-FUZZY- and IPD-FUZZY-regulators are higher than when the object is controlled using classical PI- and PID-regulators.

However, in accordance with the task set, it is necessary to analyze the control signals obtained in hybrid controllers based on a comparison of the results of the operation of a classic PI controller with an IPI-FUZZY controller and a classic PID controller with an IPD-FUZZY controller in order to obtain information on the possibility of using IPI -FUZZY- and IPD-FUZZY-regulators in practice.

To do this, in the model in Figure 1, graphs were obtained for each signal (control action, error, error integral) after the development of ANFIS in the form of a hybrid network based on PI and IPI-FUZZY controllers.

In the model in Figure 2, plots for each signal (control action, error, error differential) are obtained after the development of ANFIS in the form of a hybrid network based on PID and IPD-FUZZY controllers.

Analysis of the results

The graphs of changes in the signals of the control actions of PI and PID controllers are either on the border of the negative area, or in the area itself when controlling a technical object operating in changing conditions. For control objects, the input signal of which can only change within positive limits, the use of PI and PID controllers will lead to a deterioration in quality indicators. In addition, the overshoot with these controllers was 10% ,which may be unacceptable due to the process conditions.

The graphs of changes in the signals of control actions of IPI-FUZZY- and IPD-FUZZY-regulators are in positive areas, in addition, the amplitude of control actions does not exceed 5.2 versus 15 for classical regulators, which indicates their possible application in practice to obtain the desired control with maximum quality in case of changing control situations.

Discussion

The solution of modern applied problems related to the automation of technological processes requires the use of conceptually new approaches and control methods. The world scientific community offers ways to solve such problems using both advanced traditional methods and methods based on artificial intelligence. In most articles, where scientific results are presented in the form of algorithms or models, modeling is carried out in special software packages that allow evaluating the final results obtained, for example, graphs of transient processes when solving the problem of controlling a technical object.

However, obtaining the required (satisfactory) transient process does not guarantee the possibility of using one or another model (controller) in a real technological process. This was also shown by the results of the studies presented in this article in relation to the control of technical objects using traditional PI and PID controllers. With some requirements for the quality of transients, these PI and PID controllers cannot be applied in practice. Therefore, a detailed analysis of control loops in the process of laboratory research is necessary to verify the adequacy of the results obtained.

Conclusion

In real production, automated control systems are constantly becoming more complex, optimized, and require scaling and integration. This is due to the complexity of control objects and their number. The development and programming of a real automated control system is a complex task, depending on the number of input and output parameters. Even more difficult is the task of developing the scientific foundations applied to these systems. Therefore, the analysis of regulators used in control models of technical objects, including those operating in changing conditions, is of scientific and practical interest.

The analysis of hybrid controllers carried out in this article in the control models of technical objects operating in changing conditions made it possible to give an adequate assessment of the possibility of applying the presented controllers in practice.

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