Simulation of a Hybrid Operation of the System with a Simplified Version of the Fuzzy PD-Controller

Bohdan Durnyak[a], Mikola Lutskiv[a], Petro Shepita[a]

[a] *Ukrainian Academy of Printing, Pid Goloskom str., 19, Lviv, 79020, Ukraine*

Abstract

A mathematical model of the automatic control system with a combined fuzzy PD controller has been developed. The blurring of the P - component of control has been carried out based on three linguistic variables of the normalized error signal. The fuzzy control described by the fuzzy base of rules has been given, membership functions have been chosen, and their parameters have been adjusted, a synthesis and analysis of a hybrid robust system having a simplified rule base with a fuzzy PD-controller for objects with variable parameters has been carried out, a simulator of the system has been designed. For the convenience of adjustment and research of separate blocks and system visualization blocks have been provided. An example of synthesis and modeling of a combined fuzzy system for inertial objects of the third and fourth order has been considered. The settings for adjusting the controller have been defined and adjusted. The results of simulation modeling in the form of transient characteristics for objects of different dimensions that satisfy the specified parameters of quality control and provide better quality indicators than with a traditional controller have been given, and the results of simulation modeling have been presented.

Keywords 1

controllers, fuzzy, combination, object, parameters, variable, model, robust, scheme, simulation

1. Introduction

The current state of production, the requirements for the quality of manufactured products put new requirements for the design and development of control systems able to provide a high level of productivity of technological processes and objects with short information concerning the object and its parameters change, depending on the mode of operation and the effects of various perturbations. The main disadvantage of the control systems with traditional controllers is that they do not provide the quality of regulation when changing the object parameters. For example, an increase in the transfer coefficient of an object causes significant fluctuations in the system and it may become unstable, which impairs the quality of regulation and the quality of the finished product. The application of the principles and methods of adaptive control and intelligent management is complex and expensive, which limits their application for simple objects. Therefore, a highly relevant are the tasks of a simulator design and development, synthesis and analysis of a hybrid system with a simplified database having a fuzzy PD controller for objects with variable parameters as well determination and adjustment of parameters and research.

2. Literature review

Nowadays there is the development and practical application of fuzzy control systems in various fields of science and technology. The popularity of fuzzy sets in design is due to the fact that fuzzy

IntelITSIS'2023: 4th International Workshop on Intelligent Information Technologies and Systems of Information Security, March 22–24, 2023, Khmelnytskyi, Ukraine
EMAIL: durnyak@uad.lviv.ua (Bohdan Durnyak); lutolen@i.ua (Mikola Lutskiv); pshepita@gmail.com (Petro Shepita);
ORCID: 0000-0003-1526-9005 (Bohdan Durnyak); 0000-0002-2921-3662 (Mikola Lutskiv); 0000-0001-8134-8014 (Petro Shepita)

systems are developed faster, hardware implementation is simple, it is even simpler and cheaper than traditional ones. [1-6]. The application of fuzzy systems is quite wide-spread: from household washing machines to fuzzy controllers for automotive transmissions of Porsche, Peugeot and Hyundai [7-12]. However, to design and operate fuzzy systems, basic knowledge of the theory of fuzzy sets and fuzzy logic is required.

Fundamentals of fuzzy modeling and fuzzy control have been presented in the publications [11, 13-15], which describes the theory of fuzzy sets, fuzzy models and systems. In the articles [16-22] different versions of fuzzy controllers have been presented, as well the rules base, structural schemes of different types of controllers, their synthesis and analysis. Publications [3, 9] provide a linguistic description, structural schemes of digital fuzzy controllers, and the synthesis of the systems, including non-stationary, simulation results, and graphs of transient processes for various types of static and astatic objects of various order.

To simulate and develop fuzzy systems, Matlab: Simulink software package is used, it is an important subject in mathematical and engineering education at the universities of Western Europe, the United States and other countries [23, 24, 25, 26]. However, in the Fuzzy Logic Toolbox library, the Fuzzy Logic Controllers block does not have a direct access to its individual parts, in particular, the blocks of normalization and denormalization of output and input signals, which greatly limits the ability to simulate and study fuzzy control systems, including setting up the fuzzy controller parameters. Important tasks of normalization and especially denormalization in fuzzy models and systems have been presented in general [8, 15]. The research has shown that the choice of parameters of normalization and especially denormalization greatly affects the development of the physical regulatory effect on the object, the quality of regulation and the properties of the fuzzy system in general [27-30].

3. Design and modeling of a hybrid system with fuzzy PD - controller

The main task when designing the control system is the choice of the law (algorithm) of controller operation, as well as the calculation of the adjustment parameters, which should provide the necessary quality of regulation, so that the transients and static accuracy in a closed system satisfied the quality indicators for specified parameters of the regulated object. The existing simplified methods of calculation allow determining the numerical values of the parameters of debugging the regulators using formulas or graphs linking these values with object parameters [1, 4, 30].

The main advantage of traditional proportional P-controllers is the simplicity in implementation and setting, they create an instant proportional control effect on the object, therefore, relatively quickly correct the deviations of the adjustable value from the specified value. They are used for objects of medium capacity and small order, with a slight delay and flood changes of loads [1, 27]. The production controller forms a regulatory action (control) on the object [4, 28].

$$\mathrm{V}(t) = k_p e(t), \tag{1}$$

where e(t) is the control error, k_p is the transmitter of the controller.

Deviation of the adjustable value from the set value (error signal)

$$e(t) = y_0(t) - y(t), \tag{2}$$

where $y_o(t)$ is the specified value of the regulated quantity, y(t) is the regulated value (output of the system).

To ensure the zero error of regulation, the value of the signal e (t) = 0 is required. However, at zero value of the error signal according to the expression (1), the control action of the controller V (t) = 0. Although at zero value of static error, the controller must form a constant value of control on the object. In order to increase the accuracy of the system with the P controller, it is necessary to increase the controller's transmission coefficient, however, an increase in the transmission coefficient causes a fluctuation of the regulated value relatively to the specified value and the system may become unstable, which is a significant disadvantage that limits the use of the P-controller. To improve the accuracy of the system I-component of control is introduced [3, 29], which, if there is a deviation of the regulated magnitude, gradually increases, resulting in the regulatory control "lags" from the change in deviation, which can lead and often leads to the generation of weakly damped fluctuations of the regulated value, which is a significant disadvantage. To eliminate the oscillation, it is necessary to reduce the transmission factor of the I-component, which reduces the system performance, which is a disadvantage of the PI controllers. To increase the speed of operation, systems enter the differential component of the control law. Such controllers are called PID controllers, which are more complex than the previous ones.

The second approach to the design of controllers is that the proportional controller additionally introduces the initial value (offset) of the signal, which specifies the neighbourhood (work point) of the controller operation, then the adjusting action on the object is

$$V(t) = k_p e(t) + U_0, \tag{3}$$

where U_0 is the initial value of the control signal.

In general, the area of the initial control signal depends on the adjustable set value and the load on the object, which depends on the mode of system operation; it can vary widely and in most cases is unknown. Therefore, the initial value of the signal management will be determined on the basis of a predetermined value of the regulated quantity which is known

$$U_0 = k_c y_0, \tag{4}$$

where k_c is the desired transmission coefficient which provides the predetermined neighbourhood.

To determine a neighbourhood let us consider the work of the control system supplied with the presented controller for constant operation mode. After substitution of expression (4) in (1) we got the adjusting action on the object

$$V = k_p e + k_c y_0. \tag{5}$$

Hence output of the system is

$$y = k_p k_o e + k_c k_0 y_o, \tag{6}$$

where k_0 is a transfer coefficient of the static control system.

Based on the facts let us determine the dependence of regulated value from the set value for closed system.

$$y = \frac{k_p k_o + k_c k_0}{1 + k_p k_o} y_o. \tag{7}$$

By analogy let us determine static error of the closed system.

$$e = \frac{1 - k_c k_0}{1 + k_p k_o}. \tag{8}$$

In order that static error equals zero we have to do the equation.

$$1 - k_c k_0 = 0. \tag{9}$$

Hence let us determine the desired value of transfer coefficient that provides a set neighborhood.

$$k_c = \frac{1}{k_o}. \tag{10}$$

If transfer coefficient k_c is determined on the condition (9), then the static error (8) of the proportional controller system equals 0. Hence in a given hybrid system with P-controller in theory it is possible to obtain 0 static regulation error without introducing I-component into the regulation algorithm, which adds additional inertia to the system and worsens its dynamic properties. Since the coefficient k_c is in the numerator of the closed system equation (7) and (8), the introduction of the initial control signal channel (4) in the controller will not affect the stability of the closed system, which is an advantage of the system.

To improve the dynamic properties of the proposed hybrid system and provide robustness with in relation to the variation of the object parameters, we use a simple version of the fuzzy PD controller which forms a controlling action based on fuzzy logic [8, 30]. The differential component of the algorithm is implemented by the first difference of the normalized error signal E_n-E_{n-1}. The synthesis of the fuzzy controller consists in the choice of the membership functions of the sets of linguistic variables, the fuzification and defuzification algorithm, the fuzzy output, and the optimization of the main parameters of the controller by minimizing the selected quality criterion of a closed system [3]. To synthesize a fuzzy controller, we assume that the number of time-sets which help to estimate the linguistic variable-error of regulation is to be equal to three. The fuzzy simple version of the PD-controller is based on the knowledge of the state of the control process described by the linguistic variables [8], namely, the error is negative, zero, positive, then the control is described by a fuzzy rule base:

$$R1{:}\,If\ (E = N)\ Then\ (U_n = A)$$
$$R1{:}\,If\ (E = O)\ Then\ (U_n = B)$$
$$R1{:}\,If\ (E = P)\ Then\ (U_n = C), \tag{11}$$

where E is the normalized input of control error, Un is normalized control, N, O, P are fuzzy linguistic sets that qualitatively evaluate the control error: N is a negative error, O is a zero error P is a positive error.

Fuzzy linguistic models and sets A, B, C, which are described by the membership functions given by the type L are left, and P as right are the external ones however the mean triangular membership function [1, 3], have been used to design the fuzzy controller. The main parameter of the membership functions is the width of the window which is taken as equal to 1. Since the functions of the membership of fuzzy sets are normalized, and their values are in the range [0, 1], the input error signal must be normalized (scaled). Different methods of normalization [3, 8] are known. In order to use them we must know the ranges of changes in the input and output signals of the controller (the minimum and maximum value of the error of regulation), which makes it difficult to normalize. It is proposed to evaluate the maximum range of error correction Em = [0, y0], on the basis of which a normalized error for an arbitrary task is defined [6].

$$E = \frac{1}{y_0} e, \tag{12}$$

where y_0 is the set rate of the regulated value at the input of the system, which is known and can vary widely, depending on the operation system mode .

The normalized control formed in accordance with fuzzy rules (11) can be within [-1, 1], so to develop a physical regulating action on the object it is necessary to carry out its denormalization (scaling) and take into account the initial value of the control signal U_0.

$$V = MU_n + \frac{1}{k_0} y_0, \tag{13}$$

where M is the scale factor which is the main parameter of adjustment of the fuzzy controller and is chosen depending on the predefined quality control criterion.

Based on rule (11), selected membership functions, fuzification and defuzification operations, and regulatory actions on object (13), a structural scheme of a hybrid control system model with a simplified version of a PD-controller with a third-order inertial object in a Matlab: Simulink package has been designed (Fig 1).

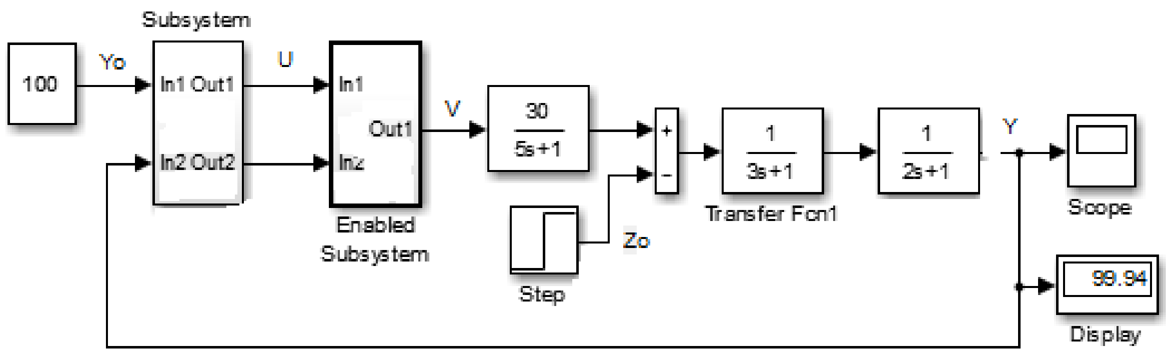

Figure 1: Scheme of fuzzy control system with fuzzy PD-controller

The fuzzy controller consists of two blocks: a normalized PD control algorithm disguised in the *Subsystem* block and *Fuzyfication* and *Defuzyfication* blocks disguised in the *Enabled Subsystem* block. The control object model located to the right is provided by the *Transfer Fcn* blocks. The normalization of the error is carried out by the expressions (2) and (12). An *Integer Delay* unit was used to determine the first difference in the error signal.

The scheme of the fuzyfication and defuzyfication units disguised in *the Enabled Subsystem* block is shown in Fig.2

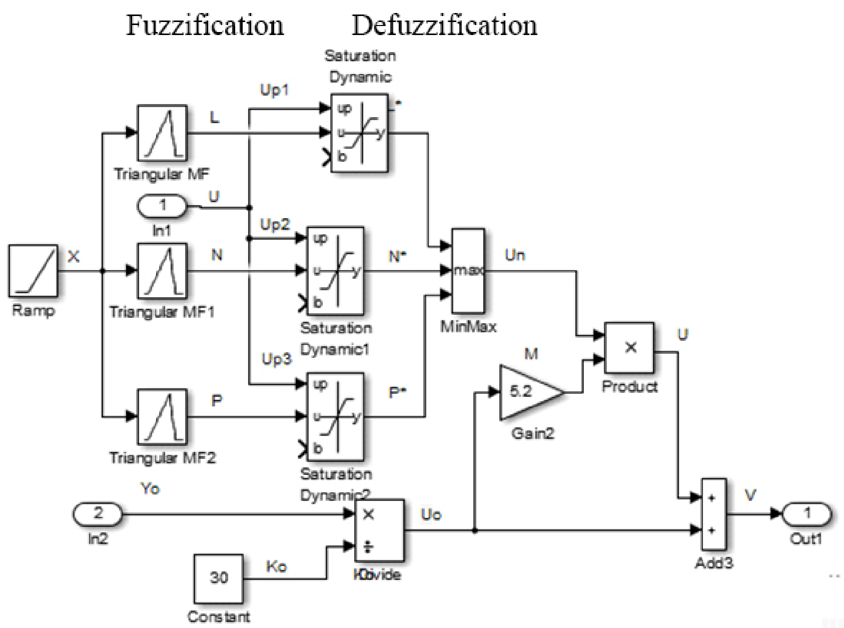

Figure 2: The scheme of the fuzyfication and defuzyfication units

Fuzzy block consists of three blocks of *Triangular* membership function *MF*, two of which are configured for *L*-left and *P*-right outer, but the middle of the triangular membership functions that are activated by a signal *X* from block *Ramp*. Defuzzification blurred signal is carried out by Mamdani method [6] by trimming the membership functions to the level U_p, which is set by the input signal E using the *Dynamic Saturation* blocks. Modified membership function of the set *A*, B*, C** are presented to the input of the MAX operator at the entrance of which is formed normalized control U_n, which is presented to the first input of block multiplication to denormalizing (multiplying by a scale factor M). At the input of the simulator physical regulatory action is formed on the object (13).This action consists of denormalizing control *U* and a predefined initial value of the control signal U_0 according to the expression (4).

4. Simulation results

Based on the above-mentioned, schemes Fig.1 and Fig. 2 a structural model diagram of a hybrid control system with a simplified version of the fuzzy PD-controller with inertial object of the third order has been made by means of the graphical editor and block libraries in the Simulink work window. Blocks of fuzzy function *Triangular MF* for the width of the windows a = 1 were adjusted. The time of quantization 0.15 sec. was set in the dialog window *Integer Delay* block. To study the object k_0=10, $T1$=5, $T2$=3s, $T3$=2s, parameters were set. The value of the controlled variable y_0=100 was taken.

The quality of the designed system was evaluated with a static error, overshooting and speed of operation. The main parameter setting of the fuzzy PD controller is a scaling factor *M*. The objective of the modeling was to determine the properties of the designed system at a variation of parameters of the object at the nominal parameters of the object. The controller for 20% and 5% overshooting was adjusted with the coefficient *M* = 5.2 and 1, 2. The simulation results are presented in Fig. 3 in the form of transients graphs with the step setting y_0=100.

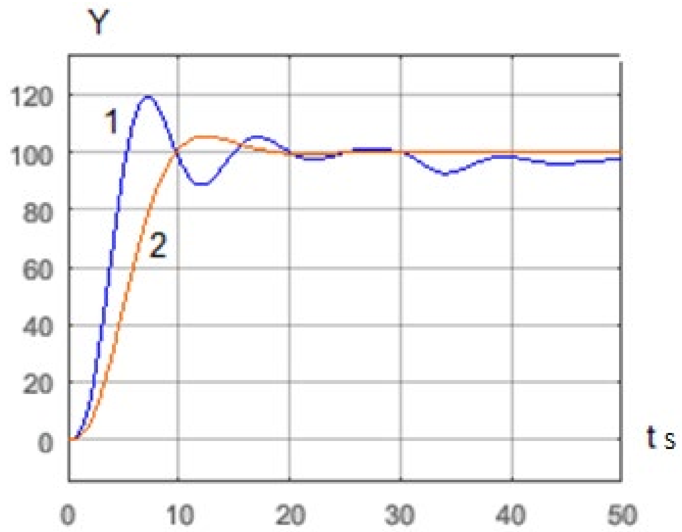

Figure 3: Transient characteristics of the system: 1 - for 20% overshooting, 2 - for 5% overshooting

Analyzing transient processes, we can conclude that the combination of fuzzy PD-controller in the control system with the inertial object of the third order provides the set of overshooting 20% and 5% and sufficiently small static errors of 0.009 and 0.001%. The time to reach the set rate of adjustable values is 5.4 and 10 seconds and the adjustment time is about 20 seconds. After reaching the equilibrium state at time t=30C it was set a sufficiently large disturbance of z_0=20 per the object. The overshooting is 7%, and the static error of the system by the disturbance is 2.5%. Thus a designed hybrid management system with a simple version of the fuzzy PD controller provides a rather small error without the input of I-component in the control algorithm for a given overshooting 20 and 5%. If the quality of the system (overshooting and static error) with the fuzzy PD - controller with three membership functions satisfies the customer, it is possible to recommend the hybrid application of the developed fuzzy controller, as the most simple.

The operation of the system with fuzzy control has been investigated in course of object's parameters changing, that is the increase of the transmission coefficient of the object k_0=30 and 40. In the first case the controller was adjusted to ensure the transition process with a 5% overshooting in the initial system to the scale factor M=5 and the initial displacement U_0=2,85. Simulation results for the coefficients of transfer of the object k_0=10, 30, 40 shown in Fig. 4.

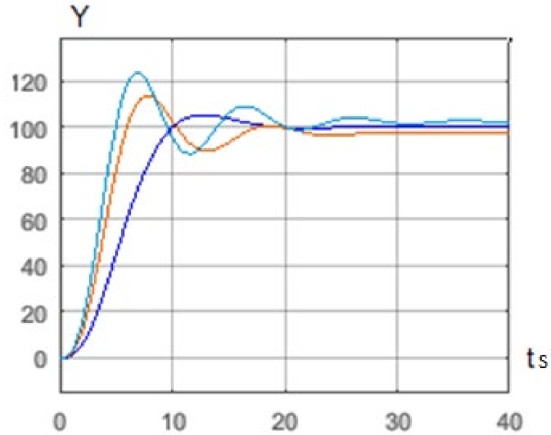

Figure 4: Transient characteristics of the system while increasing the transmission coefficient of the object at the initial system when k_0=10 the overshooting is 5%

With the increase of the transmission coefficient of the object overshooting is 13.4% and 23%, and there are damped oscillations in the system. Static error is 0.0032; 2.63; 1.91%. To compare a system with a classic PID controller with a threefold increase in the transmission coefficient of objects of the third and fourth order are unstable.

In the second case the controller was adjusted under the condition to provide a process with 20% overshooting in the initial system. The controller was adjusted at the scale factor M=7 and the initial displacement U0=3,70. Simulation results are represented in Fig.5.

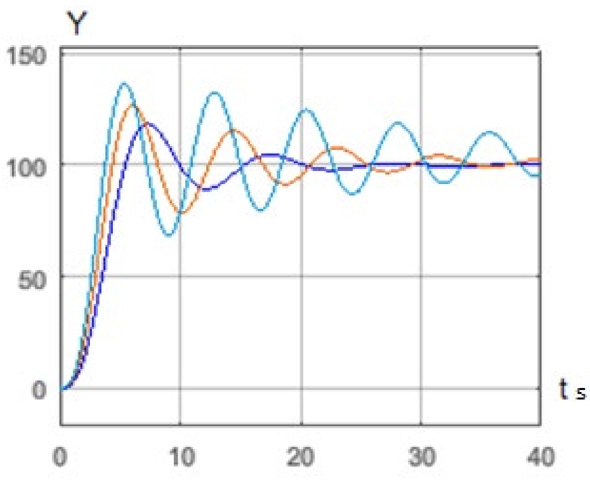

Figure 5: Transient characteristics of the system with the increase of the transmission coefficient of the object

When transmission coefficient of the object is k_0=10, the overshooting is 20%. The increase of the transmission coefficient up to 30 and 40 causes an overshooting of 27% and 36%. The static error is 0.0017; 1.27; 3.68%. Increasing the transmission ratio by 4 times degrades the quality of regulation. However, the system is stable and workable. Therefore, the set value of overshooting significantly affects the quality of regulation, which must be taken into account when designing a fuzzy controller and its adjustment.

The influence of the time constant of the objects on the quality of regulation with a fivefold increase and reduced time constants, that is *T1* = 25, *T2* = 15 seconds and with constant transmission coefficients of the object k_0 = 10 has been investigated. The simulation results are shown in Fig. 6.

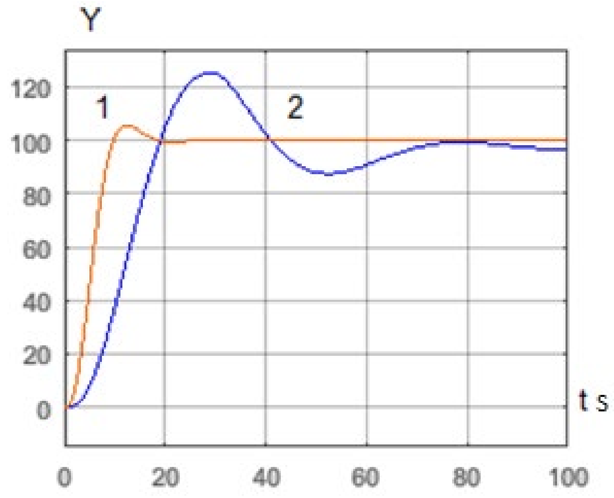

Figure 6: Transition characteristics of the system when decreasing and increasing of the time constant of the object

Changing the time constant of the object of regulation has little effect on the quality of regulation. Overshooting is 5% and 25%. Instead, the time of regulation varies widely, which is a natural phenomenon due to the change in inertial properties of the object. Based on the results of simulation and built transition characteristics of the system when changing the parameters of the object in wide limits, we conclude that the proposed hybrid fuzzy PD-controller with a simplified version provides a stable operation of the system and the quality of regulation, has robust properties, is simpler than the traditional adaptive systems. If the system quality (overshooting and static error) at the variation of the parameters of the object within the specified limits with the fuzzy PD-controller with three membership functions satisfies the customer, then the application of the developed hybrid fuzzy controller can be recommended as the simplest, which has robust properties and is simpler than the traditional adaptive systems.

.

5. Conclusions

Nowadays, there are no generally accepted reasonable methods of synthesis and determination of parameters for setting fuzzy regulators, which makes it impossible to optimize them, complicates their development and implementation. The problem of synthesis of the automatic control system with fuzzy regulators is complex and multifaceted, it contains a significant number of partial problems and possible ways to solve them

In the study a new hybrid fuzzy PD-controller with a simplified version and three membership functions was proposed, a structural diagram of the system model and a simulator for its analysis have been designed and developed.

It is proposed to determine the parameters of setting the regulator on the basis of identification of objects by transitional characteristics, provided that the transfer coefficient of the object is equal to one that ensures the choice of parameters of the regulator, regardless of the transfer factor of the object.

It is proposed to determine the parameters of setting the regulator on the basis of identification of objects by transitional characteristics, provided that the transfer coefficient of the object is equal to one that ensures the choice of parameters of the regulator, regardless of the transfer factor of the object. A structural diagram of the fuzzy system model in the MatLab: Simulink package has been developed, which makes it possible to calculate and build transitional characteristics of the system to analyze its properties and interactively test the optimal adjustment parameters of the regulator.

The results of simulation are transient characteristics of the system and it was established that the proposed PD-controller provides a stable operation of the system and good quality of regulation when changing the parameters of the object in wide limits, it has robust properties.

Based on the results of simulation and built transition characteristics of the system when changing the parameters of the object in wide limits, we conclude that the proposed hybrid fuzzy PD-controller with a simplified version provides a stable operation of the system and the quality of regulation, has robust properties, is simpler than the traditional adaptive systems. If the system quality (overshooting and static error) at the variation of the parameters of the object within the specified limits with the fuzzy PD-controller with three membership functions satisfies the customer, then the application of the developed hybrid fuzzy controller can be recommended as the simplest, which has robust properties and is simpler than the traditional adaptive systems.

The system with a hybrid PD-controller is simpler than traditional adaptive systems, which extends their application to manage simple objects with variable parameters..

6. References

[1] Durnyak, B., Lutskiv, M., Shepita, P., Hunko, D., & Savina, N. (2021). Formation of linear characteristic of normalized raster transformation for rhombic elements. Paper presented at the CEUR Workshop Proceedings, 2853, 127-133.

[2] L. Kakinada and K. Singh, “WCA optimized fuzzy PD controller for stabilizing the two wheel self-balancing robot,” 2021 Asian Conference on Innovation in Technology (ASIANCON), 2021., doi:10.1109/ASIANCON51346.2021.9544711

[3] Yang H, Wang Y. Cyclic pursuit-fuzzy PD control method for multi-agent formation control in 3D space. Int J Fuzzy Syst 2021;23(6):1904-13.

[4] Ramos-Fernández, J.C., López-Morales, V., Márquez-Vera, M.A., Pérez, J.M.X. and Suarez-Cansino, J., 2021. Neuro-Fuzzy Modelling and Stable PD Controller for Angular Position in Steering Systems. International Journal of Automotive Technology, 22(6), pp. 1495-1503.

[5] Mai, T.A. and Dang, T.S. (2021) “Optimal Fuzzy PD Control for a two-link robot manipulator based on Stochastic Fractal Search,” The European Physical Journal Special Topics, 230(21-22), pp. 3935–3945. Available at: https://doi.org/10.1140/epjs/s11734-021-00339-y.

[6] Raj, R. et al. (2022) “Derivation and structural analysis of a three-input interval type-2 TS fuzzy pid controller,” Soft Computing, 26(2), pp. 589–603. Available at: https://doi.org/10.1007/s00500-021-06601-8.

[7] Nikita, N. and Bhushan, B. (2022) “Effect of parameter variation of ball balancer system using PD and Fuzzy Control,” 2022 IEEE Delhi Section Conference (DELCON) [Preprint]. Available at: https://doi.org/10.1109/delcon54057.2022.9753641.

[8] Nigam, A. and Sharma, K.K. (2022) “Comparative analysis of power quality using PD & PID controller of hybrid power system,” 2022 6th International Conference on Trends in Electronics and Informatics (ICOEI) [Preprint]. Available at: https://doi.org/10.1109/icoei53556.2022.9776748.

[9] Abdulyaqin, S.O. et al. (2022) “Design and implementation of a modified fuzzy PD controller for the speed control of a brushed DC Motor,” Lecture Notes in Electrical Engineering, pp. 406–415. Available at: https://doi.org/10.1007/978-981-19-3923-5_35.

[10] Lo, J.-H., Wang, P.-K. and Huang, H.-P. (2022) “Reinforcement learning and fuzzy PID control for ball-on-plate systems,” 2022 International Automatic Control Conference (CACS) [Preprint]. Available at: https://doi.org/10.1109/cacs55319.2022.9969795.

[11] Duchen Sanchez, G. et al. (2022) “Observer-based PD controller for a class of high order linear unstable delayed systems,” IEEE Latin America Transactions, 20(2), pp. 291–300. Available at: https://doi.org/10.1109/tla.2022.9661469.

[12] Rai, A. and Das, D.K. (2021) “Ennoble class topper optimization algorithm based Fuzzy PI-PD controller for micro-grid,” Applied Intelligence, 52(6), pp. 6623–6645. Available at: https://doi.org/10.1007/s10489-021-02704-9.
[13] Durnyak, B., Lutskiv, M., Shepita, P., Karpyn, R., & Savina, N. (2021). Determination of the optical density of two-parameter tone transfer for a short printing system of the sixth dimension. Paper presented at the CEUR Workshop Proceedings, 2853 134-140.
[14] Durnyak, B., Lutskiv, M., Petriaszwili, G., & Shepita, P. (2020). Analysis of raster imprints parameters on the basis of models and experimental research. Paper presented at the International Symposium on Graphic Engineering and Design, 379-385. doi:10.24867/GRID-2020-p42.
[15] Durnyak B., Lutskiv M., Shepita P., Nechepurenko V. (2019) Simulation of a Combined Robust System with a P-Fuzzy Controller. Intellectual Systems of Decision Making and Problems of Computational Intelligence: Proceedings of the XV International Scientific Conference, 1020, 570-580.
[16] Imamović, B., Halilčević, S.S. and Georgilakis, P.S. (2022) “Comprehensive fuzzy logic coefficient of performance of absorption cooling system,” Expert Systems with Applications, 190, p. 116185. Available at: https://doi.org/10.1016/j.eswa.2021.116185.
[17] Salem, A.A., ElDesouky, A.A. and Alaboudy, A.H. (2022) “New Analytical Assessment for fast and complete pre-fault restoration of grid-connected fswts with fuzzy-logic pitch-Angle Controller,” International Journal of Electrical Power & Energy Systems, 136, p. 107745. Available at: https://doi.org/10.1016/j.ijepes.2021.107745.
[18] “Fuzzy relations” (2018) A First Course in Fuzzy Logic, pp. 225–252. Available at: https://doi.org/10.1201/9780429505546-12.
[19] “Complex fuzzy sets and complex fuzzy logic. an overview of theory and applications” (2018) Fuzzy Logic Theory and Applications, pp. 309–325. Available at: https://doi.org/10.1142/9789813238183_0011.
[20] Rahmah, F., Hidayanti, F., Wati, E. K., Lestari, K. R., & Sudrajat, S. W. “Solar Panel Motor tracker model comparison between PID and Fuzzy PD” (2022) International Journal of Renewable Energy Research [Preprint], (Vol12i3). Available at: https://doi.org/10.20508/ijrer.v12i3.13117.g8525.
[21] S. Aslam, Y.-C. Chak, M. H. Jaffery, and R. Varatharajoo, “The Fuzzy PD control for combined energy and Attitude Control System,” Aircraft Engineering and Aerospace Technology, vol. 94, no. 10, pp. 1806–1824, 2022.
[22] S. Raja and N. P. Ananthamoorthy, “Evaluation of newly developed liquid level process with PD and PID controller without altering material characteristics,” Journal of New Materials for Electrochemical Systems, vol. 24, no. 3, pp. 218–223, 2021.
[23] E. Ontiveros-Robles, P. Melin, and O. Castillo, “Comparative analysis of noise robustness of type 2 fuzzy logic controllers,” Kybernetika, pp. 175–201, 2018.
[24] J. Yoo, D. Lee, C. Son, S. Jung, B. I. Yoo, C. Choi, J.-J. Han, and B. Han, “Rascanet: Learning tiny models by raster-scanning images,” 2021 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), 2021.
[25] E. Alzaghoul, M. B. Al-Zoubi, R. Obiedat, and F. Alzaghoul, “Applying machine learning to DEM raster images,” Technologies, vol. 9, no. 4, p. 87, 2021.
[26] L. Zweifel, M. Samarin, K. Meusburger, V. Roth, and C. Alewell, “Identification of soil erosion in alpine grasslands on high-resolution aerial images: Switching from object-based image analysis to deep learning,” 2020.
[27] M. Azimipour, R. J. Zawadzki, I. Gorczynska, J. Migacz, J. S. Werner, and R. S. Jonnal, “Intraframe motion correction for Raster-scanned adaptive optics images using strip-based cross-correlation lag biases,” PLOS ONE, vol. 13, no. 10, 2018.
[28] Z. Mingsong, J. Lingwen, and L. Shuxiao, “A transformation of the CVIS method to eliminate the irregular frequency,” Engineering Analysis with Boundary Elements, vol. 91, pp. 7–13, 2018.
[29] J. Harder, “Looking at other Adobe applications for GIF Animation Creation and GIF alternatives,” Creating GIF Animations, 2022.
[30] A. N. Gafurov, T. H. Phung, I. Kim, and T.-M. Lee, “AI-Assisted Reliability Assessment for Gravure offset printing system,” Scientific Reports, vol. 12, no. 1, 2022.