Changing the pulse duration of a PWM as a means of improving the quality of the ACS regulation using ANN

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Abstract. This paper investigates the influence of the pulse width modulator on the quality of the automatic control system. The approach to the study of ACS using real technical means of automation has been described. A comprehensive study using different structures of neuron connections of the neuroregulator is carried out. The dynamics of changes of quality indicators of the ACS regulation when the object parameters change towards increasing and decreasing inertia is considered together with it. The research results for each of the configurations are plotted. The values of the control quality parameters are tabulated for further comparison of the configurations' efficiency.

1. Introduction
Automatic control systems of objects are usually calculated using typical linear control laws [1]. However, practice shows that all realistic control objects are non-linear elements which change their parameters during loading or unloading. If it is not possible to determine the relationship between the dynamic properties of an object and a deterministic mode value, the principles of adaptive control are used [2,3]. These control technologies make it possible to fully automate the process of adjustment of such technological control objects.

A change of operating conditions of an object will entail a change in the quality characteristics of the ACS. It is also possible that when changing the operating mode of the object, the control system may go beyond the limits of the restrictions imposed on the stability margin or, in an extreme case, go beyond the stability limit. All this can lead to equipment failure or create an emergency situation at the power unit.

These non-linear control objects can be regulated by controllers with variable settings that change automatically according to the operating conditions of the object.

A particular type of controller with variable tuning parameters can be an artificial neural network (ANN) [4, 5, 6], which can adjust its output depending on the disturbance acting on its input in the learning process [7].

2. Theoretical foundations
In this research, an automatic control system has been developed with an artificial neural network as the regulator. The structural diagram of the automatic control system model was based on [4]. A schematic diagram of the automatic temperature control system was adopted for the research. It is a single-loop control system, which includes a regulator (ANN), pulse-width modulator, actuator and the control object consisting of two aperiodic links and a delay link. The parameters of the mathematical models of
the equipment were taken from the parameters of the real technical equipment. The investigated structure of the automatic control system is shown in figure 1.

![Figure 1](image)

**Figure 1.** Structural scheme of ACS with neuroregulator.

The purpose of this study is to analyse the impact of the pulse width modulator on the quality of control of the ACS, as well as determining the optimal structure of an artificial neural network from those presented for consideration [5]. For the complex study, the most optimal configuration of the pulse width and structure of the artificial neural network was selected with subsequent analysis of the influence of the object parameters, namely the inertia and time lag, on the quality of regulation. The parameters of the object configurations are presented in the table 2.

The function of shaping the control actions in the regulator's algorithm is realized by the forward ANN of different structure with four neurons, but with different internal links. The structural diagrams of the ANN to be investigated are shown in figures 3, 5 and 7. The optimum values of synaptic weights for each object, ANN structure and activation function are calculated by a separate program block with respect to the ANN structure and object parameters. An external perturbation is also applied to the input of the object throughout the duration of the calculation. A comparison of the different ACS configurations will be based on a modular integral quality index.

The neuronal activation function is a logarithmic function [8] of the form:

\[ \phi(x) = \ln(x + \sqrt{x^2 + 1}) \]

![Figure 2](image)

**Figure 2.** The influence of the input parameter on the value of the activation function.

3. **Research of the first neuroregulator structure**

Three artificial neural network structures (figures 3,5,7) were taken as the basis of this research. All structures are models of a forward propagation system with one input layer, one hidden layer and one output layer.

The first structure to be considered is the one shown in figure 3.
Three configurations of the pulse-width modulator were considered during the study: with standard pulse width, increased pulse width and decreased pulse width. The resulting transients with respect to each trial were plotted in figure 4.

It is easy to see that the pulse width of the pulse width modulator directly affects the quality of regulation. When this parameter is reduced, there is a dramatic increase in regulation quality. The process is no longer oscillating, which is undoubtedly good for the durability of the actuator. When the pulse duration increases, a large dynamic deviation of the first amplitude is observed, exceeding almost 2.5 times the value of the control channel effect. It can be said that acceptance of this parameter is unacceptable, as the output value of the object is in constant dynamics with a large range.

4. Research of the second neuroregulator structure
This part of the paper will conduct a similar study as the first, but using a slightly modified artificial neural network structure. In order to draw objective conclusions the parameters of technical equipment and user settings remained unchanged. The structural diagram of the ANN is shown in figure 5.

The transients in the different configurations of the pulse-width modulator, similar to the first study, are shown in figure 6.
As we can see, the transients with standard and reduced pulse widths differ little from those obtained in the first study. However, the transient plot with increased pulse width of the pulse width modulator is very different. We can see a low frequency self-oscillation but with a larger dynamic deviation. In fact the value is never equal to the set value, so even with a modified neuroregulator structure we cannot say that this configuration is acceptable.

5. Research of the third neuroregulator structure
In order to confirm the conclusions drawn from previous experiments, an additional study was carried out with a modification of the neuroregulator structure. There is still one input layer, one hidden layer and one output layer, however the connections of neurons within the neural regulator have been changed. The structural diagram for the third study is shown in figure 7.

As expected, increasing the pulse width has a negative effect on the regulation quality. This phenomenon can be attributed to the fact that this configuration is too large for such a low-inertia control object. It can also be seen that reducing the pulse width has an extremely positive effect on the transient...
process. This means that there is no oscillation and there is no residual deviation in the value of the output parameter of the object.

The value of the modular integral quality index for each of the experiments was also calculated. The results were recorded in table 1.

Table 1. Research results.

| ANN | Modular integral quality indicator | Pulse duration |
|-----|-----------------------------------|----------------|
|     |                                   | 0.1 | 0.5 | 2 |
| First | 1334                             | 2760 | 9921 |
| Second | 1380                             | 3004 | 5273 |
| Third  | 1461                             | 2736 | 4785 |

The resulting transient images are confirmed numerically. The lowest integral modulus values correspond to processes using small PWM pulse widths.

6. Research of the influence of the inertia of the object

In order to investigate this issue in more depth, the influence of inertia of the object on the quality of regulation at parameters of the pulse-width modulator and configuration of the neurocontroller corresponding to the best value of the modular integral index was investigated. The parameters of the investigated objects are given in table 2.

Table 2. Object parameters.

| Object | Object parameter configurations | Time delay |
|--------|---------------------------------|------------|
|        | $T_d_1$ | $T_d_2$ | $K_a$ | |
| Object 1 | 70      | 15     | 0.65 | 2 |
| Object 2 | 130     | 15     | 0.65 | 5 |
| Object 3 | 200     | 15     | 0.65 | 10 |

Using the first neural regulator structure and the shortest pulse width studied, the following transient plots were obtained (figure 9).

Figure 9. Comparison of transients process.

From the resulting transient graphs, it is easy to see that the inertia of the object has a direct effect on the regulation time. As it was easy to assume, with a higher inertia object, the regulation time increased, while with a lower inertia object the regulation time decreased. It was also a natural phenomenon that the value of the modulus integral index increased (table 3).
Table 3. Research results.

| Object | Modular integral quality indicator |
|--------|-----------------------------------|
| Object 1 | 848 |
| Object 2 | 1334 |
| Object 3 | 1919 |

7. Conclusion

In this article the influence of the pulse width modulator on the quality of regulation of an automated control system was examined, and a comprehensive study of the influence of the structure of the neurocontroller and the parameters of the object was carried out.

The transients obtained in various configurations to be compared were shown in figures 4, 6, 8, 9. The results of calculation of the modular integral quality index are presented in tables 1, 3.

According to the results of the research, we can say that reducing the pulse width of the pulse width modulator has an extremely positive effect on the quality of the ACS regulation. Changing this parameter has eliminated the oscillations of the controlled variable at the object output. Also, changing the control object parameters within a reasonable range did not seriously degrade the appearance of the transient process, but only influenced the control time.

However, such a change in the pulse-width modulator parameter does not affect the ACS positively for all parameters. Frequent switching of the control sign can adversely affect the operation of the actuator or cause it to become inoperative if there is no frequency limiter or high-pass filter.

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