Research of the influence of feedback signals in the neuroregulator on the quality of regulation

D A Dementev, E D Maximova, I A Sysoletin and S V Mezin
National Research University "MPEI", Moscow, Russian Federation

E-mail: DementyevDanA@mpei.ru

Abstract. This paper describes the research on the influence of feedback signals in the neuroregulator on the quality of regulation. The approach to creation of a method of development of automatic control systems using artificial neural networks as a regulator with consideration of real technical equipment of automation is described. The effectiveness of feedback in a neural regulator is analysed by carrying out a complex study in relation to the variation of the object's parameters. For a clear comparison, the transients for each object configuration have been summarised in common graphs. In addition, in order to analyse the effectiveness of the selected configuration, a modular quality index was calculated for each case and these values are tabulated in a common table.

1. Introduction

In the age of digital transformation, the use of artificial neural networks is being actively promoted in the area of manufacturing. Artificial neural networks have found usage in tasks of equipment condition control, in systems of accident prediction, in tasks of electric traffic distribution optimization [1]. At present, automated control systems based on ANN are being actively developed [2, 3, 4]. The theory of neuroregulators [5, 6] and other intelligent control algorithms are also being actively introduced into students' education [7]. As is known, control algorithms using the artificial neural network as a regulator have their own peculiarities. The main of such features is the variability of the regulator structure. In contrast to classical regulators, which have a fixed number of optimized parameters, the neuroregulators have an unlimited number of configuration options depending on their structure. Therefore, there is a need to create a general methodology for the development of automatic regulation systems based on the ANN. It is known, that in classical regulators the presence of feedback, the so-called integrating block, improves the quality of regulation. Therefore, in order to develop a general neuroregulation methodology, it is necessary to research the influence of loopback in the structure of the artificial neural network on the quality of regulation.

2. Theoretical foundations

To perform the experiments, it is necessary to create a simulation model of the automatic control system with neuroregulator. This research is based on a model that is described in detail in [8]. The structural scheme of the investigated automated control system is presented on figure 1.
This is a single-circuit automated control system with one information input and output. To bring the simulation model closer to the real system, technical equipment has been added to the structure, namely a pulse width modulator and an executive mechanism. The object is based on a sequential connection of two aperiodic blocks and a delay blocks. For the research to be complex, it is necessary to investigate the effect of feedback in the structure of the artificial neural network on different objects whose parameters are summarized in table 1.

### Table 1. Parameters of the objects under research.

| Object   | Ta1  | Ta2  | Ka  | Time delay |
|----------|------|------|-----|------------|
| Object 1 | 130  | 15   | 0.65| 5          |
| Object 2 | 65   | 15   | 0.65| 5          |
| Object 3 | 195  | 15   | 0.65| 5          |
| Object 4 | 130  | 15   | 0.65| 20         |
| Object 5 | 130  | 15   | 0.65| 35         |

For each object from the list, it is necessary to find the optimal weighting coefficients of the artificial neural network for each structure of the neuroregulator and compare the results using the modular integral quality indicator.

### 3. Research of a neuroregulator with output neuron feedback

This research is based on the structure of the artificial neural network presented in the figure 2.

To fully research, an n-th degree signal was transmitted through the feedback channel. For example, a zero degree signal means that the artificial neural network has no feedback, while a first degree signal means that the previous value of the output neuron is transmitted via feedback. Transient diagrams for different objects are presented in figure 3-7.
Figure 3. Object 1 transition processes for different feedback degrees.

Figure 4. Object 2 transition processes for different feedback degrees.

Figure 5. Object 3 transition processes for different feedback degrees.

Figure 6. Object 4 transition processes for different feedback degrees.

Figure 7. Object 5 transition processes for different feedback degrees.
It can be seen from figures 3-7 that adding feedback and increasing its degrees does not affect the quality of regulation and adding additional feedback to the neuroregulator structure is not necessary. On the opposite, the neuroregulator without feedback shows better regulation.

It is important to note that in finding the weights of the artificial neural network, a limitation on positive values was used. If these limitations are not taken in the research, the quality of regulation improves (figure 8), but the technical equipment of automation begins to work on wear and tear (figure 9).

**Figure 8.** Transition process without limitation.

**Figure 9.** Performance diagram of AM.

To sum up, in theory the feedback on the output neuron gives a significant improvement in the quality of regulation. However, at creation of simulation models it is necessary to consider influence of technical equipment of automation. Consequently, given the conditions of the real system, feedback does not improve the quality of the process. Therefore, when developing an automated control system, feedback on the output neuron cannot be added to the structure of the neuroregulator.

4. **Research of a neuroregulator with input neuron feedback**

Now, it is necessary to consider the influence on the quality of control of feedback given to the input neuron. The structure of such a neuroregulator is presented in figure 10.

**Figure 10.** Structural scheme of neuroregulator with input neuron feedback.

This neuroregulator structure is researched for the same objects as in the previous research (table 1) and for the same technical equipment of automation. Transient diagrams for different objects are presented in figure 11-12.
Having analyzed Figures 11 and 12 we can draw the following conclusions: feedback on the input neuron does not affect the quality of regulation. For objects 3 to 5, the same studies were carried out and the same results were obtained. These results can be explained by the following assumption: since the feedback signal travels a full path through the artificial neural network, the weight of the feedback signal decreases when passing each hidden layer of the neuroregulator. So there is no need to add feedback to the input neuron to improve the control quality of the automated control system.

5. Conclusions
This article considered the influence of feedback in the ANN on the quality of regulation. Two neuroregulator structures were researched for different objects:
- With feedback on the output neuron;
- With feedback on the input neuron.

The results of all researches are summarized in table 2.

| Object | Modular integral quality indicator |
|--------|-----------------------------------|
|        | N = 0 | N = 1 | N = 2 | N = 3 | N = 4 | N = 5 |
| -      |       |       |       |       |       |       |
| Output neuron feedback |
| Object 1 | 3084 | 3415 | 3234 | 3573 | 3304 | 3553 |
| Object 2 | 2596 | 4632 | 4885 | 4820 | 4631 | 4856 |
| Object 3 | 4424 | 4349 | 4429 | 4425 | 4491 | 3769 |
| Object 4 | 3524 | 4512 | 4691 | 4812 | 4389 | 4614 |
| Object 5 | 3892 | 4891 | 4718 | 4195 | 4367 | 4156 |
| -      |       |       |       |       |       |       |
| Input neuron feedback |
| Object 1 | 3509 | 3611 | 3681 | 3549 | 3486 | 3560 |
| Object 2 | 2987 | 3014 | 3109 | 3714 | 3086 | 2945 |
| Object 3 | 4104 | 4031 | 4215 | 4167 | 4015 | 4239 |
| Object 4 | 4307 | 4219 | 4364 | 4531 | 4311 | 4205 |
| Object 5 | 4412 | 4312 | 4517 | 4369 | 4390 | 4431 |

The table above summarizes all modular integrated quality indicators that were obtained during the research. According to the research results, the main conclusion can be made: feedback in the structure of an artificial neural network does not affect (structure of the ANN presented in Fig. 10) or reduces the
quality of regulation of an automatic control system (structure of the ANN presented in Fig. 2). At the same time, the feedback degree also has no impact on the quality of the ACS. The conclusions are correct for single circuit automated control systems only. For the conclusions to be correct for any control system, it is necessary to conduct the same research for the following systems:

- multi-circuit automated control systems;
- multidimensional automated control systems.

A classic object was selected as an object. That's why it is necessary to perform research for other objects, for example, for low-inertia objects. Automatic control systems based on artificial neural networks is a new and actively developing trend in automation, which requires the creation of a general methodology for the development of neuroregulators. The main advantage of neuroregulators as opposed to classical regulators is the simplicity of parameter optimization for any system complexity. But this is only possible by creating a methodology. To create the methodology, it is necessary to research the influence of each neuroregulator parameter. This article describes the influence of only one custom parameter. To create a general methodology, it is proposed to research the influence of the following elements of the artificial neural network structure on the regulation quality of the automated control system:

- hidden layer count;
- number of neurons per hidden layer;
- additional information inputs (various mathematical modifications of the object output);
- activation functions;
- Minimum pulse duration of pulse width modulator.

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