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Examining the Effectiveness of Anti-Vibration Gloves With a Neural Network

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Whether anti-vibration gloves are effective in protecting against vibrations depends not only on the materials they are made of, but also on the parameters of the source of vibration. Depending on those parameters, the effectiveness of the same means of protection may be radically different. This article presents a methodology of using a neural network to test anti-vibration gloves. A network can map gloves in various conditions, i.e., for vibrations of various amplitudes and spectra, and for various forces exerted by the worker on a tool. Real, measured vibration signals produced by different tools were used in training a neural network. The results presented in this article prove that real properties of gloves are accurately represented by their models developed as a result of training a neural network.

vibration   anti-vibration gloves   neural network   effectiveness

1. INTRODUCTION

Anti-vibration (AV) gloves are the most common means of personal protection against mechanical vibrations. However, their effectiveness may vary according to the conditions in which they are used. The most important factors affecting their effectiveness (in addition to the properties of the materials the gloves are made of) are the nature of the source of vibration (spectrum, amplitude), the forces exerted by the operator on the tool and the properties of the material that the workpiece is made of. The considered system tool–means of protection–the human body is nonlinear. Identification of such a system in the form of approximating functions is difficult because its exact structure is not usually known. The use of a neural network to model the behaviour of a means of protection in this system makes it possible to approximate any nonlinearities and to tune parameters on the basis of measurement data. Signals characterizing the source of vibration and other signals affecting the AV properties of the means of protection are the input of the artificial neural networks. The networks then produce a signal that excites the tool operator's palm; that is their output.

2. METHODS OF DETERMINING THE EFFECTIVENESS OF AV GLOVES WITH NEURAL NETWORKS

AV gloves can be modelled by identifying them as objects with a known response. The task of an artificial neural network is to select parameters of the object's model so that the model's response best reflects the object's response. In this case, vibrations acting on gloves are input signals and the signals reaching the operator's hand are the object's response (Figure 1).

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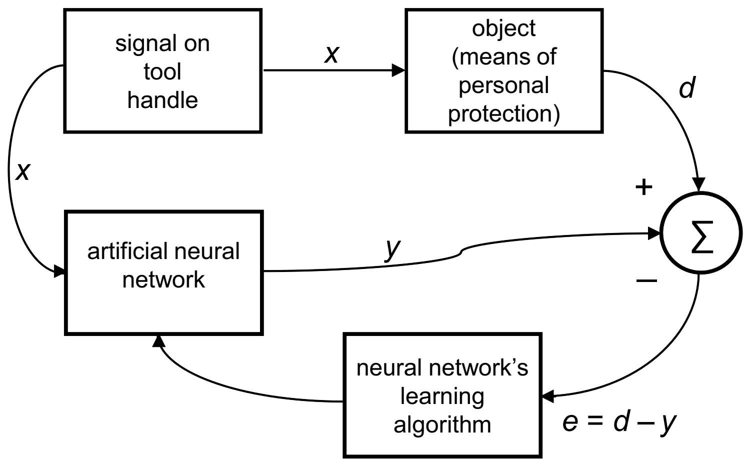

Figure 1. Identifying parameters of anti-vibration gloves with a neural network.

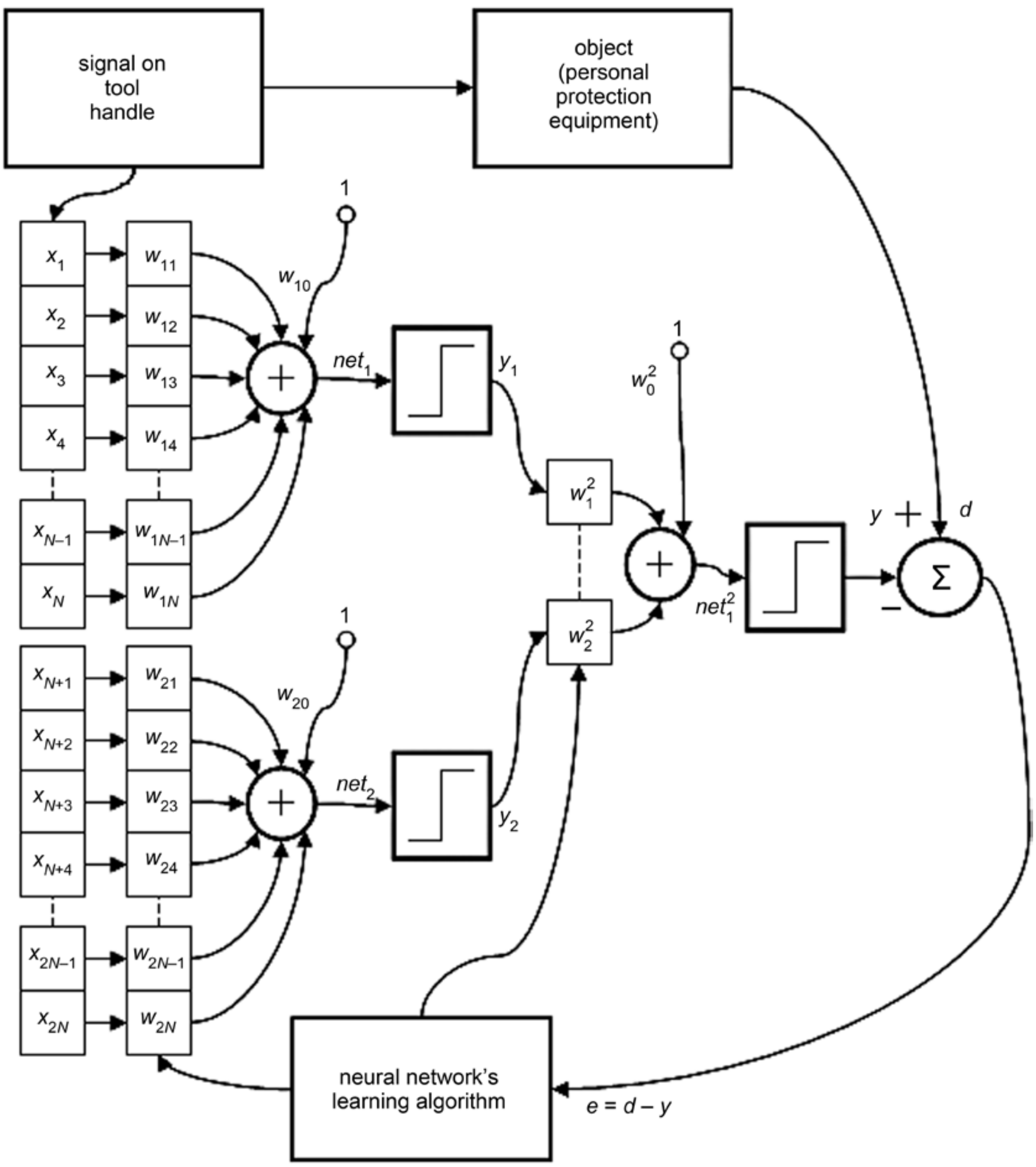

Figure 2. Identifying parameters of anti-vibration gloves with a multilayer, nonlinear neural network.

After the training process based on learning sequences, the neural network of a given structure can be used to simulate the behaviour of gloves for different input signals, which were not included in the set of learning sequences. Different structures of neural networks can be used to model the effectiveness of the means of protection. Within the various individual structures, networks can contain different numbers of neurons. The usefulness of the networks is assessed with simulations studies. A multilayer, nonlinear structure of a neural network is the basis of the methodology of determining the effectiveness of AV gloves. Figure 2 illustrates the process of identifying the parameters of gloves with this structure.

Adoption of an appropriate training method is the most important problem associated with an artificial neural network. The purpose of training is to obtain compliance between the response of neurons $\boldsymbol{y}$ and the required response $\boldsymbol{d}$ for all learning sequences $<\boldsymbol{x}, \boldsymbol{d}>$ used in the training process. For the presented multilayer network structure, the algorithm of backpropagation error was the training method.

2.1. Recording Real Signals During Tests of Vibration Transmissibility of Gloves

In training the neural network, real signals were used to model the means of protection (AV gloves). They were recorded during tests of vibration transmissibility of eight types of AV gloves. Three kinds of the most common hand tools that produce vibrations of various nature were chosen as sources of vibration:

- a hammer drill;
- an angle grinder;
- a pneumatic hammer.

The study was carried out during normal work of three operators of those tools. Signals were recorded in the form of time runs of vibration acceleration on the tool handle and on the operator's palm in the glove (with an adapter with a vibration transducer placed inside the glove) and the feed force exerted by the operator on the tool. Figure 3 is a diagram of the system.

The results of the tests carried out for each glove and for each of the three measurement tools were recorded in measuring information cards; Figure 4 is a sample set of results.

The recorded signals were used in training the developed neural network. Vibration acceleration signals and the signals of feed force were the

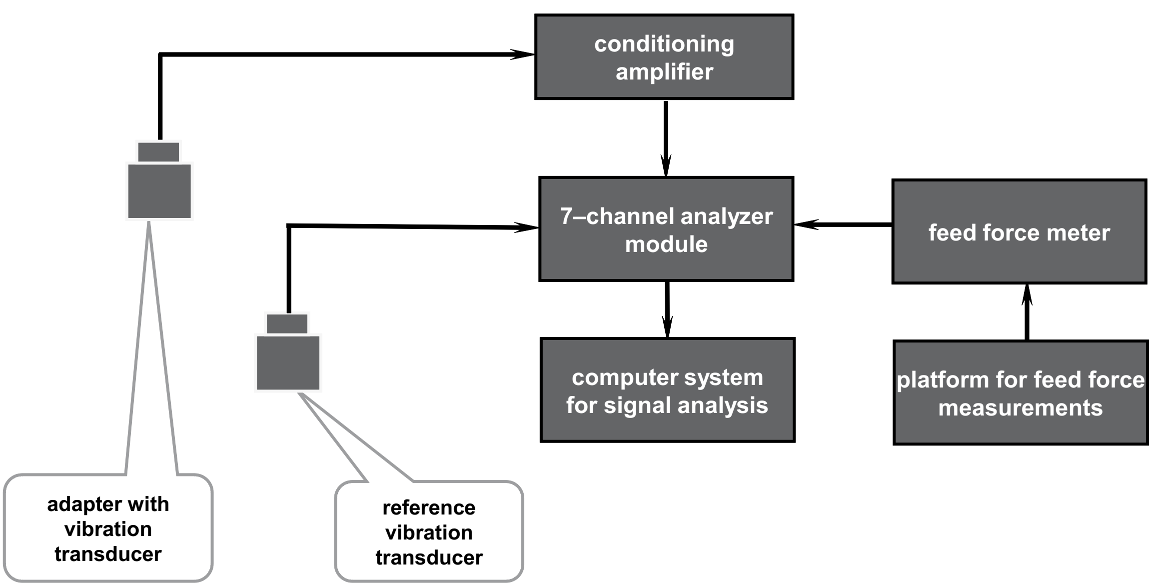

Figure 3. Measuring system for testing the vibration transmissibility of gloves.

Operator	1	2	3
Signal handle	szlif_tema1_r	szlif_tema2_r	szlif_tema3_r
Signal adapter	szlif_tema1_a	szlif_tema2_a	szlif_tema3_a
Feed force	szlif_tema1_n	szlif_tema2_n	szlif_tema3_n

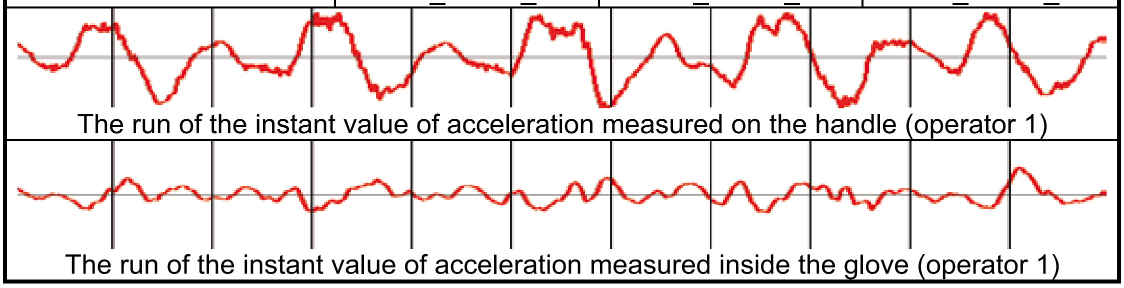

Figure 4. Measuring information card, an example.

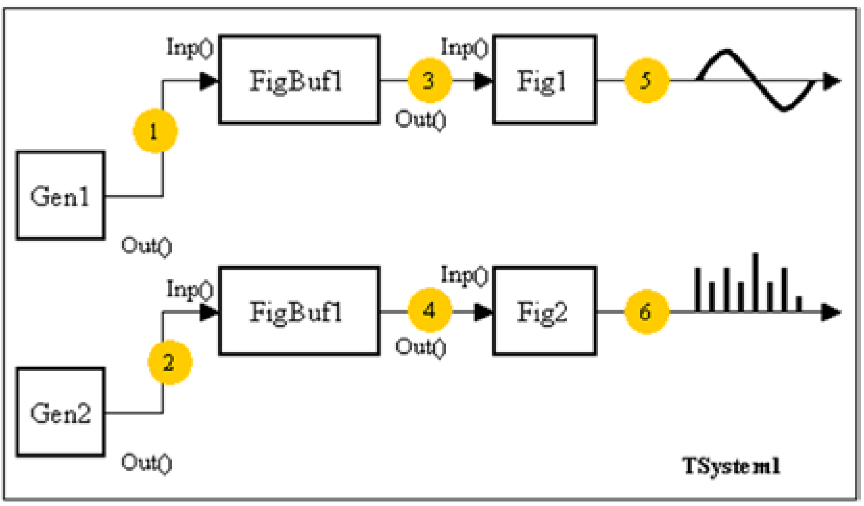

Figure 5. Sample system consisting of two signal generators and recorders for visualizing the runs at the outputs of the generators.

input; the acceleration signal on the operator's palm was the output.

2.2. Software for Simulation Tests

Special software was used in training the neural network and in simulation studies. It was developed as a set of classes for creating different configurations of neural networks and other objects necessary in research. The objects implemented in the software were, among others, sources of test signals (including sources for converting the results of measurements on the test stand) and elements responsible for implementing methods of training neural networks and imaging the results of simulations. The software includes functions for capturing measurement data obtained on the test stand or in real conditions. By simply combining the components it is possible to create any structures of systems: from simple systems for supporting simulation calculations (Figure 5) to complex structures reflecting neural networks (Figure 2).

A set of classes reflecting devices used on the test stand makes it possible, within the same software, to integrate the neural network with component elements of the measurement system and other components of the system modelling the behavior of AV gloves.

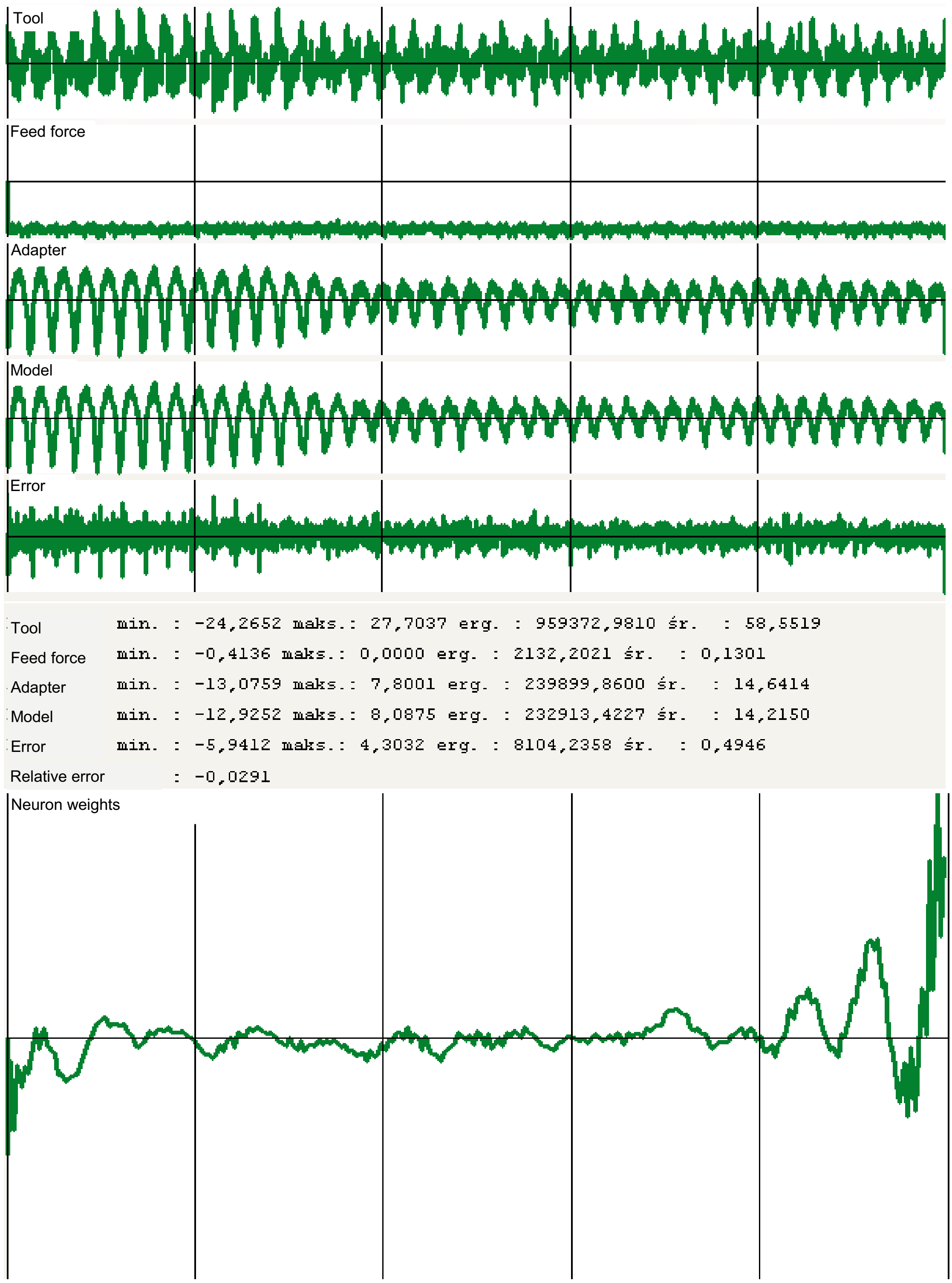

Figure 6. The results of simulation calculations: glove 8/drill 1/operator 3, 256 weights neural network, 128 weights neuron processing feed force.

3. SIMULATION RESULTS

Simulation calculations were done with the developed software. They included changing the parameters of the artificial neural network that reproduced the parameters of AV gloves that protect against hand–arm vibration. Graph and text data were used in a preliminary assessment of the neural network in terms of the accepted parameters (number of weights) and the correctness of the learning algorithm (learning rate factor). The value of the relative error between the sums of squared samples in the buffer of the signal measured on the adapter inside the glove and produced at the output of the neural network representing the glove model and the decreasing run of the error signal were accepted as evaluation criteria. Simulations were carried out for two models of a unidirectional neural network. They differed in the way the convergence rate (adaptation step) of the learning algorithm was implemented. In the first model, there was one adaptation step for the acceleration signal on the tool handle and for the feed force signal. In the second model, the weight coefficients of the neurons which process the signal of the feed force were trained at different convergence rates than the weight coefficients of the neurons that process the acceleration signal. After a pilot learning cycle, subsequent cycles of network learning were repeated until they did not lead to any further reduction in the value of the relative error. The recorded time runs of the acceleration of mechanical vibration measured on the test-handle and on the operator's palm, and the runs of the feed force were used in the simulation calculations. Simulations were performed for sine, noise and real signals measured for various values of feed forces when hand tools were used. Figure 6 shows a sample simulation result.

Figure 7 shows sample graphs of the relative error during the training of the neural network simulating the behavior of the eight tested gloves. They were derived for calculations in which one learning cycle contained a sequence of 16 385 samples.

4. SUMMARY

Training a neural network aimed at obtaining a response as close as possible to a real response of an AV glove used in various conditions. In

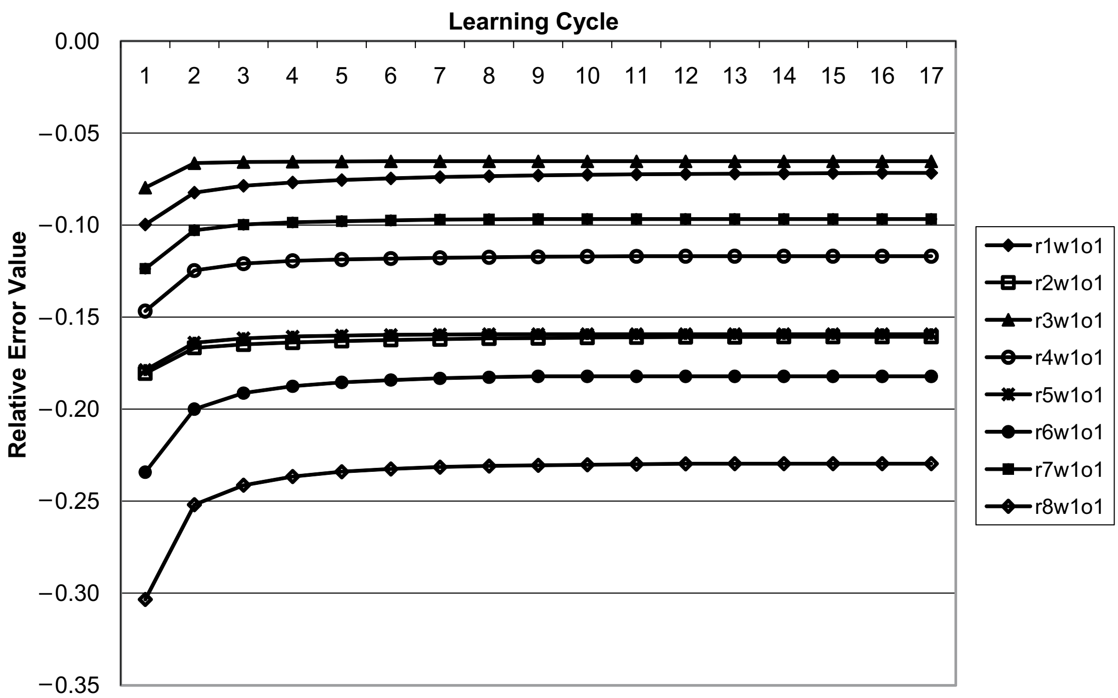

Figure 7. Changes in the value of the relative error when training a neural network simulating the behaviour of 8 gloves (r1–r8) for operator 1 (o1) using a drill (w1).

all cases of training both models of the neural network for different gloves for all operators, the network learning algorithm used was convergent and allowed completion of the learning process after ~10 cycles. The second network model—the one that used different values of the convergence coefficients for the neurons processing the acceleration signal and for the neurons processing the feed force signal—produced a faster decrease in the value of the relative error, which meant a faster process of training and a more accurate model of the glove. Selecting individual learning coefficients made it possible to accelerate the learning process without the threat of losing the stability of the learning algorithm. The value of the relative error between the sums of the squared samples in the buffer of the signal measured on the adapter inside the glove and produced at the output of the neural network representing the glove model was the measure of the quality of the learning process (the accuracy of the accepted neural model). The simulation studies confirmed the correctness of implementing both the neural network and its learning algorithm. There were differences in the values of the relative error; they depended on the tool and the operator who used it. The obtained results demonstrate the great potential of using a neural network for modelling AV gloves.

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