Application of artificial neural networks digital filtering in measurements

O A Galkovskii
Department of BEMT, Vladimir State University, 87, Gorky str., Vladimir, Russian Federation

E-mail: OGVLSU@mail.ru

Abstract. The problem of this paper is suppression of the noise component of the useful signal in the researching of factors affecting the coefficient of friction of a new type of machine polymer guide rail. The parasitic component occurs during measurements, due to the vibration sensitivity of the sensor and the specifics of measurements. To suppress this component, a neural network program filter modelling the noise function has been developed. Filtering of the noise component of the signal occurs in real time, so the requirements of the software to the system resources are the determining factor, with the same accuracy characteristics of artificial neural networks. Thus, the topology of radial basis functions is optimal for the problem of modelling the physical noise function. The software implementation of the neural network filter is made in the "G" language of the LabView development environment. Approaching the number of neurons of the hidden layer to the dimension of the training sample increases the accuracy of the function simulation, but at the same time causes retraining. The accuracy of the simulation of the function of the proposed system was 0.142%.

1. Research problem
The task of determining the factors affecting the coefficient of friction of a new type of polymer guide rail machines and the development of equipment for research and control in the production of tribotechnical parameters of these guide rails in the framework of research work for Vladimir machine-tool plant "Technics". The investigated polymer-metal friction pair is the guide rail of a precision metalworking machine.

When researching the tribotechnical characteristics of the surfaces of the put into operation machines, a separate parasitic component of the useful signal may occur, caused by the characteristics of the measurement conditions due to increased vibration sensitivity of the sensor and the operation of other equipment at the measurement site. Vibrations transmitted to the measuring equipment through the bad from sources outside the measuring unit impose a monotonous noise component on the useful signal.

To suppress this noise, a neural network program filter was developed that simulates the noise function with its further subtraction from the fixed signal.

The fundamental difference between the creation of artificial neural networks (ANN) and the development of classical methods of modelling a physical function is that in the second case, a mathematical model of the studied environment is formed and verified on real data. And ANN is based directly on real data, which allows you to simulate physical processes without accurate knowledge of the functional relationships within these processes.

Thus, neural networks implement a system that fully simulates the process under research.
The main advantages of ANN are parallelization of information processing and the ability to self-study, i.e. to create generalizations. The term generalization refers to the ability to obtain an adequate result on the basis of data that are not encountered in the learning process. Neural networks have the ability to adapt their synaptic weights to environmental changes. In particular, neural networks trained to operate in a particular environment can be easily retrained to operate under conditions of minor fluctuations in the parameters of the environment. These properties allow neural networks to solve complex, large-scale problems that are currently considered intractable.

2. Theoretical basis
A neural network is a distributed parallel mathematical system implemented by software or hardware, consisting of elementary units of information processing, accumulating experimental knowledge and providing them for further processing. ANN is a system of simple artificial neurons connected and interacting with each other in a special way.

A formal neuron is a unit of information processing in a neural network. On the block diagram in figure 1 shows a generalized model of a neuron. In this model, there are three main elements: a set of synapses, an adder, and an activation function.

A set of synapses or connections characterized by their own weight or strength. Specifically, the signal $X_j$ at the input of synapse $j$ associated with neuron $k$ is multiplied by the weight $\omega_{kj}$. The first index refers to the neuron in question and the second-to the input end of the synapse, which is associated with this weight. The synaptic weight of an artificial neuron can have both positive and negative values. The adder adds up the input signals weighted relative to the corresponding synapses of the neuron. This operation can be described as a linear combination.

The activation function limits the amplitude of the output signal of the neuron. This function is also called compression function.

![Figure 1. Nonlinear model of neuron.](image1)

![Figure 2. Graph of multidimensional Gauss function.](image2)

The generalized mathematical model of any neuron has the form:

$$\begin{align*}
  u_k &= \sum_{i=1}^{m} \omega_{kj} x_i, \\
  y_k &= \varphi(u_k + b_k),
\end{align*}$$

where $x_1, x_2, \ldots, x_m$ – input signals; $\omega_{k1}, \omega_{k2}, \ldots, \omega_{km}$ – the synaptic weight of a neuron $k$; $u_k$ – linear combination of input impacts; $b_k$ – threshold; $\varphi(\cdot)$ - activation function; $y_k$ – the output signal of the neuron [1], [2].

Due to the fact that the filtering of the noise component of the signal occurs in real time, and the accuracy characteristics of the considered ANN are the same, the requirements of the software to the system resources are the determining factor. Thus, the topology of radial basis functions (RBF) is optimal for the problem of modelling the physical noise function.

The RBF method is based on the traditional interpolation method in multidimensional space. In the context of neural networks, hidden neurons implement a set of "functions" that are an arbitrary basis"
for the decomposition of input images (vectors) [3]. The basic architecture of RBF networks assumes the presence of three layers. The input layer consists of sensor elements that connect the network to the external environment. It performs a nonlinear transformation of the input space to the hidden space. The dimension of the hidden layer in RBF networks, as a rule, significantly exceeds the dimension of the input layer. It is also important to note the fact that increasing the dimension of the hidden layer increases the accuracy of the approximation.

The method of radial basis functions is reduced to the choice of the function $F$, which has the following form:

$$F(x) = \sum_{i=1}^{N} \omega_i \varphi (\|x - x_i\|),$$  \hspace{1cm} (3)

where $\{\varphi (\|x - x_i\|) | i = 1, 2, \ldots, N\}$ — set of $N$ arbitrary nonlinear functions, $\|\cdot\|$ — the norm, usually the Euclidean norm. Known data points $x_i \in \mathbb{R}^{m_0}$ are chosen as centers of radial basis functions.

Thus:

$$\begin{bmatrix}
\varphi_{11} & \varphi_{12} & \cdots & \varphi_{1N} \\
\varphi_{21} & \varphi_{22} & \cdots & \varphi_{2N} \\
\vdots & \vdots & \ddots & \vdots \\
\varphi_{N1} & \varphi_{N2} & \cdots & \varphi_{NN}
\end{bmatrix}
\begin{bmatrix}
\omega_1 \\
\omega_2 \\
\vdots \\
\omega_N
\end{bmatrix}
= 
\begin{bmatrix}
d_1 \\
d_2 \\
\vdots \\
d_N
\end{bmatrix},$$  \hspace{1cm} (4)

where

$$\varphi_{ji} = \varphi (\|x_j - x_i\|), \ (i, j) = 1, 2, \ldots, N.$$  \hspace{1cm} (5)

The optimal activation function in this problem is a multidimensional Gauss function (figure 2):

$$F_\lambda (x) = \sum_{i=1}^{N} \omega_i \exp \left(-\frac{1}{2\sigma_i^2} \|x - x_i\|^2 \right),$$  \hspace{1cm} (6)

where linear weights $\omega_i$ are defined as

$$\omega_i = [d_i - F(x_i)], \ i = 1, 2, \ldots, N,$$  \hspace{1cm} (7)

where $d_i$ — the desired response, and $F(x_i)$ is the corresponding output signal.

In ANN theory, the problem of modelling a function of a physical process is reduced to solving the regularization problem through the decomposition of this function by a neural network into classes of elementary components.

This activation function has an output maximum equal to 1 if $x = x_i$. As the distance between the vectors decreases, the output of the radial basis function increases. Thus, the radial basis neuron acts as an indicator that generates a value tending to 1, when the input $x$ tends to the weight vector $x_i$ [1-6].

3. Results.

The software implementation of the neural network filter is made in the "G" language of the LabView development environment.

The ANN learning process is the following algorithm. An arbitrary array of the amplitude of the simulated function is divided into component parts, the latter is the purpose of training, and the rest are fed to the ANN inputs. The filtered noise function is periodic, due to the measurement conditions, so the learning process is cyclical and ends when the specified accuracy index is reached (figure 3).

![Figure 3. ANN learning subroutine Block diagram.](image-url)
The subroutine selects the reference centers of the hidden layer functions based on the training objectives and initiates the subroutines for calculating the weights of the hidden layer and the output layer. Both algorithms are reduced to solving the regularization problem and selecting the weights of the hidden and output layers of the ANN.

The approximation of the number of neurons of the hidden layer to the dimension of the training sample increases the accuracy of the function simulation, but at the same time reduces the flexibility of ANN, i.e. causes retraining. At the same time, at 70 neurons of the hidden layer, the model error is ±15.5%, at 100 neurons - ±7.5%, at 120 - ±1%, at 130 - ±0.071%. Further increase in the number of neurons is impractical, since the accuracy of this ANN is sufficient within the framework of the problem and further increase in the number of neurons will lead to retraining of ANN. Figure 4 shows the waveform of the noise function (top) and the simulated ANN function (bottom).

![Waveform of noise functions (upper) and simulated ANN (lower).](image)

**Figure 4.** Waveform of noise functions (upper) and simulated ANN (lower).

### References

1. Haykin S 2006 *Neural networks. A comprehensive foundation* (New Jersey: Prentice Hall) p 103
2. Lanczos C 1997 *Linear Differential Operators* (London: Van Nostrand) p 564
3. Legaev V P Generalov L K and Galkovskii O A 2016 *Russ. Ingin. Res.* 36 7 565-70
4. Gorbachenko V I 2007 *Neurocomp.: develop., app* 9 150-9
5. Broomhead D S and Lowe D 1988 *Complex System* 2 321-55
6. Tihonov A N 1963 *Dokl. Akad. Nauk. USSR* 1151 501-4