Development of a neural network model for controlling the process of dosing bulk food masses

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Abstract. The current problem of automatic control of the process of dosing bulk food masses is considered and analyzed on the basis of the development of a mathematical model using the apparatus of artificial neural networks. The purpose of this work is to obtain recommendations for using a neural network model with a PID controller.

1. Introduction

In modern technogenic living conditions and with great emotional and stress loads, the population of the Russian Federation has an increasing need for high-quality and healthy foods for the body. One of the most important technological operations during the acceptance, storage and processing of bulk food masses, for example, in the production of ground roasted coffee, is dosing [1]. Dosing of bulk food masses is an important task in the food industry. In addition, in various industries, the problem of stable and correct product delivery to the dosing mechanism is very relevant. Using volumetric dispensers, the mass of the bulk product to be dosed, such as ground coffee, is measured by its volume. However, during the dosing process, there are problems with the stability of the supply of ground coffee to the dosing mechanism and the ability to control the resulting vaults [2].

Let us consider the solution to the problem by dosing ground coffee, which is a loose food mass [3, 4]. In this regard, the improvement of the traditional volumetric method for dispensing ground coffee consists in converting obsolete methods and systems into automatic control signals using a neural network model from the controllers to automatically affect a variable amount of ground coffee. A particular problem arises when dosing ground coffee fractions of different particles [5, 6].

When the density of ground coffee is set, it is difficult to evenly distribute the particles in the volume and shape of the package at the stage of automatic dosing into the package, if the coffee differs in different particle sizes of fractions [7, 8]. There are also insufficient theoretical and experimental studies on the physical and mechanical properties of ground coffee, as well as automation of quality control [9]. As we know, the effect of the oil layer on gravity waves has not been studied. Therefore, we consider and analyze the actual problem of automatic control of the process of dosing bulk food masses based on the development of a mathematical model using the apparatus of artificial neural networks.
The aim of the work is to obtain recommendations on the use of a neural network model with a PID controller. The current problem of automatic control of the process of dosing bulk food masses is considered and analyzed on the basis of the development of a mathematical model using the apparatus of artificial neural networks. The purpose of this work is to obtain recommendations for using a neural network model with a PID controller.

The article substantiates the prospects for the use of neural network technologies in the development of ACS by the process of dosing of bulk masses to obtain the necessary quality of products. At the same time there is a problem of development of the mathematical models providing the set course of production.

In this connection, the article presents comprehensive studies aimed at automating the level control when dosing bulk with the use of artificial neural networks; the development of a virtual level sensor of these bulk masses on the basis of a neural network model; the study of the possibility of integrating such a sensor into the control system of the technological process of dosing. The development of modern neural network models allows to build an effective system of regulation and control of technological processes of dosing of bulk masses.

2. Experimental procedure
When developing a neural network model for solving the problem of controlling the level of ground coffee in the hopper of a Cup dispenser, first of all, it is necessary to choose the most appropriate type and architecture of the neural network. The result of the analysis of learning network of the type multilayer perceptron with one hidden layer is the best architecture for the process of dispensing ground coffee as per the choice of neural network structure in accordance with the complexity of the problem being solved batch-process ground coffee was much better than when using a single-layer type due to their low computational capacity. In order for the neural network to be able to perform the task, it must be trained. The number of hidden layers for a multi-layer perceptron neural network was determined experimentally in the Matlab environment, taking into account the theoretical justification. The number of neurons in each layer contributes to obtaining the smallest error during the operation of the intelligent neural network for the process of dispensing ground coffee.

When forming the training sample of the NS (figure 1), only informative parameters and the algorithm of training with a teacher were used for the process of dosing ground coffee.

![Figure 1](image)

Figure 1. The structure of the developed neural network, such as a multi-layer perceptron with one hidden layer for the process of dispensing ground coffee
The process of learning the algorithm with a teacher is a presentation of a network of sample training parameters of the $X_i$ properties, the process of dispensing ground coffee. Each parameter is fed to the network inputs, then processed inside the neural network structure, and the network output signal $y_i$ is calculated, which is compared with the corresponding value of the target vector representing the required network output.

Then an error is calculated using a certain rule, and the weight coefficients of links within the network $W_{ij}^{(1)}$, $W_{ij}^{(2)}$ change depending on the selected algorithm. The vectors of the training set are presented sequentially, then errors are calculated and weights are adjusted for each vector until the error across the entire training array reaches an acceptably low level [10, 11].

The same training sample was fed to the input of the neural network. For the implemented network, the output signal of the $i$ neuron of the hidden layer $o_i$ and the activation function of neurons $\phi_i$ in General will have the form [12]:

$$o_i = f \left( \phi_i \sum_{i=1}^{n} x_i W_{ji}^{(1)} \right)$$

$$o_i = f \left( \phi_i + \rho W_{1i}^{(1)} + \omega_1 W_{2i}^{(1)} + q_3 W_{3i}^{(1)} + h W_{4i}^{(1)} + \omega_2 W_{5i}^{(1)} + Cd W_{6i}^{(1)} \right)$$

Output layers, where the value of the level value, $h$, and the portion of ground coffee $q_3$ is controlled, the following is true:

$$y_i = f \left( \phi_i + \sum_{j=1}^{n} o_i W_{ji}^{(1)} \right)$$

$$y_i = \frac{1}{1 + \exp \left( -\sum_{j=1}^{n} o_j W_{ji}^{(1)} \right)}$$

Then from (2) the values of $h$ and $q_3$ will be:

$$h = f \left( \phi_i + \frac{1}{\sum_{j=1}^{n} o_i W_{ji}^{(1)}} f \sum_{j=1}^{n} W_{ji}^{(2)} \right), q_3 = f \left( \phi_i + \frac{1}{\sum_{j=1}^{n} o_i W_{ji}^{(1)}} f \sum_{j=1}^{n} W_{ji}^{(2)} \right)$$

Formulas (3) show that the output values of the signals are affected by the weights of both layers, while the signals generated in the hidden layer do not depend on the weights of the output layer. If we choose a sigmoid unipolar form as a function of activation of neurons $\phi_i$ then we get for the output values.

$$y_i = \frac{1}{1 + \exp \left( -\sum_{j=1}^{n} o_j W_{ji}^{(1)} \right)}$$

To control the formation of stagnant zones in the hopper of the dispenser and to increase the uniformity of content of ground coffee in packages due to the control of the movement actuator of a feed device and the device dispensing material is adopted a method based on neural network model with PID controller.
The disadvantages of neural networks are the inability to predict the control error for impacts. Thus, since the process of controlling the dosage of ground coffee is non-linear, complex and cannot be identified, it is possible to solve the control problem using a neural network controller. The results of the experiments showed that the application of the drive control methodology for the dosing process using simple methods of control and logical control of the level of ground coffee is impossible [13].

The structure of an automatic control system with a PID controller and a neural network as an auto-tuning unit is shown in figure 2. The neural network in this structure plays the role of a functional Converter, which for each set of signals \( u_i \) generates the coefficients of the PID controller \( K_p, K_i, K_d \) [14].

The process of searching for unknown parameters of neurons \( W^{(k)}_{ij} \) is iterative. At each iteration, all coefficients of the network are found using the method of back propagation, which is one of the most effective methods of training multi-layer neural networks.

![Figure 2. The structure of a neural network, such as a multi-layer perceptron with a single hidden layer - a PID controller](image)

Based on these structures (figures 1 and 2) is built the structure of neural network the type multilayer perceptron with one hidden layer of PID controller for process automation control, volumetric bulk of the food of the masses, which is presented in figure 3. This structure is most promising for the task.

The input vector of the neural network structure consists of circuit elements (figure 1), automatic measurement data that characterize the state of the technological process of dosing ground coffee at a certain point in time. At the output of the neural network of the process of dispensing ground coffee, an output signal of the level of the bulk mass under study and the portion consumption in the measuring cups of the dispenser is formed. The specified values of control \( u_i \) in the process of dispensing the ground coffee are the speed of the device feeder coffee \( \omega_1 \) sad and performance of the device dispensing coffee Q which examines the speed dispenser \( \omega_2 \) sad, intermediate coordinate (level) \( h \) in the bunker and the volume portion \( q_3 \).
The parameter values \( y(n-1) \) show the current values of the control values of the coefficients of the last time value, \( x(n-1) \) the current values of the input parameters of the last time value of the complex packaging machine as a control object, such as the volume of coffee from the coffee feeder \( q_1 \) and the volume from the output hole of the hopper \( q_2 \). The current mismatch of the output signal of the process of dispensing ground coffee is determined by the formula.

\[
e = (x_1 - y(n)).
\] (5)

The hidden layer consists of the current mismatch of the last pid time value of the controller \( \varepsilon(n-1) \), the instantaneous control error \( \varepsilon \), and the mismatch of the output signal of the ground coffee dosing process \( e \). This means that this layer acts as a stationary preliminary compensator for disturbing factors on the ground coffee dosing process. This compensator is a constant matrix \( G_j \), where the instantaneous control error of the pid controller \( \varepsilon \) is reduced between the control loops and errors in the last two time steps are determined in the formula (6).

\[
\varepsilon = G_j e
\] (6)

As perturbing factors \( b(n) \), we consider the product expiration rate \( v \), physical and mechanical properties as the coefficient of expiration of ground coffee particles \( C_d \), and the coffee density \( p \). The current values of the input parameters of the ground coffee dosing process \( x(n) \) and the output signal of the pid controller \( \varepsilon \) ensure high quality of regulation and allows you to optimize management according to certain criteria. Thus, for the implemented network, the output signal of the I neuron of the hidden layer of the pid controller is determined by the formula (7) using the reverse propagation procedure.

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**Figure 3.** The structure of the developed neural network, such as a multi-layer perceptron with one hidden layer - a PID controller for controlling the process of volumetric dosing of ground coffee.
\[ x_i(n) = x_i(n-1) + W_{ij}^{(n)} e_i(n) + W_{ij}^{(n-1)} e_i(n-1) \]
\[ + W_{ij}^{(n-2)} e_i(n-2), \]

where \( W_{ij}^{(n)}, W_{ij}^{(n-1)}, W_{ij}^{(n-2)} \) — common persistent variables are defined by parameters tuning of PID controller for different control loops speed drives, level ground coffee, the portions of the volume of ground coffee.

Then the weight coefficients of connections within the network for the drive speed control circuits and the volume of ground coffee are determined by the formula (8).

\[
W_{ij}^{(n)} = \begin{pmatrix}
W_{q_{10}} & W_{w_{10}} \\
W_{q_{10}} & W_{w_{20}} \\
W_{q_{11}} & W_{w_{11}} \\
W_{q_{11}} & W_{w_{21}} \\
W_{q_{12}} & W_{w_{12}} \\
W_{q_{12}} & W_{w_{22}} \\
W_{q_{13}} & W_{w_{13}} \\
W_{q_{13}} & W_{w_{23}} \\
W_{q_{14}} & W_{w_{14}} \\
W_{q_{24}} & W_{w_{24}}
\end{pmatrix} + \begin{pmatrix}
W_{q_{00}} \\
W_{w_{00}} \\
W_{q_{01}} \\
W_{w_{01}} \\
W_{q_{02}} \\
W_{w_{02}} \\
W_{q_{03}} \\
W_{w_{03}} \\
W_{q_{04}} \\
W_{w_{04}}
\end{pmatrix}
\] (8)

Output signals from the automation system for managing the dosing of ground coffee will be displayed.

\[
h = u_n + \sum_{i=1}^{n} x_i(n) W_{ij}^{(n)} + x_i(n-1) W_{ij}^{(n-1)}
\] (9)

\[
q_3 = u_{q3} + \sum_{i=1}^{n} x_i(n) W_{ij}^{(n)} + x_i(n-1) W_{ij}^{(n-1)}
\] (10)

The network error for the output layer is calculated using the formula:

\[
\delta x_i = f'(x_i) \sum_{j=1}^{n} \delta y_j \frac{dy_j}{dx_i}
\] (11)

Thus, using a method based on the neural network model with a PID controller allows working with sets of input parameters of any decomposition level and taking into account the influence of each perturbation parameter on the evaluation of the quality of the level value and the volume portion of ground coffee using the values of weight coefficients [15]. The obtained values are compared with benchmarks by aggregating, resulting in the calculated deviation of the level of ground coffee from the reference and the output of matching this index to the given value to perform further operations food production dispensing of the bulk food of the masses.

For this system, the minimum learning error was 1.04%, which falls within the margin of error defined by 1.5%. The margin of error was selected and agreed with the technologists responsible for the quality of the product line for the production of ground coffee products in Ecuador.
3. Conclusion
A mathematical formulation of the problem of automatic control of the level of ground coffee in the hopper is presented. It is shown that the complexity of setting leads to functional limitations of the volumetric dosing process, due to a decrease in the possibilities of stable operation of the dispenser in the required range of parameters for dosing ground coffee.

When using simple methods of control and logical control of the level of ground coffee, it is impossible to control the formation of stagnant zones in the hopper of the dispenser and to increase the uniformity of the contents of ground coffee in packages by controlling the movement mode. The non-stationary nature of perturbations of technological factors in the production process of ground coffee complicates the management of the dosing process as a whole. Ensuring defined conditions are the expiration of the ground coffee is realized through the developed model of process control of the dosing of ground coffee, allowing you to explore a random perturbation of the speed change drive feeder feeder coffee feeder and feeder of coffee, and change the properties of ground coffee.

The results obtained showed that it is possible to solve this problem by using a neural network model and further developing a software and hardware complex for controlling the process of dosing bulk food masses on its basis. As a result of the analysis and processing of the conducted experiments, a neural network model of the control system for the process of dosing ground coffee was created. For the developed model of control of the process of dispensing ground coffee, a method for determining the parameters of the model for automatic control of the level of ground coffee in the dispenser hopper is proposed.

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