Analysis of a Dataset for Modeling a Transport Conveyor

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Abstract

The analysis of the works, which considered the use of neural networks for modeling a multi-section transport conveyor, was carried out. The prospects for the use of neural networks for the design of highly efficient control systems for the flow parameters of a multi-section transport conveyor are studied. The problem that limits the use of neural networks for building control systems for the flow parameters of a multi-section transport conveyor is considered. The possibility of constructing generators for generating a data set for the process of training a neural network is being studied. A method for generating a data set based on experimentally obtained measurements of the instantaneous values of the input material flow as a result of the operation of industrial transport systems is proposed. Using dimensionless variables, a statistical analysis of a stochastic flow of material entering the input of the transport system was performed. An estimate of the correlation time of a stochastic process characterizing the input flow of material is given. The recommendations on choosing the type of correlation function for the model of the input material flow were confirmed. It is demonstrated that the input flow of material is a non-stationary stochastic process. Approximations for modeling the input flow of materials of the operating transport system are considered.

Keywords 1

transport conveyor, neural network, non-stationary stochastic process, dataset generator

1. Introduction

Conveyor-type transport systems are widely used in the mining industry due to the low cost of material transportation [1]. The unit cost of transportation is significantly affected by the length of the transport route and the material load factor of the transport system. Within each section, to reduce the specific energy consumption, belt speed control systems [2, 3, 4], material flow control systems [5, 6] coming from the bunker to the section input, as well as control systems based on the energy management methodology [7, 8]. One of the types of models that are used to design control systems for the flow parameters of the transport conveyor and diagnose the state of the transport system are models based on neural networks.

To diagnose the wear level of a conveyor belt, a neural network with the 13-5-1 architecture (13 nodes in the input layer, 4 nodes in the hidden layer, and one node in the output layer) was proposed [9]. The conveyor belt speed control algorithm is represented by a model based on a neural network with 3-4-3 [10] and 3-10-1 [11] architectures. Transport system state models using a neural network are presented in [12] (architecture 4-9-14) and [13] (architecture 4-20-1).

The control system of the flow parameters of a multi-section transport contains a model of a conveyor section using a neural network with the 9-3-2 architecture [14]. It is shown that for the case of the non-stochastic input flow of material for the transport conveyor, the control algorithm of the input flow value has satisfactory accuracy.

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A comparative analysis of the computational performance of the models is carried out, followed by the conclusion that for transport systems with a large number of individual sections [15, 16, 17, 18], it is advisable to use a neural network when building models of the transport conveyor. It is multi-section transport conveyors with a large number of sections (several tens or hundreds of sections) that open up prospects for the widespread use of models based on neural networks. Additionally, it should be pointed out that models using a neural network scale well.

2. Problem statement

One of the problems that limit the use of neural networks for building control systems for the flow parameters of a multi-section transport pipeline is the lack of a sufficient data set for training a neural network. This circumstance is due, on the one hand, to the fact that under production conditions the transport conveyor operates in a narrow range of flow parameters, which is determined by the technological features of the material extraction process, on the other hand, the different structure of the technological route, and, accordingly, the location and connection of the conveyor sections. It is assumed that the flow of material $\lambda(t)$, incoming into the transport system is subject to stochasticity and can be described as a random process

$$\lambda(t) = \lambda_d(t) + \lambda_s(t), \quad (1)$$

where $\lambda_d(t)$ is a deterministic function of time t; $\lambda_s(t)$ is stationary centered ergodic process, which is determined by the one-dimensional distribution density [18, 19, 20]

$$f_\lambda(\lambda) = \frac{1}{\sigma_\lambda \sqrt{2\pi}} \exp\left(-\frac{\lambda^2}{2\sigma_\lambda^{\ 2}} \right), \quad (2)$$

with mathematical average $m_\lambda = 0$, standard deviation σ_λ , and correlation function [20]

$$K_\lambda(\eta) = \sigma_\lambda^{\ 2} \exp(-\alpha\eta). \quad (3)$$

The correlation time η_{kor}

$$\alpha = \frac{1}{\eta_{kor}}, \quad (4)$$

$$\eta = (t_i - t_j).$$

depends on the method of organizing the production process, determines the characteristic time of the process, at which the correlation between the sections of the random process t_i and t_j can be neglected.

Having performed experimental measurements of the values of the input $\lambda(t)$ and output $[\chi]_1(t, S_d)$ flows of material from sections of the transport conveyor with a length of S_d, under the conditions of production activity, it is possible to form a data set for training a neural network, , on the basis of that a model of the transport system is built. However, as already emphasized above, due to technological limitations on the values of the belt speed $a(t)$ of the conveyor section and the input flow $\lambda(t)$, as well as significant differences between the length and branching of transport routes, the data set, constructed in this way for training the neural network, will be very useful for optimizing the control system of the existing transport conveyor. This method is not suitable for designing a control system for the flow parameters of a new transport conveyor with a completely different material transportation route, both in length and in branching.

Another way to build an exact correspondence between the flow parameters $\lambda(t)$ and $[\chi]_1(t, S_d)$ is to use the analytical model of the conveyor section [21, 22], which allows you to calculate the value of the output flow $[\chi]_1(t, S_d)$ from the known value of the input flow and the law of belt speed change. In [23]], a method for generating a data set for training a neural network on the example of a branched eight-section conveyor with a deterministic material flow for the input sections of the transport system

$$\lambda(t) = \lambda_d(t) \sim \lambda_{d0} + \lambda_{d1} \sin(\omega_\lambda t + \varphi_\lambda), \quad (5)$$

and conveyor belt speed

$$a(t) \sim a_0 + a_1 \sin(\omega_a t + \varphi_a), \qquad (6)$$

with arbitrarily given values of coefficients λ_{d0}, λ_{d1}, a_0, a_1, angular velocities ω_λ, ω_a and angles φ_λ, φ_a. Further development of the research presented in [23] is to build a random value generator $\lambda(t)$, based on the experimental data of the instantaneous values of the input material flow. This generator can be used to form the required number of sets of input flows with specified properties (2), (3) with subsequent calculations of the output flow values using an analytical model of the conveyor section.

This work is devoted to the first step in this study, namely, the use of a set of experimental data to determine the form of a deterministic function of time $\lambda_d(t)$ for a given stationary centered ergodic process $\lambda_s(t)$, determined by a one-dimensional distribution density (2) and a correlation function (3).

3. Main material

Experimental data characterizing the dynamics of the flow of material incoming the transport system input are presented in [24–30] and can be used to construct random process generators $\lambda(t)$ (1). To determine the form of the deterministic function of time $\lambda_d(t)$ let's use the results of [29, 31]. After scanning a graphic image, a set of points (λ_i, t_i) for time values is obtained

$$t_i = (t_{\min} + i\Delta t), \quad i = 0..N, \qquad (7)$$
$$\Delta t = \frac{(t_{\max} - t_{\min})}{(N-1)},$$

where $t_{\min}$, $t_{\max}$ are initial and final values of time; $N = 11591$is number of sections (λ_i, t_i) used when scanning a graphic image.

The tabular data set (λ_i, t_i) obtained as a result of scanning is shown in Fig.1.

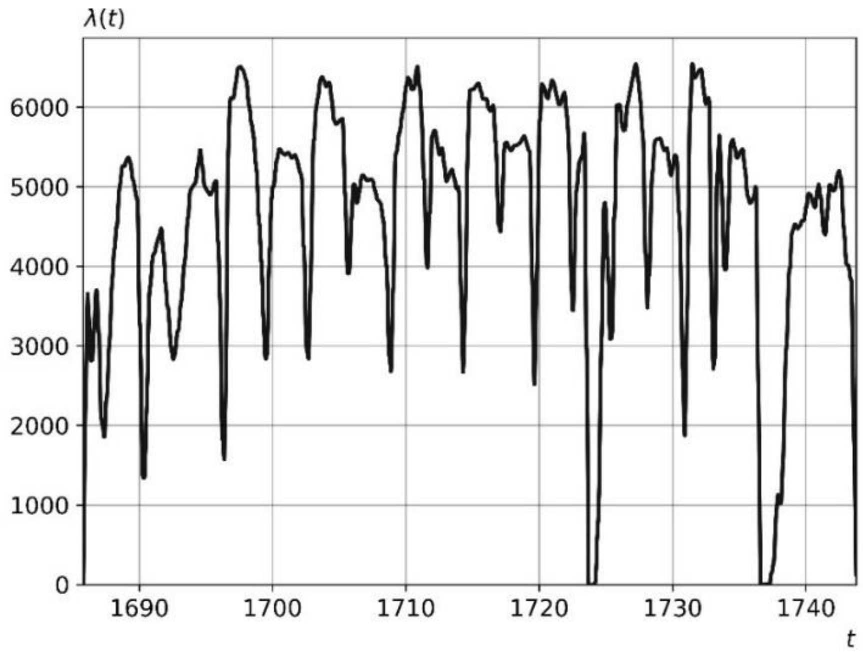

Figure 1: Actual volume capacity for the SRs 2000 bucket-wheel excavator recorded in the Belchatow surface lignite mine during the excavation of one terrace [29]

Let us introduce dimensionless variables

$$\gamma(\tau) = \frac{\lambda(t)}{\sigma_\lambda}, \qquad (8)$$

$$\gamma_s(\tau)=\frac{\lambda_s(t)}{\sigma_\lambda},$$

$$\gamma_d(\tau)=\frac{\lambda_d(t)}{\sigma_\lambda},$$

where

$$\tau=\frac{t-t_{\min}}{t_{\max}-t_{\min}}, \tag{9}$$

taking into account which the flow of material $\lambda(t)$ can be represented in a dimensionless form

$$\gamma(\tau)=\gamma_d(\tau)+\gamma_s(\tau), \tag{10}$$

where $\gamma_s(\tau)$ is a stationary centered ergodic process, which is determined by the one-dimensional distribution density

$$f_\gamma(\gamma)=\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{\gamma^2}{2}\right), \tag{11}$$

with mathematical average

$$m_\gamma=0,$$

standard deviation

$$\sigma_\gamma=1,$$

and correlation function

$$K_\gamma(\vartheta)=\exp\left(-\frac{\vartheta}{\tau_{kor}}\right),$$

$$\tau_{kor}=\frac{\eta_{kor}}{t_{\max}-t_{\min}}, \tag{12}$$

$$\vartheta=\frac{\eta}{(t_{\max}-t_{\min})}=\frac{(t_i-t_j)}{(t_{\max}-t_{\min})}=(\tau_i-\tau_j). \tag{13}$$

Taking into account the introduced dimensionless variables, the implementation $\gamma(\tau)$ takes the form shown in Fig. 2

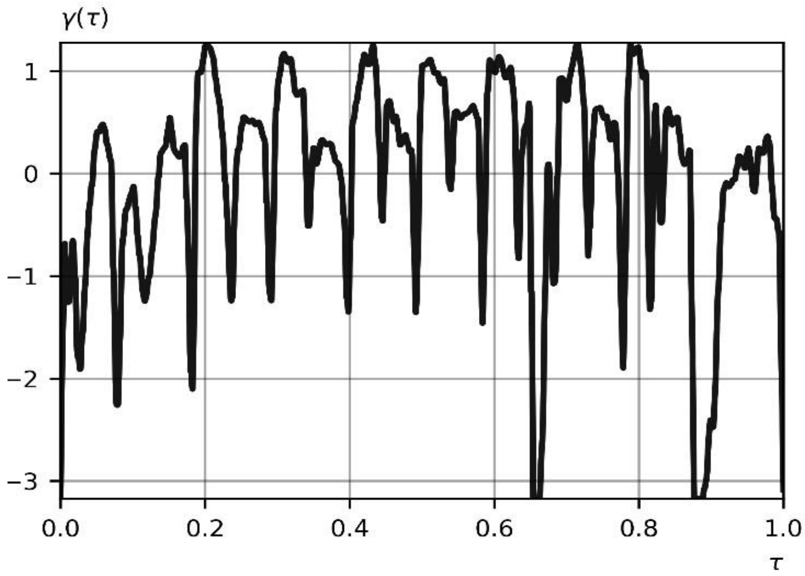

Figure 2: Implementation of a stochastic process

For a stochastic process $\gamma(\tau)$, known on the time interval [0,1] let's look for a deterministic time function $\gamma_d(\tau)$ in the form of a Fourier series expansion of a function with period T=1

$$\gamma_d(\tau)=\frac{a_0}{2}+\sum_{n=1}^{\infty}a_n\cos\left(\frac{2\pi}{T}n\tau\right)+\sum_{n=1}^{\infty}b_n\sin\left(\frac{2\pi}{T}n\tau\right), \tag{14}$$

$$\int_0^1 a_n\cos(2\pi n\tau)d\tau=0, \tag{15}$$

$$\int_0^1 b_n\sin(2\pi n\tau)d\tau=0.$$

The expansion coefficient a_0 is determined from the condition of ergodicity of a stationary centered process $\gamma_s(\tau)$

$$m_\gamma=\lim_{\tau_k}\frac{1}{\tau_k}\int_0^{\tau_k}\gamma_s(\tau)d\tau=0, \tag{16}$$

whence, taking into account (15), it follows

$$\int_0^1\gamma(\tau)d\tau\approx\int_0^1\frac{a_0}{2}d\tau=\frac{a_0}{2}, \tag{17}$$

Let's write the expression for the correlation function

$$K_{\gamma d}(\vartheta,a_n)=\lim_{\tau_k\to\infty}\frac{1}{\tau_k}\int_0^{\tau_k}\big(\gamma(\tau)-\gamma_d(\tau)\big)\big(\gamma(\tau+\vartheta)-\gamma_d(\tau+\vartheta)\big)d\tau\approx$$

$$\approx\frac{1}{1-\vartheta}\int_0^{1-\vartheta}\gamma(\tau)\gamma(\tau+\vartheta)d\tau-\int_0^1\gamma(\tau)\big(\gamma_d(\tau+\vartheta)+\gamma_d(\tau-\vartheta)\big)d\tau+\int_0^1\gamma_d(\tau)\gamma_d(\tau+\vartheta)d\tau, \tag{18}$$

Let's make preliminary simplifications

$$\gamma_d(\tau+\vartheta)+\gamma_d(\tau-\vartheta)=a_0+\sum_{n=1}^{\infty}b_n\big(\sin\big(2\pi n(\tau+\vartheta)\big)+\sin\big(2\pi n(\tau-\vartheta)\big)\big)=a_0+$$

$$+2\sum_{n=1}^{\infty}\cos(2\pi n\vartheta)\big(a_n\cos(2\pi n\tau)+b_n\sin(2\pi n\tau)\big). \tag{19}$$

$$\int_0^1\gamma(\tau)\big(\gamma_d(\tau+\vartheta)+\gamma_d(\tau-\vartheta)\big)d\tau=\frac{a_0^{\,2}}{2}+2\sum_{n=1}^{\infty}a_n\cos(2\pi n\vartheta)\int_0^1\gamma(\tau)\cos(2\pi n\tau)d\tau+$$

$$+2\sum_{n=1}^{\infty}b_n\cos(2\pi n\vartheta)\int_0^1\gamma(\tau)\sin(2\pi n\tau)d\tau. \tag{20}$$

$$\gamma_d(\tau+\vartheta)=\frac{a_0}{2}+\sum_{n=1}^{\infty}a_n\big(\cos(2\pi n\tau)\cos(2\pi n\vartheta)-\sin(2\pi n\tau)\sin(2\pi n\vartheta)\big)+$$

$$+\sum_{n=1}^{\infty}b_n\big(\sin(2\pi n\tau)\cos(2\pi n\vartheta)-\cos(2\pi n\tau)\sin(2\pi n\vartheta)\big). \tag{21}$$

By virtue of the fulfillment of the identity (15)

$$\int_0^1\frac{a_0}{2}\gamma_d(\tau+\vartheta)d\tau=\frac{a_0^{\,2}}{4}, \tag{22}$$

$$\int_0^1 a_n\cos(2\pi n\tau)\gamma_d(\tau+\vartheta)d\tau=\frac{a_n^{\,2}}{2}\cos(2\pi n\vartheta)-\frac{a_nb_n}{2}\sin(2\pi n\vartheta), \tag{23}$$

$$\int_0^1 b_n\sin(2\pi n\tau)\gamma_d(\tau+\vartheta)d\tau=-\frac{a_nb_n}{2}\sin(2\pi n\vartheta)+\frac{b_n^{\,2}}{2}\cos(2\pi n\vartheta). \tag{24}$$

Let's substitute the prepared expressions (20), (22)–(24) into (18) and obtain the form of the correlation function

$$K_{\gamma d}(\vartheta, a_n) \approx A_0 + \sum_{n=1}^{\infty} A_n \cos(2\pi n\vartheta) + \sum_{n=1}^{\infty} B_n \sin(2\pi n\vartheta), \qquad (25)$$

where

$$A_0 = \frac{1}{1-\vartheta}\int_0^{1-\vartheta}\gamma(\tau)\gamma(\tau+\vartheta)d\tau - \frac{a_0^{\ 2}}{4},$$

$$A_n = -2\left(a_n\int_0^1 \gamma(\tau)\cos(2\pi n\tau)d\tau + b_n\int_0^1 \gamma(\tau)\sin(2\pi n\tau)d\tau + \frac{a_n^{\ 2}+b_n^{\ 2}}{4}\right),$$

$$B_n = -a_n b_n.$$

The coefficients a_n are determined from the equality equating the coefficients for the same expansion harmonics

$$K_\gamma(\vartheta) = K_{\gamma d}(\vartheta, a_n). \qquad (26)$$

where $K_\gamma(\vartheta)$ is the given function (12) represented by the Fourier series.

4. Analysis of results

Consider the form of the correlation function in the zeroth approximation

$$K_{\gamma d}(\vartheta, a_0) = A_0 = \frac{1}{1-\vartheta}\int_0^{1-\vartheta}\gamma(\tau)\gamma(\tau+\vartheta)d\tau - \frac{a_0^{\ 2}}{4}. \qquad (27)$$

The distribution density $f_{\gamma s}(\gamma)$ of a random variable γ_s next to the distribution density $f_\gamma(\gamma)$ (11) is shown in Fig.3. To construct the diagram, 50 intervals were selected in accordance with the recommendations [32, 33] with the number of elements in the histogram $N = 11591$.

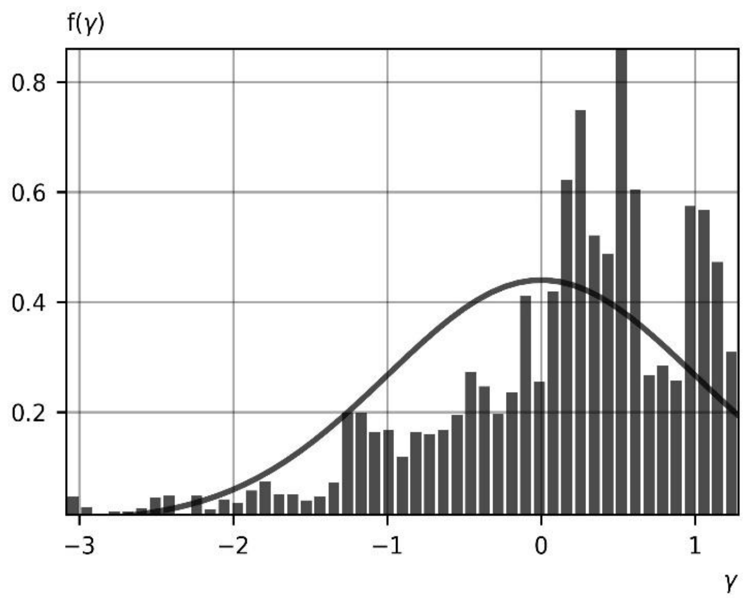

Figure 3: The density of distribution $f_{\gamma s}(\gamma)$ of a random variable

For the process $\lambda(t)$ let's define the values

$$\frac{1}{t_{\max} - t_{\min}}\int_{t_{\min}}^{t_{\max}}\lambda(t)dt = m_{\lambda s} \approx 4663, \qquad (28)$$

$$t_{\max} = 174376,$$

$$t_{\min} = 1685.825,$$

$$\frac{1}{t_{\max} - t_{\min}} \int_{t_{\min}}^{t_{\max}} (\lambda(t) - m_{\lambda s})^2 dt = \sigma_{\lambda s}{}^2 = 1470^2, \tag{29}$$

whence the form for a random process $\gamma(\tau)$ in the zeroth approximation can be represented by the equation

$$\gamma_d(\tau) = \frac{a_0}{2} \approx \frac{4663}{1470} \approx 3.2, \tag{30}$$

$$\gamma(\tau) = 3.2 + \gamma_s(\tau).$$

An analysis of the distribution histogram presented in Fig. 3 shows that the zero approximation is not enough to simulate a random input material flow [29]. To describe the non-stationarity of a random process [29], additional terms of expansion (25) are needed.

For the zero approximation, the correlation function $K_{\gamma d}(\vartheta, a_0)$ (27) of the random process can be calculated (30). The chart of the function $K_{\gamma d}(\vartheta, a_0)$ is shown in Fig.4.

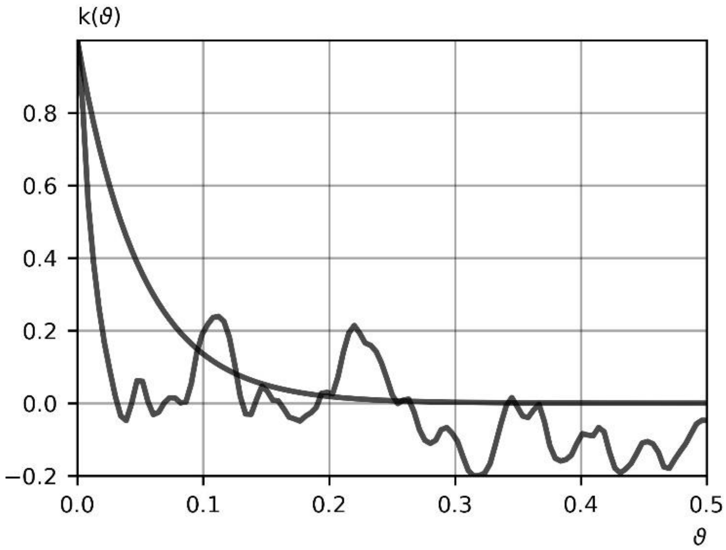

Figure 4: Correlation functions $K_{\gamma d}(\vartheta, a_0)$ and $K_{\gamma}(\vartheta)$

For comparative analysis, a monotonically decreasing function $K_{\gamma}(\vartheta)$ has been added to the Fig.4

$$K_{\gamma}(\vartheta) = \exp\left(-\frac{\vartheta}{\tau_{kor}}\right), \tag{31}$$

with correlation time τ_{kor} =1/20. Analysis of the results in Fig. 4 shows that the random process, as expected, has a fairly short correlation time. Adding non-stationary terms to series (14) will make it possible to smooth the correlation functions $K_{\gamma d}(\vartheta, a_0)$.

5. Conclusion

The quality of the neural network training process, and accordingly the accuracy of the multi-section pipeline model based on the neural network, directly depends on the data set used for training. In this regard, the formation of a data set for training a neural network is an important practical and theoretical task, the solution of which is directly related to the development of the theory of control systems for the flow parameters of a multi-section conveyor. As a method for solving this problem, this paper considers the construction of generators of a random process that simulates the input flow at the incoming to the transport system. The solution to this problem is complicated by the fact that for the existing transport systems the incoming material flow is characterized not only by stochasticity but is also a non-stationary flow. Thus, the method of constructing an input material flow generator based on a set of experimental data will allow taking into account these features in close relationship with the technological features of production. Generators of this kind will make it possible to form the required number of data sets for high-quality training of neural networks in multi-sectional conveyor models. In addition, one and the same input data set can be converted into different output data sets depending on the structure of the transport route and the law of interaction between sections of the transport conveyor. In this paper, the implementation of a random process is analyzed, which is supposed to be used to construct a generator of the input material flow. The stochastic process is represented by the canonical expansion of the non-stationary part in a Fourier series. A statistical analysis of the implementation of the input material flow is carried out and a model of the input material flow in the zero approximation is presented. The recommendation to use the correlation function in exponential form for modeling the input material flow has been confirmed.

The prospect of further research is to improve the accuracy of approximation of the statistical characteristics of the generator to the input material flow for the available sets of experimental data. An additional task is to determine the law of distribution of the value of the input cargo flow of material entering the input of the transport system per unit time.

6. References

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