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COMPUTING TOOLS OF NONPARAMETRIC IDENTIFICATION OF THE HUMAN OCULO-MOTOR SYSTEM ON THE BASIS EYE-TRACKING DATA

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ANNOTATION. The effectiveness of the developed computational tools for constructing a Volterra model of the human oculo-motor system (OMS) is investigated on the basis of data from experimental studies «input-output» using test visual stimuli and eye-tracking technology.

Introduction. The study of human eye movements and the trajectory of their movement allows us to reveal the structure of the relationship of an individual with the environment, a person with the universe. Knowledge about eye movement is of great theoretical and applied importance, expanding the possibilities of studying the specifics of many professions in order to improve the efficiency of the subject of labor activity [1].

The purpose of research is to develop computing tools of nonparametric identification of the human OMS, taking into account its inertial and nonlinear properties, based on data from experimental studies of «input-output» using test visual stimuli and innovative eye-tracking technology. In this case, Volterra models is used in the form of multidimensional transition functions [2].

Volterra Model and the method of the identification OMS. The «input-output» ratio for a nonlinear dynamical system (NDS) with an unknown structure (such as a «black box») with a single input and a single output can be represented by a discrete cubic Volterra polynomial in the form:

$$y[m]=\sum_{n=1}^{3} y_n[m]=\sum_{k_1=0}^{m} w_1[k_1]x[m-k_1]+\sum_{k_1=0}^{m}\sum_{k_2=0}^{m} w_2[k_1,k_2]x[m-k_1]x[m-k_2]+$$
$$+\sum_{k_1=0}^{m}\sum_{k_2=0}^{m}\sum_{k_3=0}^{m} w_3[k_1,k_2,k_3]x[m-k_1]x[m-k_2]x[m-k_3], \qquad (1)$$

where $w_1[k_1]$, $w_2[k_1,k_2]$, $w_3[k_1,k_2,k_3]$ are discrete weight functions (Volterra kernels) of the 1st, 2nd and 3rd orders; $x[m]$, $y[m]$ are input (stimulus) and output (response) function (signals) of the system, respectively; $y_n[m]$ is partial components of the response (convolution of n-th order sequences); m is a discrete time variable.

The problem of identification is to choose test signals $x[m]$ and develop an algorithm that allows to identify partial components $y_n[m]$, (n = 1, 2, 3) based on the responses received $y[m]$ and determine on their basis multidimensional Volterra kernels: $w_1[k_1]$, $w_2[k_1,k_2]$, $w_3[k_1,k_2,k_3]$ [2].

Taking into account the specifics of the studied OMS, test step signals are used for identification. If the test signal $x[m]=\theta[m]$, where $\theta[m]$ is a unit function (Heaviside function), then the partial components of the response $y_1[m]$, $y_2[m]$, $y_3[m]$ will be equal to the transient function of the first order $h_1[m]$ and diagonal sections of the transient functions of the second and third orders $h_2[m,m]$, $h_3[m,m,m]$, respectively:

$$y_1[m]=h_1[m]=\sum_{k_1=0}^{m} w_1[m-k_1],$$
$$y_2[m]=h_2[m,m]=\sum_{k_1,k_2=0}^{m} w_2[m-k_1,m-k_2], \qquad (2)$$
$$y_3[m]=h_2[m,m,m]=\sum_{k_1,k_2,k_3=0}^{m} w_3[m-k_1,m-k_2,m-k_3].$$

Determination of subdiagonal intersections of transient functions is based on the NDS test using L test step signals with given amplitudes a_i, i=1,2,…,L (L>=N, N is the degree of the Volterra polynomial). In this case the responses of the NDS are denoted by $y_1[m]$, $y_2[m]$, …, $y_L[m]$. Reviews of the Volterra model will be view

$$\tilde{y}_i[m] = a_i \hat{y}_1[m] + a_i^2 \hat{y}_2[m] + a_i^3 \hat{y}_3[m], i = \overline{1, L}, \tag{3}$$

where $\hat{y}_1[m] = \hat{h}_1[m]$, $\hat{y}_2[m] = \hat{h}_2[m,m]$, $\hat{y}_3[m] = \hat{h}_3[m,m,m]$ – obtained estimates of the partial components of the model – multidimensional transition functions.

To determine the transient functions $h_1[m], h_2[m,m], h_3[m,m,m]$, the method of least squares (LSM) is used which provides the minimum standard error of the deviation of the model responses from the responses of the OMS to the same stimulus:

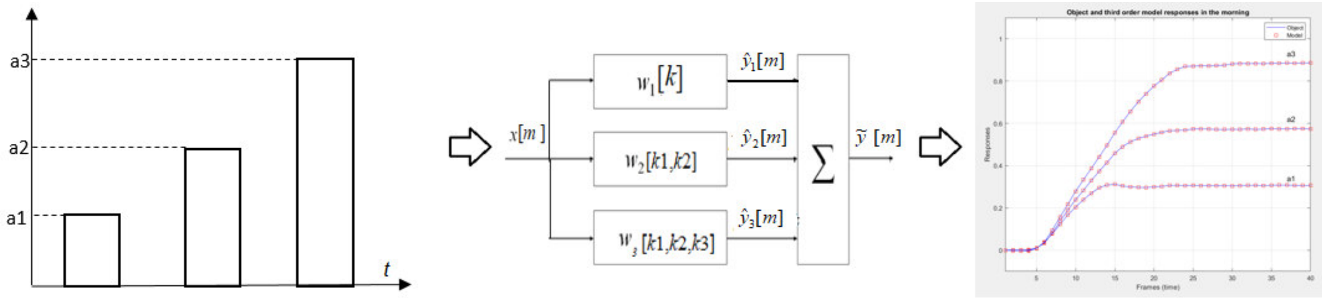
$$J_N = \sum_{j=1}^{L} \left(y_j[m] - \sum_{n=1}^{N} a_j^n \hat{y}_n[m] \right)^2 \to \min. \tag{4}$$

The minimization of criterion (4) is reduced to solving a system of normal Gaussian equations, which in vector-matrix form can be written as

$$\mathrm{A'A}\hat{\mathrm{y}} = \mathrm{A'}\,\mathrm{y}, \tag{5}$$

where $\mathrm{A} = \|\alpha_{ij}\|$, $\alpha_{ij} = a_i^j$, $i, j = \overline{1, N}$.

The OMS modeling process based on the Volterra model is shown in Fig. 1.



Test Signals | Volterra Model | Responses of the OMS and the model at various amplitudes of the test signals

Fig. 1. The OMS modeling process based on the Volterra model.

The experiments were organized in order to classify subjects by the state of fatigue. The data for constructing the model – the OMS responses to the same test signals, were obtained using the Tobii Pro TX300 eye tracker at different times of the day: "In the Morning" (before work) and "In the Evening" (after work) [2].

Conclusions. The developed computing tools of nonparametric identification of the human OMS on the basis data processing of the eye-tracking are tested on real data from an experimental study of the OMS. Verification of the constructed model confirms the adequacy model of the investigated OMS – a practical coincidence (within an acceptable error) of the responses of the OMS and its model at the same test signal (Fig. 1).

The revealed variability of the transient functions of the 2nd and 3rd orders for different psychophysiological states of the respondent (level of fatigue) has observed. Thus, they can be used in diagnostic studies in the field of the neuroscience and psychology.

The development of the research subject in the future is aimed at constructing a space of diagnostic features for the development of a classifier of a human condition using machine learning.

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