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Nonlinear Dynamic Model of the Oculo-Motor System Human based on the Volterra Series

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Abstract: The biometric identification method is proposed based on the Volterra model and eye tracking data in dynamics. The instrumental computational and software tools for constructing a nonparametric nonlinear dynamic model (Volterra model) of the human oculo-motor system (OMS) were developed on the basis of data from experimental "input-output" studies using innovative eye tracking technology. The obtained multidimensional transient functions are used to build a biometric identification system for individuals.

Keywords: oculo-motor system, eye tracking, identification, nonlinear dynamic model, Volterra series

1. Introduction

Since the importance of nonlinearities in understanding the complex mechanisms of physiological functions becomes more relevant, the demand for effective and practical modelling methodologies that address the problem of nonlinear dynamics in the life sciences becomes more and more urgent [1], [2]. As a basic model for the study, a universal nonlinear dynamic model based on the Volterra integro-power series, which represents the input-output relationship of the studied physiological system, was chosen [3]. The goal is to develop computational methods and software tools for constructing a nonparametric dynamical model of the human OMS, taking into account its inertial and nonlinear properties, based on data from experimental input-output studies using test visual stimulus and innovative eye tracking technology; implementation of the obtained information models into the diagnostics practice of states' cognitive processes.

2. Results and Discussion

The study uses the identification approximation method based on the selection of the *n*-th partial component in the OMS response by constructing linear combinations of responses to test signals with different amplitudes [4].

Let the test signals $a_1x[m]$, $a_2x[m],\dots,a_Nx[m]$ (N is approximation model order, a_1, $a_2,\dots,a_N$ are different real numbers satisfying the term $|a_j|\le 1$ for $\forall j=1,2,\dots,N$; $x[m]$ is an arbitrary function) are successively given to the system input. Then the linear combination of the OMS responses with the coefficients c_j stands at the *n*-th partial component $\hat{y}_n[m]$ of the OMS response to the input signal $x[m]$.

In this case, a methodical error arises when choosing of the *n*-th partial component due to the partial components of the OMS response of higher orders $n>N$:

$$\hat{y}_n[m]=\hat{h}_n[m,\dots,m]=c_1^{(n)}y_{a_1}[m]+c_2^{(n)}y_{a_2}[m]+\dots+c_N^{(n)}y_{a_N}[m],\ \ n=1,2,\dots,N, \tag{1}$$

where $y_{a_j}[m] = y(a_j\theta[m])$ – OMS response to a test signal with an amplitude a_j; θ[m] is a unit function (Heaviside step function); $h_n[m,..., m]$ is a diagonal section of the discrete transition function of the n-th order

$$h_n[m,...,m] = \sum_{k_1,...k_n=0}^{m} w_n[m-k_1,...,m-k_n] \qquad (2)$$

in these parts $w_n[k_1,\ldots,k_n]$ is a Volterra kernels of the n-th order; m is a discrete time variable.

To identify the OMS in the form of multidimensional transient functions according to eye tracking data, program Signal Manager was created to generate test visual stimuli on the computer monitor screen [5]. In the studies of each respondent, three experiments were sequentially carried out for the three amplitudes a_1, a_2, a_3 (N=3) of the test signals in the horizontal direction. Experimental studies of OMS were conducted using high-tech equipment – eye tracker TOBII PRO TX300 (300 Hz) [6].

The variability (deviation) of the transient functions average values of different orders n (n=1,2,…,N) of OMS models for N=1,2,3 of two individuals – the respondent #1 $\hat{h}_{1n}^{(N)}[m]$ and the respondent #2 $\hat{h}_{2n}^{(N)}[m]$ is quantified using indicators: σ_{nN} is maximum deviation, ε_{nN} is standard deviation. Indicators of transient functions deviations of different orders of n models of respondents #1 and #2 OMS for N = 1, 2, 3 are given in Table 1.

Table 1. The multidimensional transient functions deviation indicators

N	ε_1	σ_1	ε_2	σ_2	ε_3	σ_3
1	0.025	0.056	-	-	-	-
2	0.066	0.118	0.489	0.264	-	-
3	0.158	0.22	0.83	0.808	1.182	0.66

3. Concluding Remarks

Experimental studies of OMS were carried out for two individuals. Based on the data obtained using the eye tracker, the transition functions of the first, second and third orders of the OMS were determined. There is a significant difference between the diagonal sections of the two individuals' second and third order transition functions. Thus, they can be used to form a space of informative features and build statistical classifiers of the personality using machine learning.

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