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BIOMETRIC METHOD OF PERSONALITY AUTHENTICATION BASED ON THE EYE TRACKING DATA

A new method of biometric identification of a computer user is proposed based on the Volterra model and eye tracking data in dynamics (eye tracking technology). The instrumental computational and software tools for constructing a nonparametric nonlinear dynamic model (Volterra model) of the human oculo-motor system have been developed on the basis of data from experimental studies "input-output" using innovative eye tracking technology. The obtained multidimensional transition functions are used to construct a biometric identification system for individuals. Figs.: 10. Tabl.: 1. Refs.: 9 titles.

Keywords: method of biometric identification; authentication; oculo-motor system; Volterra model; eye tracking technology; multidimensional transient functions; software tools.

Introduction. Based on the analysis of information security threats and existing means of identification and authentication of information system users, it can be argued that password protection is currently one of the most common ways to protect information from unauthorized access in individual computers and systems and networks worldwide. However, without the use of other protection mechanisms, password protection, in itself, is not reliable, because it cannot provide the required level of protection [1]. Various electronic keys (tokens, cards, etc.) are also quite common as identifiers. Recently, identification systems that use human biometric characteristics in solving the problem of access to information systems are becoming more common [2 – 4].

The aim of the research is to increase the efficiency (reliability) of information protection on the computer through the development of hardware and software identification of human oculo-motor system (OMS) based on nonlinear dynamic model and data of experimental input-output research using innovative eye tracking technology. The Volterra model in the form of multidimensional transition functions (MTF) is used for identification.

The object of research is the process of biometric identification of a computer user on the basis of eye tracking data in dynamics - responses to given test visual stimuli (the process of eye tracking).

The subject of research is software tools for constructing the Volterra model – evaluation of multidimensional transient functions of OMS according to the data eye tracking, determination based on transient functions of

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informative features and construction of defining rules of optimal classification.

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 Volterra series in the form [5]:

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

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 $w_n[k_1, \ldots, k_n]$ and $x[m]$); m is a discrete time variable.

The Volterra series is replaced by a polynomial and is usually limited to the first few terms of the series in practice. In this study we limited ourselves to the first three terms of the series (we chose the degree of the Volterra polynomial model $N = 3$).

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 multidimensional Volterra kernels: $w_1[k_1]$, $w_2[k_1, k_2]$, $w_3[k_1, k_2, k_3]$.

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 the unit function (Heaviside function), then the partial components of the response $y_1[m]$, $y_2[m]$, $y_3[m]$ are the first order transition function and diagonal sections of the second and third order transition functions, respectively:

$$y_1[m]=h_1[m]=\sum_{k_1=0}^{m} w_1[m-k_1],$$
$$y_2[m]=h_2[m,m]=\sum_{k_1,k_2=0}^{m} w_2[m-k_1,m-k_2], \tag{2}$$
$$y_3[m]=h_3[m,m,m]=\sum_{k_1,k_2,k_3=0}^{m} w_3[m-k_1,m-k_2,m-k_3].$$

In this case, the responses of the Volterra model of the OMS are calculated based on the expression:

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

where $\hat{y}_1[m]=\hat{h}_1[m], \hat{y}_2[m]=\hat{h}_2[m,m], \hat{y}_3[m]=\hat{h}_3[m,m,m]$ are obtained estimates of the partial components of the model (MTF).

The research uses an approximation identification method [6]. The approximation method of identification in domain time is based on the allocation of the n-th partial component in the OMS response by constructing linear combinations of responses to test signals with different amplitudes [6, 7].

Let at system input test signals are given successively $a_1x[m]$, $a_2x[m],\ldots,a_Nx[m]$ (N is approximation model order, $a_1, a_2,\ldots,a_N$ are different real numbers, which satisfy the term $|a_j| \le 1$ for $\forall j=1,2,...,N$; $x[m]$ is arbitrary function). Then the linear combination of the OMS responses with the coefficients c_j is amount to the n-th partial component of the OMS response to the input signal $x[m]$. In this case, a methodical error arises in the selection of the n-th partial component, due to the partial components of the OMS response of higher orders $n>N$:

$$\sum_{j=1}^{N} c_j y(a_j x[m]) = y_n(x[m]) + \sum_{j=1}^{N} c_j \sum_{n=N+1}^{\infty} y_n(a_j x[m]), \tag{4}$$

where $y_n(x[m])=y_n[m]$;

$$y(a_j x[m]) = \sum_{n=1}^{\infty} a_j^n \sum_{k_1=0}^{m} \ldots \sum_{k_n=0}^{m} w_n[k_1,\ldots,k_n]\prod_{i=1}^{n} x[m-k_i];$$

if c_j is real coefficients such that

$$\mathrm{A}_N\,\mathrm{c}=\mathrm{b}, \tag{5}$$

where

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$$\mathrm{A}_N = \begin{bmatrix} a_1 & a_2 & \dots & a_N \\ a_1^2 & a_2^2 & \dots & a_N^2 \\ \dots & \dots & \dots & \dots \\ a_1^N & a_2^N & \dots & a_N^N \end{bmatrix}, \quad \mathrm{c} = \begin{bmatrix} c_1 \\ c_2 \\ \dots \\ c_N \end{bmatrix}, \quad \mathrm{b} = \begin{bmatrix} b_1 \\ b_2 \\ \dots \\ b_N \end{bmatrix},$$

and $b_l = 1$ at $l = n$ and $b_l = 0$ at $l \neq n$, $\forall l \in \{1, 2, \dots, N\}$.

For example for $N = 2$:

$$\begin{bmatrix} a_1 & a_2 \\ a_1^2 & a_2^2 \end{bmatrix} \cdot \begin{bmatrix} c_1^{(1)} \\ c_2^{(1)} \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \quad \begin{bmatrix} a_1 & a_2 \\ a_1^2 & a_2^2 \end{bmatrix} \cdot \begin{bmatrix} c_1^{(2)} \\ c_2^{(2)} \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix};$$

for $N = 3$:

$$\begin{bmatrix} a_1 & a_2 & a_3 \\ a_1^2 & a_2^2 & a_3^2 \\ a_1^3 & a_2^3 & a_3^3 \end{bmatrix} \cdot \begin{bmatrix} c_1^{(1)} \\ c_2^{(1)} \\ c_3^{(1)} \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix},$$

$$\begin{bmatrix} a_1 & a_2 & a_3 \\ a_1^2 & a_2^2 & a_3^2 \\ a_1^3 & a_2^3 & a_3^3 \end{bmatrix} \cdot \begin{bmatrix} c_1^{(2)} \\ c_2^{(2)} \\ c_3^{(2)} \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix},$$

$$\begin{bmatrix} a_1 & a_2 & a_3 \\ a_1^2 & a_2^2 & a_3^2 \\ a_1^3 & a_2^3 & a_3^3 \end{bmatrix} \cdot \begin{bmatrix} c_1^{(3)} \\ c_2^{(3)} \\ c_3^{(3)} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}.$$

The evaluation of transient functions can be set in general as follows:

$$\begin{gathered} \hat{h}_n[m, \dots, m] = \hat{y}_n[m] = \sum_{j=1}^{N} c_j^{(n)} y(a_j \theta[m]) = \\ = c_1^{(n)} y_{a_1}[m] + c_2^{(n)} y_{a_2}[m] + \dots + c_N^{(n)} y_{a_N}[m], \quad n = 1, 2, \dots, N, \end{gathered} \tag{6}$$

where $y_{a_j}[m] = y(a_j \theta[m])$ – OMS response to a test signal with an amplitude a_j.

Results. To identify the OMS in the form of MTF according to the data eye tracking program Signal Manager was created to generate test visual stimuli on the computer monitor screen (Fig. 1). The obtained physiological features of the OMS, in experiments on eye movement tracking, step signals (bright dots) with different distances a_j (j = 1, 2, …, N; N is number of experiments) from the starting position are used. Thus, visual stimuli can be

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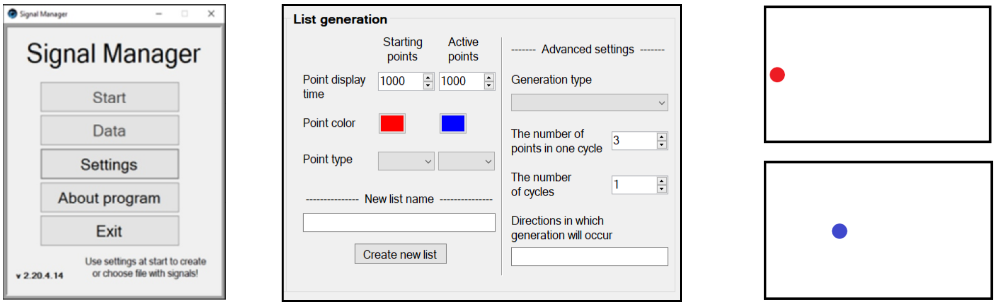
considered as functions $x_j[m] = a_j\,\theta[m]$, where $\theta[m]$ is a unit a unit function of avicide. With the help of an eye tracker, the responses of the OMS are recorded, which are used to determine the MTF [8]. Signal Manager can generate a visual test of any given complexity.



The main menu of the program

Setting up a visual stimulus generator

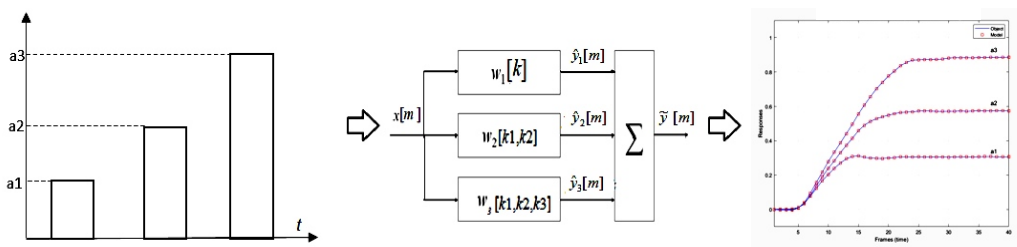
Starting and test visual stimuli

Fig. 1. The interface of the program for generating test visual stimuli Signal Manager

In the studies of each respondent, three experiments were performed sequentially for the three amplitudes a_1, a_2, a_3 ($N = 3$) of the test signals in the horizontal direction. The distance between the starting position and the test stimuli is: (1/3) lx, (2/3) lx and (1.0) lx, where lx is the length of the monitor screen. Coordinates of the starting position ($x = 0$, $y = (1/2)ly$), where ly is the width of the monitor screen. Experimental studies of OMS were conducted using high-tech equipment – eye trecker TOBII PRO TX300 (300 Hz).

The experiments were organized to identify individuals based on MTF data [9].

The OMS modeling process based on the Volterra model is shown in Fig. 2.



Test Signals

Volterra Model

Responses of the OMS and the model at various amplitudes of the test signals

Fig. 2. The OMS modeling process based on the Volterra model

In Fig. 3 and Fig.4 OMS responses to test visual stimuli with amplitudes a_1, a_2 and a_3. in two individuals are shown that were obtained on different days and at different times of the day.

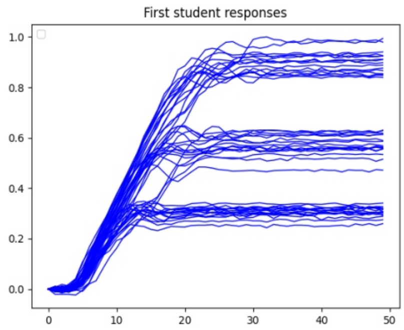


Fig. 3. 1st student's OMS responses to visual stimuli with amplitudes a_1, a_2, a_3

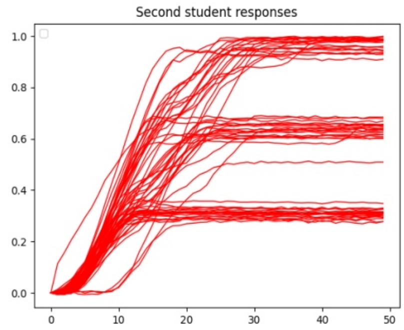


Fig. 4. 2nd student's OMS responses to visual stimuli with amplitudes a_1, a_2, a_3

According to the averaged data of OMS responses to visual stimuli (Fig. 5), the transient functions of OMS when using Volterra models of different degree N ($N = 1, 2, 3$) were determined. Graphs of transition functions for two individuals based on the model at $N = 1$ are presented in Fig. 6, at $N = 2$ – in Fig. 7 and at $N = 3$ – in Fig. 8. As it can be seen from Fig. 6 – 8, the obtained transient functions of the 1st order almost coincide for two individuals. However, the diagonal intersections of the transition functions of the 2nd (Fig. 7, 8) and third (Fig. 8) orders in two individuals change significantly in size, therefore, can be effectively used as a source of primary data in building a system of recognition of individuals with application of machine learning.

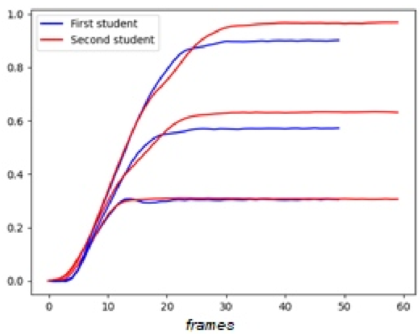


Fig. 5. Average responses of OMS of two students

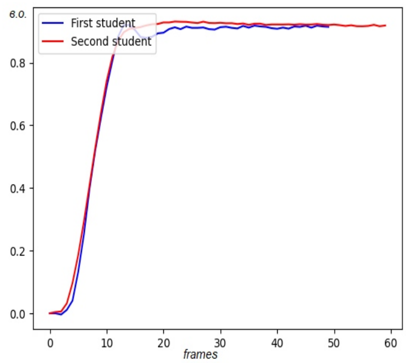


Fig. 6. Transition functions 1st orders of two individuals

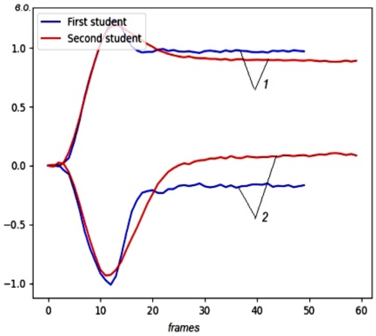


Fig. 7. Transition functions: *1* – 1st; *2* – 2nd orders of two individuals

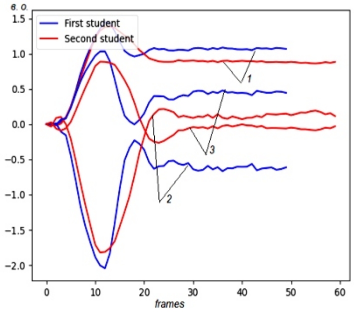


Fig. 8. Transition functions: *1* – 1st; *2*– 2nd; *3* – 3rd orders of two individuals

Received responses with the help of calculations on models at $N = 3$ from various amplitudes of test signals. Graphs these are presented in comparison with similar responses OMS for premier and second of the students in Fig. 9 and 10, respectively.

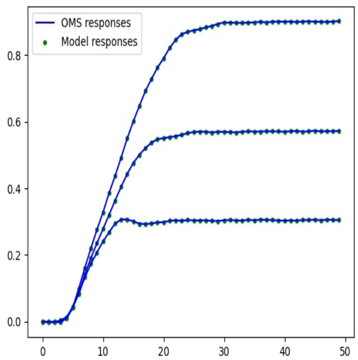


Fig. 9. Average responses of the OMS and of model Volterra for N=3 of premier student

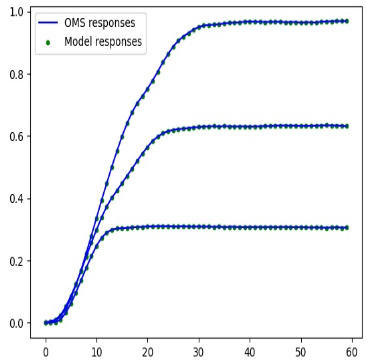


Fig. 10. Average responses of the OMS and of the model Volterra for N=3 of second student

The analysis of the MTF variability. The variability (deviation) of transient functions 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

$$\sigma_{nN} = \max_{m\in[0,M]} \left| \hat{h}_{1n}^{(N)}[m] - \hat{h}_{2n}^{(N)}[m] \right|, \tag{7}$$

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ε_{nN} is standard deviation

$$\varepsilon_{nN} = \left(\frac{1}{M} \sum_{m=0}^{M} \left(\hat{h}_{1n}^{(N)}[m] - \hat{h}_{2n}^{(N)}[m] \right)^2 \right)^{1/2}, \tag{8}$$

where M is the number of measurements.

Indicators of deviations of transient functions of different orders of n models of OMS of respondents #1 and #2 for $N = 1, 2, 3$ are given in Table 1.

Table 1

The deviation indicators of MTF

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

Building a classifier of the individuals. For identity recognition of the individuals based on the OMS nonlinear dynamical model conducted researche:

– Building a feature space for designing classifier of the individe with using machine learning.

– Classifiers construction with using statistical methods of learning the pattern recognition based on the data obtained using eye tracking technology.

The analysis of the reliability of personality recognition in the space of features calculated on the basis of the MTF consists in forming various combinations of features and evaluating their informativeness based on the classification results on the data sample under study using criteria for the probability of correct recognition (P).

Bayesian classifier of a individuals in two-dimensional features space is provided of the maximum recognition reliability at the combinations by the following of the features:

$$\left\{ x_{13} = \min_m h_1^{'}(m) \; \& \; x_{15} = \min_m h_3^{'}(m,m,m) \right\} \tag{9}$$

or

$$\left\{ x_{13} = \min_m h_1^{'}(m) \; \& \; x_{11} = \max_m h_2^{'}(m,m) \right\} \tag{10}$$

Evaluation of the confidence index of personality recognition in the first and second cases: P=0.974 and P=0.947, respectively.

Conclusion. Instrumental computing and software tools for building a nonparametric nonlinear dynamic model of the human oculomotor system based on experimental data "input-output" using innovative technology of eye tracking have been developed. In the future, the obtained transition functions will be used in the construction of a system of biometric identification of individuals. Software tools for identifying OMS in the time domain in the form of multidimensional transition functions are implemented in the Python IDLE programming environment.

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Біометричний метод аутентифікації особистості за даними айтрекінга / Павленко В.Д., Шаманіна Т.В., Чорі В.В. // Вісник НТУ "ХПІ". Серія: Інформатика та моделювання. – Харків: НТУ "ХПІ". – 2021. – № 1 (5). – С. 142 – 152.

Пропонується новий метод біометричної ідентифікації користувача комп'ютера на основі моделі Вольтерри і даних відстеження погляду в динаміці (технологія айтрекінга). Інструментальні обчислювальні і програмні засоби для побудови непараметричної нелінійної динамічної моделі (моделі Вольтерри) окуло-моторної системи людини були розроблені на основі даних експериментальних досліджень "вхід-вихід" з використанням інноваційної технології айтрекінгу. Отримані багатовимірні перехідні функції використовуються для побудови системи біометричної ідентифікації фізичних осіб.. Іл.: 10. Табл.: 1 Бібліогр.: 9 назв.

Ключеві слова: метод біометричної ідентифікації; автентифікація; очно-рухова система; модель Вольтерри; технологія відстеження очей; багатовимірні перехідні функції; програмні засоби.

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Биометрический метод аутентификации личности по данным айтрекинга / Павленко В.Д., Шаманина Т.В., Чори В.В. // Вестник НТУ "ХПИ". Серия: Информатика и моделирование. – Харьков: НТУ "ХПИ". – 2021. – № 1 (5). – С. 142 – 152.

Предлагается новый метод биометрической идентификации пользователя компьютера на основе модели Вольтерра и данных отслеживания взгляда в динамике (технология айтрекинга). Инструментальные вычислительные и программные средства для построения непараметрической нелинейной динамической модели (модели Вольтерра) окуломоторной системы человека были разработаны на основе данных экспериментальных исследований "вход-выход" с использованием инновационной технологии айтрекинга. Полученные многомерные переходные функции используются для построения системы биометрической идентификации физических лиц.. Ил.: 10. Табл.:1 Библиогр .: 9 назв.

Ключевые слова: метод биометрической идентификации; аутентификация; окуло-моторная система; модель Вольтерры; технология айтрекинга; многомерные переходные функции; программные средства.

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Keywords: method of biometric identification; authentication; oculo-motor system; Volterra model; eye tracking technology; multidimensional transient functions; software tools.