A mathematical model of changes of parameters of handwritten patterns depending on the signers states

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Abstract. Authors of some studies point out the need of taking into account the state of employee to reduce the risk that he will cause damage to organization including information resources. An assessment of psychophysiological state is possible on the basis of the dynamic parameters of a signature. Etalons creation of handwritten signature for each state significantly complicates the formation of etalons base of subjects. The purpose of the study is to provide a mechanism for the formation of subjects etalons in different states without the need to collect of handwritten signature in each states. To achieve the goal we should solve the problem of finding the regularity of the signature parameters changes while changing the states of signers. We develop a model of changing signature parameters depending on the state based on the discovered regularities. We compared the accuracy of the obtained model by estimating the probabilities of erroneous decisions obtained in the experiment of states recognition using etalons obtained in a natural way and using a model. To carry out the research, we used the apparatus of probability theory and mathematical statistics. This included using the multidimensional Bayes functional and Bayes hypothesis formula. As a result the author describes the model of biometric etalons of handwritten signatures of the user. The model assumes the use of formulas and calculated coefficients for calculating the distribution of signature features characteristics in the changed state from the values of the signature features in the normal state. The introduction of this model will significantly simplify the procedure for obtaining the etalons in changed state. The mentioned above model can find applications in systems of dynamic biometric identification.

1. Introduction
At present, to effectively protect the information resources of an organization, it is necessary to take into account the possibility of infliction of harm by its own employees. This statement is confirmed by studies of sources of information security threats [1]. An employee of an organization may cause harm maliciously or because of he being in a non-optimal state, for example, into alcohol intoxication. The solution to this problem is in the application of developments in the field of assessment the psychophysiological state (PPS) of employees, for example, at the time of biometric authentication. The most suitable for this purpose are dynamic biometric images. There are studies on the recognition of the subjects states by thermograms of the face and neck [2] and handwritten signature [3,4]. It is required to create a biometric etalons for each psychophysiological state in order to recognize them later. This significantly complicates the process of creating a etalons base and leads to a multiple increase in the expenditure of time. This approach is shown in detail in [3]. It consists in the fact that at the time of the formation of the etalon the physiological parameter is registered using the experience of the existing technologies of polygraph tests [4]. As a physiological parameter is the heart rate variability (HRV) [5]. The range of values of the parameter is divided into ranges, each of which is associated with the signatures written by the subject in a certain psychophysiological state. Etalon is formed from the signatures assigned to each range. This approach also assumes the registration of the
physiological parameter at the stage of recognition of the subject for comparing the values of the biometric features of the presented signature with the etalons of subjects in this state.

2. Proposed Approach

2.1. Research objective
It is evident that the implementation of described etalon forming procedure for each of the states in practice will be difficult. In this paper, we propose solution that will allow the conversion of the etalon of the handwritten signature formed in the "normal" state of the signers to the etalon of the same signer formed in the "changed" state with sufficient accuracy. It is necessary to achieve results, according to which it will be not significant excess of the probability of errors achieved using the approach given in [6] and applying the similar methods.

2.2. Forming the base of handwritten signatures of various psychophysiological states
To study the regularities of changing the parameters of handwritten images, signatures were collected using a Wacom graphic tablet. By analogy with [3] the HRV was chosen as physiological parameter. Information on HRV was recorded on Holter's monitor "Cardiotechnics 04". An experiment on the formation of a signature database was conducted with the involvement of test subjects that was entered alternately into the following states (the change of state was confirmed by information from the Holter monitor) [6]:

- Adequate (or normal) state – the optimal state in which there are the best results of the subject activity.
- Excitement – in this state for the subject is characterized by psychic activity, increased heart rate, rapid breathing. Test subject The experiment participant took coffee, which increased his heart rate by an average of 10%.
- Fatigue (after physical exertion) – is a state that occurs after an intense physical exertion which volume for each subject was set individually, on the basis of functional tests. It is characterized by a heart rate increase of subject by 10-30%.
- Relaxed state - is characterized by mild drowsiness, low working capacity. To simulate present state, subjects took natural herbal remedies for sedation. Subjects heart rate returned to the values at rest, or there was decreased by 3-5%.
- Alcoholic intoxication –subject took alcohol, which dosage was calculated according to the Widmark formula (1) so that its concentration value was at least 0.5 %

\[
c = \frac{A}{m \cdot r}
\]

where \( c \) – concentration of alcohol in the blood in %, \( A \) – weight of drunk alcohol in grams, \( m \) – subject body weight in kilograms, \( r \) – the distribution coefficient of Widmark (0.70 for men, 0.60 for women).

In the experiment, 60 subjects were involved. Each subject reproduced signature at least 30 times on a Wacom graphic tablet in each of the listed states. For convenience, we use the term "modified" PPS of subject which images will include samples that are the subjects entered in any state different from normal. For each subject who was in a certain PPS a separate etalon of the handwritten patterns was formed to further evaluate the accuracy of the etalon conversion by means of a model. The etalon consists of mathematical expectations and mean-square deviations of the features values calculated from the corresponding samples.

2.3. Extraction of biometric features
Each time the user entered a signature on the graphic tablet, the signature coordinates \( x,y \) and the pen pressure on the tablet \( p \) were fixed. Signature realizations were equalized in duration before we calculating the parameters that characterizing the appearance of the signature and the dynamics of the
signature reproduction. In addition at this stage an initial and final values of all the points with zero pressure was discarded.

Each signature representing the functions \(x(t), y(t), p(t)\) was transformed into a vector of values of a set of biometric parameters (further features) that given in table 1.

| №  | Short Description                                                                 | Number of Features | Nearest distribution law                  |
|----|----------------------------------------------------------------------------------|--------------------|-------------------------------------------|
| 1  | The first 16 amplitudes (the most low frequency) of function \(p(t)\) harmonics normalized by energy | 16                 | normal distribution, rarely lognormal distribution |
| 2  | The first 16 amplitudes (the most low frequency) of function \(v(t)\) harmonics normalized by energy | 16                 | normal distribution                        |
| 3  | Correlation coefficients between pairs of signature \(x(t), y(t), p(t)\) functions and their derivatives — \(x'(t), y'(t), p'(t)\) functions | 15                 | normal distribution                        |
| 4  | Distances between some signature dots are normalized on the signature length in three-dimensional space (the third dimension is pen pressure on the tablet) | 120               | normal distribution, rarely lognormal distribution |
| 5  | Some characteristics of the static signature image: ratio of the signature length to its width, signature center, signature slope angle, angle of inclination between the halves centers of the signature. | 5                  | normal distribution                        |
| 6  | Daubechies wavelet transform coefficient D6 of \(v(t)\) and \(p(t)\) functions | 70                 | Laplace distribution, normal distribution  |

2.4. Model of changes of parameters of handwritten patterns depending on the signers states

During the analysis of handwritten etalons we found that the changes of the most features during the transition from the normal signer state to any other PPS are similar in character and sufficiently stable [7]. These changes can be manifested to varying degrees in different subjects, some of the features vary in different ways depending on the state, a small part of the features varies chaotically.

Bringing the etalon to the desired form is proposed to be carried out according to the formulas (2), discarding the features which changes while changing the PPS are chaotic. Correction coefficients using to convert the etalon in the normal state to the etalon in the changed state were calculated.

\[
E'_{c} = \begin{bmatrix} m'_{c1} & \ldots & m'_{cN} \end{bmatrix} = E_{c} \times K_{m} = \begin{bmatrix} m_{c1} & \ldots & m_{cN} \end{bmatrix} \times \begin{bmatrix} \kappa_{m1} & \ldots & \kappa_{mN} \end{bmatrix} \approx E_{c} = \begin{bmatrix} m_{c1} & \ldots & m_{cN} \end{bmatrix},
\]

\[
\Theta'_{c} = \begin{bmatrix} \sigma'_{c1} & \ldots & \sigma'_{cN} \end{bmatrix} = \Theta_{c} \times K_{\sigma} = \begin{bmatrix} \sigma_{c1} & \ldots & \sigma_{cN} \end{bmatrix} \times \begin{bmatrix} \kappa_{\sigma1} & \ldots & \kappa_{\sigmaN} \end{bmatrix} \approx \Theta_{c} = \begin{bmatrix} \sigma_{c1} & \ldots & \sigma_{cN} \end{bmatrix},
\]

where \(E_{c}\) and \(E_{n}\) – are matrixes of mathematical expectations of the subject features in the changed and normal state respectively, \(\Theta_{c}\) and \(\Theta_{n}\) – are matrices of mean-square deviations of the subject features in the changed and normal state, respectively, \(K_{m}\) and \(K_{\sigma}\) – are vectors of correction coefficients for mathematical expectations and mean square deviations, respectively, \(N\) – is a number of features. We call a transformed etalon consisting of matrices \(E'_{c}\) and \(\Theta'_{c}\) synthetic.
A computational experiment to recognize PPS was carried out. The method of sequential application of the two-dimensional (ordinary) of Bayes hypothesis formula (3) and \( \eta \)-dimensional functional (4) were applied, similarly to the way it was done in [6] to form solutions.

\[
P(H_h|A_j) = \frac{P(H_h|A_{j-1})P(A_j|H_h)}{\sum_{n=1}^{\eta} P(H_h|A_{j-1})P(A_j|H_h)}
\]

where \( P(H_h|A_j) \) – is posteriori probability of \( h \) hypotheses, depending on \( j \) feature, \( P(A_j|H_h) \) – is conditional probability \( h \) hypotheses, depending on \( j \) feature.

\[
P(H_h|A_j) = \frac{\prod_{s=1}^{n} f_h(a_{j(s,x,s)})}{\sum_{k=1}^{\eta} \prod_{s=1}^{n} f_k(a_{j(s,x,s)})}
\]

where \( j(s, x) \) – number of feature, which does not coincide with the \( s \) step number but depends on it, \( f_h(a_{j(s,x,s)}) \) is a probability density of \( a_{j(s,x,s)} \) feature.

3. Results and Discussions

We use two hypotheses associated with the etalons of normal and changed states. The probability of the states recognition error using synthetic etalons of the changed PPS exceeded the analogous estimate from [6] and amounted to 0.118 and 0.105. Despite the fault of probabilities the result can be called satisfactory. We can conclude that the constructed model simplifies describing the changes in the parameters of handwritten patterns that occur when the signer uses alcohol, caffeine or sedatives, and also after physical exertion. The reliability of recognition of subjects PPS by handwritten patterns can be increased if an apparatus of neural networks will be used. Neurons can be constructed on the basis of one of the functionals mentioned in the present article.

4. Conclusions

The paper presents model of changing the features of a handwritten patterns depending on the signers PPS. The model allows transforming etalons formed in a normal PPS, to the etalons of the changed state of the signers. It was possible to achieve an average error probability of 0.105 while applying the method of recognizing the changed state of the signer using this model and the multidimensional Bayesian functional.

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