Hybrid algorithms of the person identification by face image

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Abstract. In this paper, the problem of constructing hybrid algorithms for identifying a person (IAP) by the image is considered, which is the main one in the development of biometric systems based on them. To solve this problem, we propose a model of algorithms, consisting of the following stages: selection of the area of the face in the image; searching pupils on the face image (FI); determining the location of the mouth and nose; forming a set of geometric features; allocation of subsets of strongly coupled features; the definition of representative features in each subset of strongly related features; interim assessment for the FI class for each set of representative features; estimate for the FI class for all intermediate estimates. A distinctive feature of the proposed hybrid algorithm (HA) is the integration of the results of various methods for determining anthropometric points at the level of calculating the final score for each class of facial images. The main purpose of this paper is to develop an algorithm for integrating various methods of identifying features when IAP on a FI.

1. Introduction
In recent years, an ever wider circle of specialists have been paying attention to the problem of IAP's identity by the image of a person, and the number of scientific publications on this subject is constantly growing. This is due to the fact that in recent years, the identification of a person's FI has been increasingly applied in various areas of daily life.

It is known [1,2] that the problem associated with modeling the processes of IAP's FI was affected even at the earliest stages of the development of computer imaging technologies. These methods and algorithms are rapidly developing, and this has caused the emergence of intelligent systems based on modern information technologies [3,4], and now these systems are widely used. Examples include: communication between people via the Internet (videoconferences, consultations, mail); search for information on the Internet and access to it; organization of electronic commerce; customer-bank systems; access control (to the database, program system, buildings, etc.); person search in the database of the FI.

It should be noted that all the above tasks have one common property: they require a connection between the person and the system in the interactive mode. And most importantly, only the registered
user has the right to enter the system, and the intelligent system manages these processes. In this regard, one of the central tasks in intelligent systems is the task of user identification. This task is successfully solved with the help of biometric methods of identity identification. With these circumstances, to date, in many developed countries, research in the field of identity is based on biometric parameters [5]. Among them, the identification of the person on the FI is recognized as the most acceptable for mass application [4-7]. However, the development and application of algorithms for pre-processing images of a person in identifying an individual are little studied [4].

This work is devoted to the development of algorithms for pre-processing an image of a person, which form the basis for creating systems for IAP's identity on a FI. The main attention is paid to the formation of the space of geometric features. A distinctive feature of the HA is the integration of the results of various methods for determining anthropometric points.

The aim of the work is to develop an algorithm for integrating various methods of IAP by the FI. To achieve this goal, the following tasks have been accomplished:

- we analyzed the main literature on the subject of the study and determined the range of problems to be solved;
- we developed an algorithm for the integration of various methods for IAP on a FI;
- we conducted experimental studies to assess the operability of the developed algorithm.

2. Related Work

It is known [3,7,8] that each FI can be represented by some vector of features. Then to each image of the face a certain vector containing ideally the complete information about this image corresponds. Further processing of data related to the recognition of a person's FI is performed over a set of these vectors. However, the definition of an adequate set of features that takes into account the features of the implementation of algorithms for identifying features and providing the required quality of recognition is one of the most complex problems in the theory of pattern recognition in general, and in the problem of constructing personal identification systems in the FI in particular [7-10].

In the literature on pattern recognition, in particular [9], three categories of attributes are considered: physical, structural and mathematical. To date, a large number of algorithms have been developed, aimed at solving the problem of identifying features when recognition a person's FI. These include: algorithms for identifying physical features [3,4,6,7,12]; algorithms for isolating structural features [3,6,7,13]; algorithms for highlighting mathematical features [3,7,10,14]. It should be noted that one of the first methods of face recognition associated with analyzing the geometric characteristics of a person was developed and was originally applied in forensic science [15,16]. The main idea of the method is to determine the key points (or areas) and then to select a set of characteristics based on them. Each feature is either the distance between the key points, or the ratio of such distances. These signs are formed on the basis of various ratios of distances between elements (anthropometric points) of the face [3,4,6-8].

On the basis of this brief overview, one can conclude that one of the central tasks in the problem of identifying features is the questions of determining the key features (or highlighting) of a digital image. To date, a large number of methods and algorithms have been developed to solve the problem of isolating the geometric features of the FI. However, the coordinates of the same set of anthropometric points of the FI when they are distinguished by different methods are slightly different. Naturally, the application of the same recognition algorithm (RA) to the results of various algorithms for distinguishing features can give different solutions.

Classically, in this case, the RA that gives the smallest number of recognition errors is selected. The following hypothesis is put forward: integration of the results of RAs will increase the accuracy of the classification of the feature sets distinguished by different methods. The validity of this hypothesis has been studied in this paper.
3. Statement of The Problem

Let us consider the set of admissible images of a person $\mathbb{F}$, which is divided into a finite number of subsets (classes) $K_1, ..., K_l$:

$$\mathbb{F} = \bigcup_{i=1}^{l} K_i, \quad K_i \cap K_j = \emptyset, \quad i \neq j, \quad i, j \in \{1, ..., l\}.$$ 

Fragmentation $\mathbb{F}$ is not completely determined. There is only some initial information $\mathcal{Z}_0$ about classes $K_1, ..., K_l, ..., K_l$.

Let there be some sample $\tilde{\mathbb{F}}^m$ ($\tilde{\mathbb{F}}^m \subset \mathbb{F}$), which consists of $m$ FIs (objects) $\tilde{\mathbb{F}}^m = \{\mathcal{F}_1, ..., \mathcal{F}_u, ..., \mathcal{F}_m\}$ ($\mathcal{F}_u \in \mathbb{F}, u = 1, m$):

$$\tilde{\mathcal{K}}_j = \tilde{\mathbb{F}}^m \cap K_j, \quad \mathcal{C}\tilde{\mathcal{K}}_j = \tilde{\mathbb{F}}^m \setminus K_j.$$ 

Then the initial information $\mathcal{Z}_0$ about classes can be specified in the form:

$$\mathcal{Z}_0 = \{\mathcal{F}_1, \bar{\alpha}(\mathcal{F}_1), ..., \mathcal{F}_u, \bar{\alpha}(\mathcal{F}_u), ..., \mathcal{F}_m, \bar{\alpha}(\mathcal{F}_m)\},$$

$$\bar{\alpha}(\mathcal{F}_u) = (\alpha_{u1}, ..., \alpha_{uj}, ..., \alpha_{ul})$$

where $\alpha_{uj}$ – predicate value $\mathcal{P}(\mathcal{F}_u) = "\mathcal{F}_u \in K_j"$.

Let there be given an arbitrary set of images of the face $\tilde{\mathbb{F}}^q = \{\mathcal{F}_1', ..., \mathcal{F}_q'\}$ – control set ($\tilde{\mathbb{F}}^q \subset \mathbb{F}$). The main task of IAP’s personality according to the geometric characteristics of the FI is to construct an algorithm $\mathcal{A}$, which computes predicate values $\mathcal{P}(\tilde{\mathbb{F}}^q)$ from the initial information $\mathcal{Z}_0$. In other words, the desired algorithm $\mathcal{A}$ takes the set $(\mathcal{Z}_0, \tilde{\mathbb{F}}^q)$ to the matrix $\|\beta_{ij}\|_{q \times 1}$ [16]:

$$\mathcal{A}(\mathcal{Z}_0, \tilde{\mathbb{F}}^q) = \|\beta_{ij}\|_{q \times 1}, \quad \beta_{ij} \in \{0, 1, \Delta\},$$

where $\beta_{ij}$ interpreted as in [17].

4. Proposed Approach

To solve this problem, we propose an approach consisting of the following parts:

- formation of geometric features of the FI;
- recognition of the person by the selected geometric features of the FI;
- personality recognition based on the integration of the results of all the extreme recognition operators.

4.1. Formation of geometric features

At this stage, a set of geometric features is identified, which are defined as the distances between the anthropometric points of the face. In this case, the coordinates of the anthropometric points of the face are determined using different methods [1-7]. Algorithms for selecting a set of geometric features consist of the following basic operations.

4.1.1. Selecting a face area on an image. At this stage, 3 procedures are used to select the area of the face in the image. The first procedure is based on the allocation of areas of the image by the color of the human skin on the color image. In the second procedure, a face mask is searched based on the analysis of the correlation coefficients. The third procedure for selecting the area of the face is carried out on the basis of the Viola-Jones algorithm.

4.1.2. Search pupils on the FI. At this stage four procedures are used to determine the coordinates of the middle pupils on the FI. The first procedure is based on the search for a circle using the Hough transform. In the second procedure, the pupils are searched based on the analysis of the integral projection of brightness. The third and fourth procedures work in the same way as the first ones, differing from them in that the search area is reduced using the Viola-Jones algorithm.
4.1.3. Determining the location of the mouth and nose in the FI. To determine the location of the mouth and nose, integral projections are used, but before that, it is required to normalize the original FI, based on the obtained coordinates of the pupil centers using previous procedures.

4.2. Recognition of the identity of the selected geometric features of the FI

At this stage, the questions of constructing an extremal recognition operator for each set of distinguished geometric features. It should be noted that the construction of the extremal operator is carried out within the framework of the model of recognition operators, based on the principle of potentials. This model of recognition operators includes the following main steps.

4.2.1. Difference function determination $d(\mathcal{F}_u, \mathcal{F}_v)$ between FIs $\mathcal{F}_u$ and $\mathcal{F}_v$. At this stage, a function is specified that characterizes the difference between $\mathcal{F}_u$ and $\mathcal{F}_v$ for each set of selected geometric characteristics $X$. The difference between these objects is determined as follows:

$$d(\mathcal{F}_u, \mathcal{F}_v) = \sum_{i=1}^{n} \lambda_i (f_{ui} - f_{vi})^2,$$

where $\lambda_i$ – weight coefficient, which corresponds to the feature $x_i$.

4.2.2. Difference function determination $\Pi(\mathcal{F}_u, \mathcal{F}_v)$ between images $\mathcal{F}_u$ and $\mathcal{F}_v$. At this stage, the proximity function is between objects $\mathcal{F}_u$ and $\mathcal{F}_v$ with the help of potential functions.

At this stage, the proximity function between images $\mathcal{F}_u$ and $\mathcal{F}_v$ is defined as a potential function of the second type $\Pi(\mathcal{F}_u, \mathcal{F}_v)$, decreasing when an object is deleted $\mathcal{F}_v$ from the object $\mathcal{F}_u$ [17,18]:

$$\Pi(\mathcal{F}_u, \mathcal{F}_v) = 1/(1 + \xi d(\mathcal{F}_u, \mathcal{F}_v)),$$

where $\xi$ – recognition operator parameter.

4.2.3. Calculation of the membership score for an object $\mathcal{F}$ by class $K_j$. The total potential for a class is assumed to be the function:

$$\Pi_j(\mathcal{F}_v) = \sum_{\mathcal{F}_u \in \tilde{K}_j} \gamma_u \Pi(\mathcal{F}_u, \mathcal{F}_v), \tilde{K}_j = \mathcal{F}_u \cap K_j,$$

where $\gamma_u$ – recognition operator parameter.

The above steps fully define the model of recognition operators based on the principle of potentials. Any operator $\mathcal{B}$ from this set is completely determined by specifying a set of parameters $\pi$. The set of all recognition operators in the framework of the model under consideration is denoted by $\mathcal{B}(\pi, \mathcal{F})$.

Then the problem of constructing an extremal recognition operator can be formulated as the problem of finding the optimal operator $\mathcal{B}(\pi^*, \mathcal{F})$ among the recognition operators $\mathcal{B}(\pi, \mathcal{F})$, ensuring the fulfillment of the following condition [18]:

$$\mathcal{R} = \inf_{\pi} \left( \frac{1}{\sum_{u=1}^{Q} H(\alpha(\mathcal{F}_u) - \mathcal{B}(\pi, \mathcal{F}_u) \circ C(c_1, c_2)))} \right),$$

where $\|\cdot\|$ – norm of a Boolean vector, $Q$ – number of control sample objects. Here $\pi$ – vector of configurable parameters of the recognition operator; $C(c_1, c_2)$ – decisive rule [17].

Thus, we define an extremal recognition operator within the recognition operators based on the potential principle. With the consistent use of the operator $\mathcal{B}(\pi^*, \mathcal{F})$ to objects $\mathcal{F}_1', \ldots, \mathcal{F}_q'$, we obtain the matrix $\|\Pi_j(\mathcal{F}_j')\|_{Q \times Q}$. As a result of this stage, we obtain an extremal recognition operator for each set of geometric features identified in the second stage. It should be noted that when $n$ sets of geometric features are selected, we obtain $n$ extremal recognition operators constructed from these sets. As a result of applying these recognition operators to biometric samples $\mathcal{F}_1', \ldots, \mathcal{F}_q'$ we get $n$ matrix, presented in the form:
\[ \| \Pi_i^{(F_i')} \|_{q\times l} \ldots, \| \Pi_i^{(F_i')} \|_{q\times l} \ldots, \| \Pi_i^{(F_i')} \|_{q\times l} \]

where \( \| \Pi_i^{(F_i')} \|_{q\times l} \) is the rating for the object \( F_i' \), calculated using the \( u \)-th extreme recognition operator \( B_u(\pi^*, F) \).

4.3. Identification of personality by integrating the results of all extreme recognition operators

At this stage, we consider the construction of an extreme integrator based on the Bayesian approach. This model of integration includes the following main steps.

4.3.1. Selection of subsets of strongly coupled identification operators. Let \( \pi \) be the extremal recognition operators. Then, as a result of this stage, a system of \( \pi \) “independent” subsets of strongly connected identification operators (IO) is \( \mathcal{D}_\pi (\pi = 1, \pi^n) \). Setting different values for the parameter \( \pi^n \) one can obtain various stochastic integrators. Power of subsets \( \mathcal{D}_\pi \) depends not only on the parameter \( \pi^n \), but also on the initial data. It should be noted that all operations are associated with the identification of subsets of strongly connected IO according to the corresponding matrices \( \| \Pi_i^{(F_i')} \|_{q\times l} \).

4.3.2. The definition of a representative operator in each subset of strongly connected IO. At this stage, there is a set (vector) of representative IO. \( \mathcal{R}_{\pi^n} \) – a partition of the set of operators into \( \pi^n \) subsets \( \mathcal{D}_{1\pi}, \ldots, \mathcal{D}_{\pi^n} \), the corresponding partition of the index set of IO into the set \( h_1, \ldots, h_{\pi^n}, \ldots, h_n \), such that \( n_1 + \ldots + n_\pi + \ldots + n_n = n \).

We consider the set of boolean vectors \( \{\tilde{\omega}\} \), which consists of \( n \) components. Let us single out all the unit coordinates of the vector \( \tilde{\omega} \), whose number is \( \pi^n \). Let these elements correspond to the coordinates \( i_1, \ldots, i_{\pi^n} \) of the vector \( \tilde{\omega} \).

We remove from consideration all the IO, except for the operators \( B_{i_1}, \ldots, B_{i_{\pi^n}}, \ldots, B_{i_{\pi^n}} \) (in \( \mathcal{D}_{\pi^n} \)), which correspond to the unit coordinates of the vector \( \tilde{\omega} \). We denote the resulting part of the set of IO by \( (B_{i_1}, \ldots, B_{i_{\pi^n}}, \ldots, B_{i_{\pi^n}}) \) and call the \( \tilde{\omega} \)-space of IO. Let \( \mathcal{S} \) be the set of all possible sets (subsets) of IO:

\[ \mathcal{S} = \{ B_{i_1}, \ldots, B_{i_{\pi^n}} | B_{i_1} \in \mathcal{D}_{i_1}, \ldots, B_{i_{\pi^n}} \in \mathcal{D}_{i_{\pi^n}} \} \]

For each element of the set \( \mathcal{S} \) there is a unique boolean vector \( \tilde{\omega} \). The set of boolean vectors corresponding to all elements of \( \mathcal{S} \), is denoted by \( \mathcal{M} (\mathcal{M} = \{\tilde{\omega}\}) \). Then a set of representative IO can be specified as a boolean vector \( \tilde{\omega} \) (\( \tilde{\omega} \in \mathcal{M} \)). Thus, the problem of choosing a set of representative IO is reduced to defining a vector \( \tilde{\omega} \).

4.3.3. Computing the integral estimate of a biometric sample. Let the estimates of the membership of \( (P_{i_1}, \ldots, P_{i_{\pi^n}}, \ldots, P_{i_{\pi^n}}) \) of biometric samples \( F_{i_1}', \ldots, F_{i_{\pi^n}}', \ldots, F_{i_{\pi^n}}' \) be:

\[ P_u = \| p_u^{(F_i')} \|_{q\times l} \]

where \( p_u^{(F_i')} = \Pi_u^{(F_i')} / \sum_{u=1}^{i_{\pi^n}} \Pi_u^{(F_i')} \).

Evaluation of the integrator \( B(B_{i_1}, \ldots, B_{i_{\pi^n}}, F) \) for a class is defined as follows:

\[ r(K, F) = (p_1^{(F_i')} \times \ldots \times p_1^{(F_i')} \times \ldots \times p_1^{(F_i')}) / \Sigma, \]

\[ \Sigma = \sum_{i=1}^{i_{\pi^n}} p_1^{(F_i')} \times \ldots \times p_1^{(F_i')} \times \ldots \times p_1^{(F_i')}, \]

where \( \pi^n \) – the given parameter of the integrator under consideration, being the number of representative IO.

Then the integrator is estimated as follows:

\[ B(K, F) = (r(K, F))^\nu / \sum_{i=1}^{i_{\pi^n}} (r(K, F))^\nu \).

where $v$ – a given parameter of the integrator under consideration, which plays the role of a regulator of the "contrast" of the output values.

Thus, we have defined a model of stochastic integrators based on the Bayesian approach. It should be noted that any integrator $\mathbb{B}(\mathcal{F}) (\mathbb{B}(\mathcal{F}) = \mathbb{B}(\mathcal{B}_1, \ldots, \mathcal{B}_m, \mathcal{F}))$ from this model is completely determined by specifying the set $\theta$, which is considered in this subsection. The set of all integrators from the proposed model will be denoted by $\mathbb{B}(\theta, \mathcal{F})$. Search for the best algorithm is carried out in the parameter space $\theta$.

At this stage, the parameter $v$ is set, which regulates the "contrast" of the outputs of the statistical integrator (17). If $v < 1$, then the probability estimate $\mathbb{P}(K_j, \mathcal{F}_i')$ is more smoothed than the estimate $\mathbb{P}(K_j, \mathcal{F}_i)$. On the contrary, at $v > 1$ large probability values $\mathbb{P}(K_j, \mathcal{F}_i')$ become even closer to 1, and small ones - even more decrease. With the optimal value of $v$, which maximizes the quality of biometric identification, the output estimates are closest to posteriori probabilities.

Thus, an arbitrary integrator from this model is completely determined by specifying a set of parameters $\theta = \{n', \{\mathbb{P}_u\}, v\}$

5. Experimental Results
The initial data for assessing the quality of the HA is a sample consisting of photo portraits. The number of classes in this experiment is five. The volume of the initial sample is 200 images of the photo portraits. Moreover, the number of objects in each class is different (from 32 to 49 objects).

Comparison of identification results on the basis of the HA is performed with the results presented in [19]. Comparative analysis of these algorithms in solving the problem considered was carried out according to the following criteria: 1) accuracy of recognition of objects of the control sample; 2) the time spent on learning the algorithm; 3) the time spent on recognition objects from the control sample.

To calculate these criteria, the 10×10-fold cross validation method is used to solve the problem [20].

Comparison of the obtained results shows that the HA allowed to increase the accuracy of face recognition by over 9% (96.36% vs. 86.95%). However, in this case there is an increase in the learning time of the HA, as well as the time spent on recognition objects from the control sample.

The results of the conducted experimental research show that the HA allows to increase the recognition accuracy. This is because the HA combines the results of RAs, based on the idea of the synthesis of reliable systems of unreliable elements, proposed by J. Neumann, E.F. Moore and C.E. Shannon.

At the same time, we note that the time spent on solving this problem increases, especially in the process of integrator training. In this regard, the application of such algorithms is advisable when creating systems that operate in offline mode, but require high accuracy of identification.

6. Conclusion
An algorithm for IAP from a FI is proposed, based on the integration of the results of various RAs. This algorithm increases the accuracy of solving the problem of IAP by the image of a person and can be used to compile various software complexes that are oriented towards the solution of this problem. In addition, the obtained results can be used in the creation of identity systems that allow solving the currently important tasks such as: searching for a person in a database based on a person’s image, access control, and information protection in computer systems, etc.

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