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A PROBABILISTIC APPROACH TO CLASSIFICATION OF DIGITAL FACE IMAGES

Abstract. In the present paper, we deal with the application of the probabilistic approach, which makes it possible to optimize the face image classification task. The mathematical expectations and variances of the investigated random parameters are used as basic statistics. The proposed method allows us to carry out a fast and reliable preliminary classification and to exclude obviously dissimilar face image from the further analysis.
Keywords: biometric identification, face recognition, facial geometry, anthropometric characteristics, identification features, statistical method.

PODEJŚCIE PROBABILISTYCZNE DO KLASYFIKACJI CYFROWYCH OBRAZÓW TWARZY

Streszczenie. W niniejszej pracy mamy do czynienia z zastosowaniem podejścia probabilistycznego, które pozwala zoptymalizować zadanie klasyfikacji obrazów twarzy. Wartości oczekiwane i wariancje badanych parametrów losowych są stosowane jako podstawowe statystyki. Zaproponowana metoda pozwala przeprowadzić szybką i właściwą wstępną klasyfikację i wykluczyć bardzo odmienne obrazy twarzy z dalszej analizy.
Słowa kluczowe: identyfikacja biometryczna, rozpoznawanie twarzy, geometria twarzy, cechy antropometryczne, cechy identyfikacyjne, metoda statystyczna.

Introduction

There are a lot of people recognition methods based on uniquely detectable biological traits. The major types of biometric identification technologies that can be useful in businesses, law enforcement and biometric forensics for identifying or verifying individuals use various biological and behavioral characteristics such as fingerprints, iris patterns, retina design, facial geometry, hand recognition, hand veins drawing, voice recognition, keystroke or typing recognition and so forth. In spite of the fact that person identification can be carried out by the different individual traits, the face recognition is one of the most attractive, flexible, reliable and widespread identification approach among the existing biometric methods [8, 11, 14–16, 18, 25, 30].

The problem of formalization and automatization of the facial recognition process was considered at the earliest stages of pattern recognition systems development and still remains an urgent challenge. In recent years, the number of scientific research and publications on this subject steadily increases. On the one hand, this is explained by the increasing opportunities of the computer equipment and its operation cost reduction. On the other hand, special attention to biometric technologies is dictated by existence of a wide range of applied tasks in the most different spheres where automatic person identification is an integral part of their successful application. So, for example, the person identification on the basis of face recognition can be applied in identity cards control systems (a passport, a driving license), information security (access to computers, databases, etc.), observations and investigations of criminal events, and security in the banking sector (ATMs, remote account management systems) [8, 15, 16, 24–27, 30].

At present, the problem of human identification is considered from two positions according to the purpose of automated identification systems: the real-time mode and search of the identified object in large databases. In the first-class systems the image of a human face is used as the key confirming or disproving the data entered for identification. The purpose of such systems is a quick solution of identification task. The systems realizing a solution of the second class tasks, as a rule, return a set of images that are most similar to the required one, and the choice of the final decision is provided to the expert. As far as the database may contain hundreds of thousands of records, such systems are not able to work in real time. The purpose of these systems is the task solution within reasonable time.

From a practical point of view, the development of systems for solving the problems of the first class is simpler and requires less effort than for solving the problems of the second class. Development of systems of the second class is very important first of all in criminalistics and information retrieval application.

The choice of facial anthropometric characteristics

It is obvious that people significantly differ from each other in such features as an arrangement of eyes, eyebrows, nose, ears, mouth, etc. Therefore, it is not surprising that historically the first approach to a solution of the problem of automatic face recognition was based on selection and comparison of some facial anthropometrical characteristics [1–7, 9, 10, 17, 21, 23, 28, 29, 31].

The applied systems which are carrying out person identification on the basis of facial analysis use anthropometric points and all experience on people identification accumulated in forensic science. The main problem encountered in the development of face recognition systems consists in the choice of a set of characteristic points that uniquely describe a specific human face. At the same time it is necessary to consider the following requirements:

– the process of recognition should be independent of image scale;
– the selected characteristic point set should provide relative stability of the recognition procedure under minor change of the image (a slight turn and tilt of the head, change in facial expression, etc.);
– the number of the facial feature points satisfying the above requirements and providing high precision of recognition should be minimal whenever possible as the computing complexity of algorithms (and the identification time, respectively) is usually proportional to the cardinality of a selected set of the anthropomorphic points.

The most suitable anthropometric technique

When solving the identification problem, each object is described by a set of variables which is also called a feature vector, or an attribute vector. The set of the facial anthropometric characteristics presents a parametrical basis for face recognition procedure in automatization identification systems. The criminalistics methodology, which is based on metric measurements of facial parameters in terms of a selected set of anthropometric points, can be used as a basis for the formation of a space of quantitative characteristics. At the same time, the key requirement imposed on the used parameters consists in their reliability and accuracy of their detecting in the automatic mode [10, 13, 16, 20, 24].

After the choice of a set of anthropometrical points (a feature vector) it is necessary to create a quantitative feature vector. The linear sizes containing all the available reliable information about quantitative facial characteristics are usually considered as such features. In order to form this vector it is necessary:

– to detect the most important anthropometric points on the face image;
– to determine the linear sizes of separate parts of the face;
– to calculate the relative distances between facial feature points.

It should be noted that the measurement of distances between anthropometric points is usually carried out only horizontally and vertically. This results from the fact that such distances require less computational costs for their acquisition and processing; besides in this case the measurement accuracy will also be higher. The basic distances are measured by the number of pixels considering discretization of digital facial images [3, 6, 7].

The method for calculating anthropometric features

In order to eliminate the influence of possible scale differences of facial images it is necessary to use not the absolute but relative distances between the facial anthropometric points, which have been considered as quantitative features. Therefore, some ratios of distances between facial characteristic points are chosen as the main features. For this purpose, the absolute distances are divided by the basic distance. One of the linear sizes is usually chosen as a basic distance taking into account the following recommendations:

– the anthropometric points determining the basic distance should be detected with high precision on any facial image in order to reduce permissible inaccuracy of relative distance calculation;
– the basic distance should be large in comparison with other distances whenever possible;

In addition, it is necessary to consider the horizontal and vertical dimensions separately in order to eliminate the influence of the head rotation around the horizontal and vertical axes on the relative distance values.

It is obvious that the upper part of the face is more static and less susceptible to any kinds of changes (both age-related and cosmetic). Therefore, the distance between the eyes pupils is certainly the most important measured value, it is the basic horizontal distance in relation to which all the main face proportions are usually determined. Let us note that the distance between the centers of the horizontal pupils line and the midpoint of the upper lip region is usually chosen as the basic vertical distance. The choice of these distances as basic ones is caused by the circumstance that their values should not change considerably for the head tilts at small angles (within the limits of real values, as a rule not exceeding 5−10 degrees) [3, 6, 7, 28, 29].

Let there be given a set of distances between the facial anthropometric points $L = \{l_1, l_2, \ldots, l_n\}$. On the basis of ratios of the elements of this set it is possible to create a basic set of features $\Delta = \{\delta_1, \delta_2, \ldots, \delta_n\}$ as follows

$$\delta_j = \frac{l_j}{l^*} \ \ (j = 1,2, \ldots n),$$

where $l^* \in L$ represents the basic distance.

The use of identification features in the form of the ratio between two distances makes them independent of the facial image size.
In addition, for practical purposes the set of features can be divided into two subsets:

– the first subset includes features compiled on the basis of the relationships between the distances measured in accordance with the horizontal direction,
– the second subset includes features compiled on the basis of the relationships between the distances measured in accordance with the vertical direction.

In this case there are two subsets of features $\Delta^{(1)} = \left\{\delta_1^{(1)}, \delta_2^{(1)}, \dots, \delta_{n_1}^{(1)}\right\}$ and $\Delta^{(2)} = \left\{\delta_1^{(2)}, \delta_2^{(2)}, \dots, \delta_{n_2}^{(2)}\right\}$ corresponding to the horizontal and vertical directions, respectively; at the same time, it is obvious that $n = n_1 + n_2$. It is clear that the features that belong to the first subset will be sufficiently stable to head rotation around the vertical axis. Similarly, the features belonging to the second subset will be fairly sustained to the slight inclination of a head up or down with respect to the horizontal axis.

In practice, a face recognition task of the second class is reduced to searching for only a certain number of images in the database (from one to ten) the most similar to the given. The specified image is compared with the available images in the database by calculating the Euclidean distance between two points in an n-dimensional space (n is the number of compared features) [8, 11, 18, 25].

In the general case, without splitting the input features into two subsets, the similarity measure of the facial images D is calculated by the following formula:

$$D = D_i(\Delta_i, \Delta_0) = \sqrt{\sum_{j=1}^{n} \left(\delta_j^i - \delta_j^0\right)^2},$$

where $\Delta_0 = \{\delta_1^0, \delta_2^0, \dots, \delta_n^0\}$ and $\Delta_i = \left\{\delta_1^i, \delta_2^i, \dots, \delta_n^i\right\}$ are the feature vectors of the identifiable facial image and of the ith image in the database, respectively; $i = 1, 2, \dots, N$, N is the total number of relevant images in the database.

In the case when two different features vectors corresponding to the horizontal and vertical directions are used we can apply the following relation

$$D = D_i\left(\Delta_i^{(1)}, \Delta_0^{(1)}\right) + D_i\left(\Delta_i^{(2)}, \Delta_0^{(2)}\right).$$

The approach based on the extraction of anthropometric points on the face image and analysis of their mutual arrangement in addition to its inherent simplicity provides sufficient accuracy at rather low computational cost and complexity of the recognition algorithm.

Statistical method for classification of face images

A conceptual proposition that the used basic parameters are considered as random variables occupies an important place in the development of mathematical support of face recognition systems. Therefore, along with the accurate and robust extraction of a set of anthropometric points in facial image as well as with forming a feature vector (the ratios of the measured distances) on its basis, the key role in automatic face recognition systems should be assigned to statistical classification approach for optimization and acceleration of the identification process.

The statistical method allows us to take into account the specific data of practical experience which represent in accumulated form the previously obtained unique complex of these and other statistics (the estimators of the required probabilistic characteristics of anthropometric parameters) on the basis of the available face image databases. The mathematical expectations and variances of the investigated random parameters can be used as basic statistics in order to realize the defined idea.

Let us consider some anthropometric parameter ξ representing a random variable whose values fall into a certain interval $[a, b]$ (a and b are real numbers). Let a sample $(x_1, x_2, \dots, x_N)$ be formed for the parameter ξ on the basis of available face images database, where $x_i \in [a, b]$, $i = 0, 1, \dots, N$; N is the number of images. The mathematical expectation and variance of the parameter ξ for the given sample are calculated by the formulas:

$$\mathrm{E}\xi = \frac{1}{N}\sum_{i=1}^{N} x_i, \tag{1}$$

$$\mathrm{V}\xi = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mathrm{E}\xi)^2. \tag{2}$$

The statistics (1) and (2) are unbiased estimations of the corresponding probabilistic characteristics.

We reduce the parameter ξ to the unified standardized form by means of the following transformation

$$\hat{\xi} = \frac{\xi - a}{b - a}. \tag{3}$$

Thus, each possible value $\hat{\xi} \in [0, 1]$ for any numbers a and b ($a < b$). Besides, in view of the linearity of expression (3) the analogues of statistics (1) and (2) for the normalized parameter ξ are calculated by the rules

$$\mathrm{E}\hat{\xi} = \frac{\mathrm{E}\xi - a}{b - a}, \tag{4}$$

$$\mathrm{V}\hat{\xi} = \frac{V\xi}{(b-a)^2}. \tag{5}$$

Since the values of all the measured parameters fall into the range [0,1], then formulas (3) - (5) can be used to calculate an overall comparison error of two face images.

The classification by reference statistical classes

The procedure of face classification according to specified characteristics (age category, sex, ethnicity, etc.) can be carried out by means of the sets of statistics previously calculated on the basis of face samples meeting the necessary requirements from the available database [11, 14, 16, 19, 22, 25, 30].

Let us assume that in the basis set of face images representing the kth class ($k = 1, 2, \dots, K$; K is the number of classes under consideration) for some anthropometric parameter $\xi_i^{(k)} \in \left[a_i^{(k)},\ b_i^{(k)}\right]$ ($i = 1, 2, \dots, n$; n is the number of anthropometric parameters) we have the sample $\left(x_{i,1}^{(k)}, x_{i,2}^{(k)}, \dots, x_{i,N_k}^{(k)}\right)$, where $x_{i,j}^{(k)} \in \left[a_i^{(k)},\ b_i^{(k)}\right]$; $j = 1, 2, \dots, N_k$; N_k is the sample size.

Then, in accordance with the relations (1) - (5), for the target values of the expectation and variance of the normalized analogue $\hat{\xi}_i^{(k)}$ of the parameter $\xi_i^{(k)}$ for the kth class the following calculated relationships are true

$$\mathrm{E}\hat{\xi}_i^{(k)} = \frac{1}{b-a}\left(\frac{1}{N_k}\sum_{j=1}^{N} x_{i,j}^{(k)} - \xi_i^{(k)}\right), \tag{6}$$

$$\mathrm{V}\hat{\xi}_i^{(k)} = \frac{1}{(b-a)^2(N_k-1)}\sum_{j=1}^{N}\left(x_{i,j}^{(k)} - \mathrm{E}\xi_i^{(k)}\right)^2. \tag{7}$$

Thus, each face image is assigned to a statistical class representing a probability space given by a statistical sample. The classification of a new unknown face is reduced to the calculation of some generalized measure of its inclusion into a statistical class. As such a measure we can choose the statistical anthropometric weight of the face image under consideration. To form such a weight, it is necessary to estimate the probabilities that the measured anthropometric features of the face under test fall within the appropriate statistical classes.

As it is known, for the facial anthropometric features such as the most important facial ratios, the typical probability density function with increasing a statistically significant sample size approaches to a normal distribution N_{a,σ^2}, which depends on two parameters: the mathematical expectation α and the standard deviation σ. Hence, for the anthropometric parameter $\hat{\xi}_i^{(k)}$ we have $\alpha = \mathrm{E}\hat{\xi}_i^{(k)}$, $\sigma = \sqrt{\mathrm{V}\hat{\xi}_i^{(k)}}$, and the values $\mathrm{E}\hat{\xi}_i^{(k)}$ and $\mathrm{V}\hat{\xi}_i^{(k)}$ are calculated in accordance with (6) and (7), respectively. Thus, we can assume that the probability density function for the kth class is described by the relation

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-\alpha)^2/(2\sigma^2)}.$$

In this case the probability $\mathrm{P}_i^{(k)}$ that the normally distributed random variable of the normalized anthropometric parameter $\hat{\xi}_i^{(k)}$ takes the values in the specified confidence interval $\left[\hat{\xi}_{i,min}^{(k)}, \hat{\xi}_{i,max}^{(k)}\right] \subset [0,1]$ $\left(\hat{\xi}_{i,min}^{(k)} = \mathrm{E}\hat{\xi}_i^{(k)} - \delta,\ \hat{\xi}_{i,max}^{(k)} = \mathrm{E}\hat{\xi}_i^{(k)} + \delta\right)$ can be calculated as follows:

$$\mathrm{P}_i^{(k)} = \mathrm{P}\left(\hat{\xi}_{i,min}^{(k)} \le \hat{\xi}_i^{(k)} \le \hat{\xi}_{i,max}^{(k)}\right) = \Phi_0\left(\frac{\hat{\xi}_{i,max}^{(k)} - \hat{\xi}_i^{(k)}}{\sigma}\right) - \Phi_0\left(\frac{\hat{\xi}_i^{(k)} - \hat{\xi}_{i,min}^{(k)}}{\sigma}\right),$$

where $\Phi_0(x)$ is the error function

$$\Phi_0(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2/2} dt.$$

If $\hat{\xi}_i^{(k)} \notin \left[\hat{\xi}_{i,min}^{(k)}, \hat{\xi}_{i,max}^{(k)}\right]$, then the probability of the correct solution $\mathrm{P}_k = \mathrm{P}\left\{\left|\hat{\xi}_i^{(k)} - \mathrm{E}\hat{\xi}_i^{(k)}\right| > \delta\right\}$ within the framework of the described scheme can be estimated on the basis of Chebyshev's inequality. In this case, as the required probability P_k we can take the threshold value, which bounds it from above

$$\mathrm{P}_i^{(k)} = \frac{\mathrm{V}\hat{\xi}_i^{(k)}}{\delta^2}. \tag{8}$$

Now, having the probabilities $\mathrm{P}_i^{(k)}$ $(i = 1, 2, \ldots, n)$ for all the anthropometric features, we can form the general measure $\mu^{(k)}$ of belonging of the face image to the kth class $(k = 1,2,\ldots,K)$. In this case, the product of the probabilities (8) can be taken as the required estimation of image similarity:

$$\mu^{(k)} = \prod_{i=1}^{n} \mathrm{P}_i^{(k)}. \tag{9}$$

Thus, the similarity measure (9) can be used for searching the face images that are the closest to the given one in the database.

Conclusion

The probabilistic approach considered in the article makes it possible to optimize the face image classification task, to reduce the negative impact of such factors as low quality of source images, errors of anthropometric measurements, fluctuations of basic descriptors and their overruns of the limits of the confidence intervals, restrictions on established classification characteristics and so forth.

The proposed method allows us to carry out a fast and reliable preliminary classification and to exclude obviously dissimilar face image from the further analysis. It seems expedient to use the described approach as one of the first methods in the ensemble of face image classifiers.

Let us note that using this method the time costs of face classification are reduced significantly since the basic calculations of mathematical expectation and variance are performed at the preliminary stage, while the time for calculating the measure (9) of belonging of the face image to the selected class depends only on the number of used anthropometric features.

Furthermore, it should be also emphasized that practical application of the probabilistic approach under consideration should ensure very high productivity when a necessary set of statistics is formed for a large volume and high quality database of face images.

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