Methods of Face Photo-Sketch Comparison[1]

G. A. Kukharev[a,b], K. Buda[b], and N. L. Shchegoleva[a]

[a] *Saint Petersburg State Electrotechnical University, ul. Prof. Popova 5, Saint Petersburg, 197376 Russia*

[b] *Westpomeranian University of Technology, Zolnierska, 49, WIZUT, Szczecin, Poland*

e-mail: kuga41@mail.ru, kbuda@wi.zut.edu.pl, stil_hope@mail.ru

Abstract—Article presents the state of the art problem of comparing photo portrait and the corresponding hand-drawn portrait (sketch). Proposed novel methods of automatic sketch generation. The result of the application of this methods on two popular face database are given. It is shown that for sketch recognition you can use simple system.

Keywords: face recognition, art sketch, sketch synthesis, face photo-sketch comparison, sketch recognition system, two-dimensional principal component analysis.

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INTRODUCTION

In recent years we observed increased importance of matching original photo-image with its forensic sketch. We are presenting the scope of related problems and the state of the art of proposed approaches and solutions. Presented survey is mainly based on references [1–11] authored by leading persons in this field. Discussed are proposed solutions of relevant problems, such as retrieval the original face image in big database based on given sketch, prepared according to oral descriptions of witnesses or participants of some events (including the criminal ones); relations between sketches of faces and corresponding images of faces, solution to the problem of mutual recognition: face image—sketch.

PROBLEMS OF FACE IMAGE—SKETCH MATCHING

Five variants of sketches were used, as presented in Fig. 1, taken from different papers about sketch synthesis and recognition [1–7].

First row contains five face images and second row shows corresponding sketches, characterized as follows:

1. Forensic sketches are drawn by interviewing a witness to gain a description of the suspect [6, 7];

2. Face sketches prepared based on verbal descriptions with the aid of facial composite software (composite sketches [6, 7]);

3. Sketches made by artists based on face photo (art sketches), reflecting main characteristic features of people and their faces [2].

4. Sketches generated automatically based on original face photo (viewed sketch) and completed by artists [1];

5. Sketches generated automatically based on original face photo (viewed sketch).

Analysis presented in [6, 7] shown that stable recognition results using two first variants (forensic face sketches and composite face sketches) and steady retrieval of corresponding photo in databases is unattainable.

This bad result is a consequence of three basic reasons:

1—bad quality of used sketches;

2—lack of image databases adequate for such applications;

3—imperfect methods of photo-sketch recognition.

First and second reasons are presented and partially investigated in [5, 6].

Sketch quality depends on technique of oral portrait descriptions transformation into corresponding visualization. Here we have to do with witness subjectivity, usually the ordinary people, having no crime detection knowledge, their specific observation and description ability, influencing the translation of their description of perpetrator into corresponding sketch.

Second reason is connected with inadequacy of “old face databases” (mug shot images gallery) to modern computer technology of image processing as used in face biometric applications.

Third reason is connected with underdeveloped technology of comparing photo—sketch, causing with lack of simple and effective method of matching,

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Fig. 1. Examples of face images and corresponding sketches.

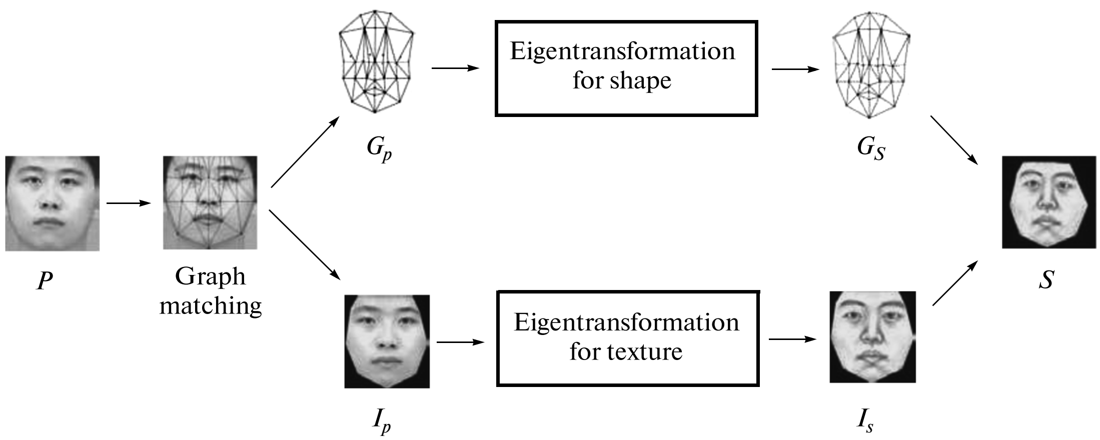

Fig. 2. Linear transformations relating photo and sketch (as presented in [3]).

lack of appropriate benchmark bases of the pairs photo—sketch, and consequently lack of experience in such comparison.

APPROACHES AND SOLUTIONS ANALYSIS

Above was the reason of attempts to create bases of sketches and extensions of existing benchmark face databases [1, 2], development of comparison methods photos—sketches, and modeling the task of retrieving the photos based on given sketches [3–10].

In results bases of sketches has been created—CUHK Face Sketch database (CUFS) and the base CUHK Face Sketch FERET Database (CUFSF), containing 606 and 1194 pairs of photo—sketches [1, 2], respectively. Some instances of such pairs presented in Fig. 1 in column 4 (base CUHK, included into base CUFS) and 5 (base CUFSF).

Besides, new ideas concerning automatic sketch synthesis from face photo, were developed. In majority of cases these development were made using the base CUHK.

One such idea presented in [3] started with the fact that photos and corresponding sketches concerns the same people, suggesting existence of linear transformations relating both form of graphical presentation, as presented in Fig. 2.

Obtained in [3] results seem to confirm proposed sketch generation idea.

In [4, 9] was used the “facial composite”, developed in the mid of XX century. First facial composite system used the pieces of various images of face, and combined them creating new face image. In the papers [4, 9] authors used contemporary computer techniques developing this method, such as Markov model, multi-scale Markov fields [4], and the library of face image segments, used as graphical components of sketch [9]. Both approaches used pairs of photo—

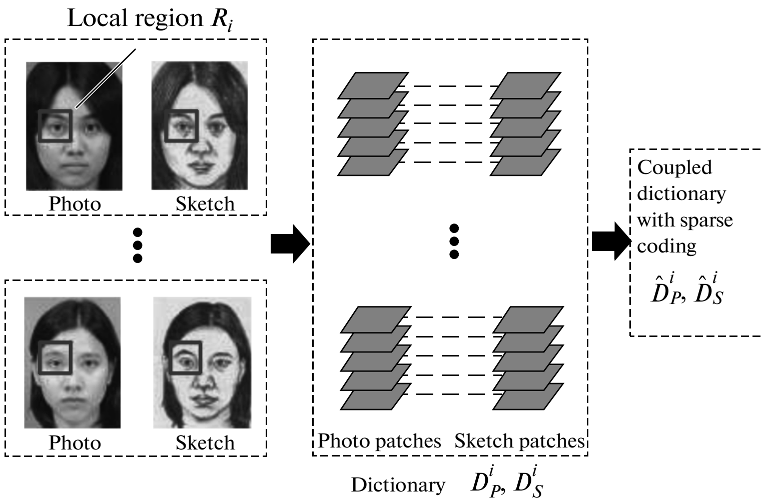

Fig. 3. Transformation of local fragments photo-sketch [9].

Fig. 4. Sketches generated with various methods. *1*—original photo; *2*—Art Sketch; *3*—result of method [3]; *4*—result of method [9].

sketch in building corresponding models, which is used for sketch synthesis from new photos.

Application of the related face image fragments library presented in Fig. 3. Selected image fragments are represented as compact vectors in reduced features space, using e.g. the PCA method. Next the transformation of image fragments used linear parameter of correspondence between the features. Value of this parameter in determined in the learning stage of transformation.

Methods presented in [3, 4 and 9] have some important drawbacks. These methods require:

—Creation of additional libraries of pairs photo-sketch (use in the stage of model's learning);

—Are computationally expensive (e.g. calculating the PCA and HMM models);

—Not always exactly transforms the border and shape of original faces.

Therefore often transformations are limited to the central regions of faces.

Figure 4 illustrated sketches generated with these methods [3, 9].

The method that does not have these drawbacks was presented in [10]. Original photos were decomposed into global and local areas, and within these areas are performed all transformations. Global area is, e.g. hair area, or area of naked skin. Local areas are—eyes, eyebrows, nose, lips, wrinkles, shadows and light reflections, allowing representing specific features and details of faces.

Fig. 5. Examples of cropped face images and corresponding sketches [2].

Basic operations of image processing are as follows:

—Intensity inversion (negative) and decomposition of colors into basic components (e.g. components R, G and B);

—Detection of segments corresponding to skin color and hair color;

—Image smoothing (blur filtration, neighboring pixels averaging, low-pass filtration);

—Intensity gradients determination (detection of wrinkles, shadows);

—Image pixel-wise subtraction.

Publication [10] is of great value, and presented algorithm, which has simple implementation. But from the other side presented ideas are not novel, and commonly used in image processing. Below we present simple method of constructing such sketches (see for instance the pair photo-sketch in column 5 in Fig. 1).

Please note that unlike methods presented in [3, 4 and 9], method presented in [10] render impossible the inverse transformation from sketch to original photo image, because in direct transformation photo-sketch part of information is lost (is not retained in the sketch).

METHODS OF PHOTO-SKETCH MATCHING AND POSSIBILITY OF THEIR MUTUAL RECOGNITION

CUHK base contains sketches generated automatically from original images and corrected by artists, having 188 pairs photo-sketch. CUFSF base contains sketches, that are drawn while viewing an original photos from the base FERET, retaining basic face features of imaged people, but having some artefacts (elements of caricature or exaggeration) that are made by artist.

Differences in synthesis of sketches in base CUHK and base CUFSF lead to different effectiveness of recognition, for former base amounting to nearly 100%, [3–5], and later base correct recognition is achieved only in case of exact agreement of size and orientation of face in the XY plane. Unfortunately website [2] contains only cropped sketches of very bad quality (as concerns resolution, size and texture), practically not allowing its usage in representative investigations.

Examples of cropped face images (from base FERET) and corresponding sketches (from base CUFSF [2]) are presented in Fig. 5.

In comparison to cropped sketches from database [2], sketches shown in Fig. 5 have visible additional touch-ups in the selected regions and its elements (forehead, nose, lips etc.). These operations were made by hand—i.e. not in automatic (computer) mode of image processing. Besides, texture in the region of face is smoothed with low-pass filter. And, finally, basic anthropometric parameters were corrected (eyes line, distance between eyes center, etc.).

It is possible, that for the investigation purpose of photo-sketch matching and its mutual recognition, such corrections are necessary. But in case of actual applications, like criminal investigations (were important is to retrieve the perpetrator based on given sketch), it is not only prohibited, but also practically not possible. Simply because it is not known which photo of the perpetrator will match given sketch, and its parameters!

Please note that presenting the results of mutual recognition photo-sketch, for base CUHK [1], in [3, 4] presented were not only processing procedures, but also parameters of training and test samples, making possible to identify model of conducted experiments.

But in [5, 8], for base CUHK as well as for base CUFSF, results of mutual recognition photo-sketch are not presented clearly the partition of data into train and test sets, but also parameters of test images (see, e.g., results presented in [3, 5, 8]). Therefore, evaluation of presented results is difficult, identification of implemented model of conducted experiments is impossible, as well meta-analysis of results obtained.

Fig. 6. First stage of input image processing.

Here we are making a short analysis of processing the pairs photo-sketch, as presented in [3–11]:

—in [3] implemented linear and eigen-transformation, including PCA. Achieved result up to 81% at rank = 1 for base CUFS, containing 300 pairs of test images;

—in [4] implemented model based on stochastic Markov fields, and classifiers of type LDA. Obtained result of 96% at rank = 1 and 99% at rank = 10, for base CUHK, containing 100 pairs of test images;

—in [5]—for each pair photo-sketch employed are coupled information-theoretic projection (CITP), based on coupled information-theoretic encoding (CITE), further enhancement of feature similarity based on CCA, and finally PCA + LDA classifier is used. Result obtained is 99.9% at rank = 1 for base CUFS. Published result for the base CUFSF (sketches for base FERET) amounted to 98.7%. *It is unclear, however, at which result rank and number of test images*;

—in [6] sequentially used the method SIFT, multiscale LBP and classifier based on LDA. Result obtained amounted to 99.5% at rank = 1, for base CUHK;

—in [8] Gabor filter was applied for enhancement of elements of sketch form, next the Radon transform for enforcement of information about texture, and finally for the segments texture of the interest areas the BPH (Binary Pattern Histogram) was evaluated, representing sketch in the form of "Gabor Shape". Result obtained is 99.9% at rank = 1, for the base CUHK\CUFS; Result for the base CUFSF (sketches for the base FERET) was 99.1%. *Again, it is not clear what was the rank of the result and the number of used test images*;

—in [11] set of photo images and corresponding sketches were transformed onto eigen-space based on PLS. There is substantial correlations between features representing photos and sketches in such space. It makes possible to describe photo in terms of sketches (and vice versa), using the bilinear regression, and consequently to recognize photo based on sketch, and sketch based on photo. Result obtained is 93.6% for the base CUHK. It is not clear the range of result estimate and details of 5 variants of data group samples from the total number of 100 test images as well as the number of used test images.

In summary of performed analysis we can note as follows:

—in our opinion application of various rather complicated processing methods to the bases CUHK and CUFSF is not justified. It is possible that important role played "fashion" on the methods CMM, CITE, CITP, LBP, rather than strong arguments for their selection;

—result for base CUFSF was not fully correct presented, and were repeated many times in the papers of different authors.

It is interesting to note that only Radon transform (see paper [8]) was used as the method allowing to reconstruct practically non existing texture based on sketch-transform.

It seems also justified application of linear transformations in coordinate system spanned by eigen-vectors [3] as well as projection onto subspaces obtained with PLS and CCA [11] for transformation of photo into sketches and vice versa.

We can also mention that in applications involving processing of the pairs of images (photo and sketch), implementation of projections onto subspaces should be made using 2D methods, presented detail in, e.g. [12–14]. These give substantial reduction of computation costs for all transformations mentioned above, improve stability of solutions of eigen-problems, additionally solved the small sample problem accompanying image processing problems. Above features of 2D subspace projection methods are presented in [14–15].

AUTOMATIC EXPRESS METHOD OF PHOTO-SKETCH TRANSFORMATION

We are given the input color image in color space RGB. Viewed sketch generation process based on such image has three stages: first stage involve preparation operations, second stage—operation of global sketch

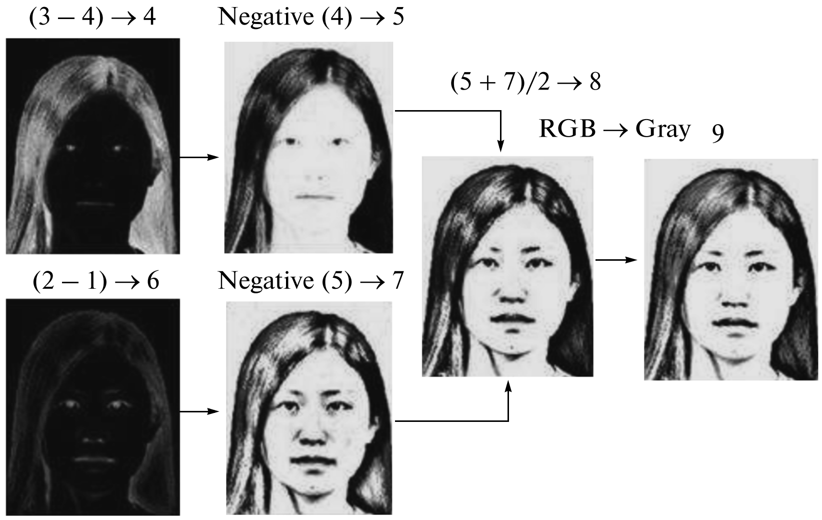

Fig. 7. Operations of second step of sketch synthesis.

Fig. 8. Comparison of sketches.

structure formation. Third stage—formation of local sketch structure using simple geometrical transformations of face area (it is particularly important when modeling sketches, in case of not full or inexact parameters of “input photo”).

Figure 6 illustrate processing involved in **first stage**, where: *1*—input color image of the base CUHK [1]; *2*—result of blurring the input image with filter “blur”; *3*—color negative of input image.

Figure 7 illustrated all operations of **second stage**. Here in step 4 and 5 regions are selected containing hair as main ROI. Here 4—difference between negative “3” and input image and 5—negative of this difference. In steps 6 and 7 are determined details of face area, which are now the ROIs. Here: 6—difference between blurred image “2” and input image and 7—negative of this difference. In step 8 results of steps 5 and 7 are added, giving the color sketch, which in step 9 is transformed to GRAY scale image.

In Fig. 8 illustrated four trios of images each containing: input image, corresponding sketch from the base CUHK and sketch obtained by proposed express—method.

Please note that sketch obtained with express-method is exact anthropometric copy of input image, and includes all necessary shadows in the hair area and face area (nose, chin, area around lips, neck...), but not contains original texture. As we can see in color image all detected details are clearly visible. Such sketch can be treated as first approximation to drafted face images. Two first steps of express-method are very simple, easy implementable, allowing to synthesize sketches for any benchmark face datebases. Example

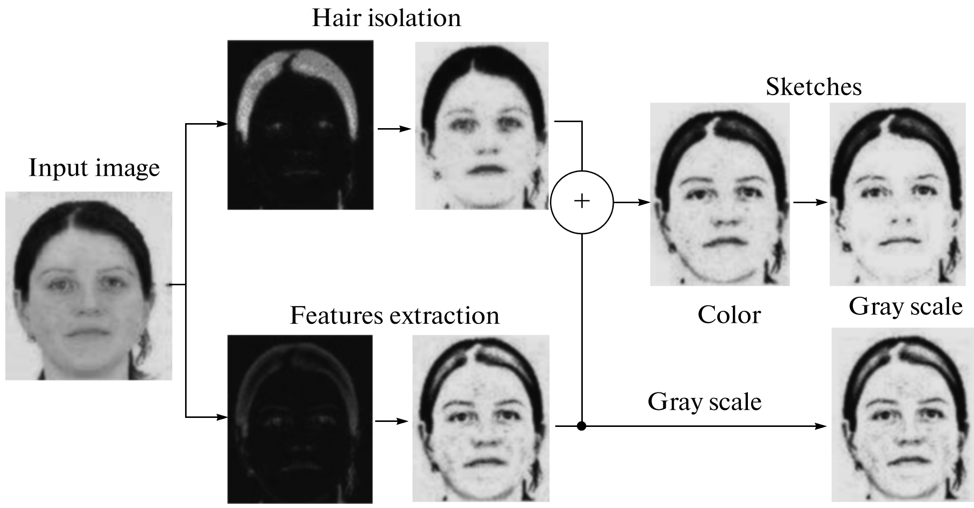

Fig. 9. Variant of sketch synthesis from the face database PUT.

Fig. 10. Photo and sketches generated based on verbal description by the witnesses.

of this is shown in Fig. 9, illustrating sketches obtained from the face database PUT [https://biometrics.cie.put.poznan.pl/].

Before we go to the **third step of sketch synthesis** let consider Fig. 10 for answering the following questions: how we can evaluate the similarity measure of input image and corresponding sketch? And how the visible similarity (visible to human) should correspond to some formal index? And what is more important to evaluate: similarity visible by human observer of input image and its sketch, or some formal index of similarity? This question is particularly important is situation "witness ⟶ verbal face description ⟶ artists ⟶ sketch" and "sketch ⟶ photo retrieved based on this sketch".

In our opinion pairs photo-sketch have a visible similarity, but there is a problem how to measure it. We start with universal quality index [17] for evaluation of similarity between original photo and its corresponding sketch. Index Q measures the similarity (deformation) of two images as combination of three factors: luminance distortion, contrast distortion and correlation lost:

$$Q = \frac{4\sigma_{FS}\bar{F}\bar{S}\sigma_{FS}}{(\sigma_F^2+\sigma_S^2)[(\bar{F})^2+(\bar{S})^2]}$$
$$= \frac{2\sigma_F\sigma_S}{\sigma_F^2+\sigma_S^2}\times\frac{2\bar{F}\bar{S}}{(\bar{F})^2+(\bar{S})^2}\times\frac{\sigma_{FS}}{\sigma_F\sigma_S},$$

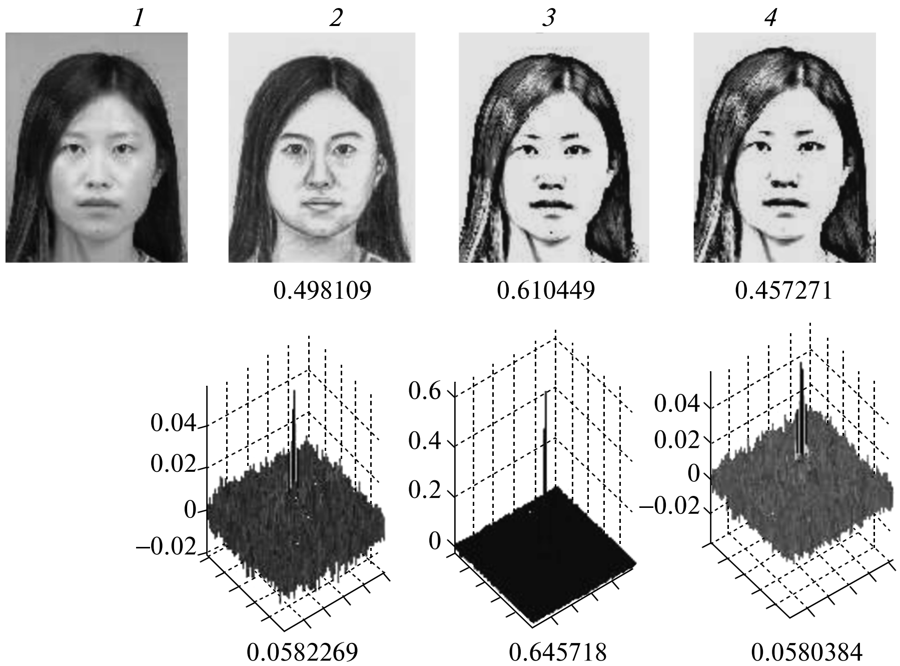

Fig. 11. Result of comparing photo with its sketches.

where: $\bar{F}$, $\bar{S}$ – luminance averages of input image and corresponding sketch;

σ_F^2, σ_S^2 – luminance variance of input image and its sketch;

$\sigma_{FS}/(\sigma_F\sigma_S)$ – amplitude correlation between input image and its sketch.

Additionally we use phase correlation [18], which unlike amplitude correlation responds sharply to local image changes.

Figure 11 illustrate: 1 and 2—original photo and its "Art Sketch" from the base CUNF; 3—sketch obtained on second stage of express-method; 4—sketch 3 modification by forming a new local structure.

Below photo 2 and 3 are shown: quality index Q, phase correlation function and their maximal values $r_{\max}$ (correlation of photo and its sketch). We can comment as follows: visual similarity means values of $Q \approx 0.5$, and $r_{\max} \approx 0.06$. This means global (holistic) similarity of photo and "Art Sketch", but are not similar at local level. For sketch obtained at second step of express-method we get $Q \approx 0.7$, and $r_{\max} = 0.62$! It means that photo and its sketch are similar on both level (it is the result of the way we form the sketch, what we comment earlier). For third sketch (with parametric changes of geometry of local segments of face area), parameters Q and $r_{\max}$ are like in the case of "Artist Sketch". Such changes are visible in all sketches generated for the base CUFS, leading to the conclusion: local changes in face geometry we obtain new sketches, with similar parameters as for "Artist Sketch". Figure 12 illustrate nine "Art Sketches" with local changes of face area and nine sketches generated at third step of express—method.

Parameter Q changed in the range 0.41—0.5, and it is worth noted these sketches are closer to real life applications.

SIMPLE SKETCH RECOGNITION SYSTEM AND CORRESPONDENCE SEARCH

We can show that practically satisfying solution to the task of sketch recognition is achievable with simple FaReS (**Fa**ce **Re**cognition **S**ystem [16]), not requiring any of the processing methods mentioned in [3–5, 8–11]. For FaReS implementing we use the base CUFS, containing $K = 100$ pairs of test images (pair photo—sketch). In the base of templates we place all 100 photos, and as test images using sketches "Artist Sketch" and sketches formed with proposed express-method.

Let the images-templates $I(k)$, $\forall k = 1, 2, ..., K$, be contained in the template base FaReS. Besides each template is represented in FaReS as feature vector $V(k)$, $\forall k = 1, 2, ..., K$. Every test-sketch S is also represented as feature vector V_s. Using this way of data representation in FaReS, classification problem (recognition) of all test images S could be treated as search of nearest image $I(k)$, $\forall k$ from the base FaReS, using certain similarity measure. Similarity measure of two

“Artist Sketch” with local changes of face area	Sketches generated at third step
	
Value of Q	Value of Q
0.4181 0.4433 0.04734	0.4157 0.4905 0.04721
0.4172 0.4689 0.4696	0.4795 0.4812 0.4792
0.4567 0.4689 0.4037	0.4396 0.4184 0.4456

Fig. 12. Modification of face area in sketches at local level.

images is taken as minimal distance between their feature vectors:

$$d(k) = distance(Vs, V(k)), \forall k.$$

In this case classification problem of test image S is reduced to calculation of distance $d(k)$, $\forall k = 1, 2, ..., K$. Index k coresponding to minimal distance will define nearness of test image S to image $I(k)$ from the base FaReS.

In the frame of supervised classification, when we have information about category (class) of image S, final result of recognition can be reported as the fraction of correctly classified test images from the set of all test images. This fraction will be given in percentage.

Algorithm

1. No special method of preprocessing of images or sketches will be not performed. In original feature space the input image and corresponding sketch will be represented by their values of pixel in gray-level scale. For sizes $M \times N$ of input images and sketches, dimension of feature space is MN.

2. Photo is transformed with 2D principal component analysis (2D PCA) [16] into spectrum. Size of spectrum matrix is also $M \times N$. Spectrum magnitude fall rapidly in the direction of main diagonal of spectral matrix. Therefore we build feature vector using only from the left upper corner of spectral matrix. Each feature vector contains only $d(d + 1)/2$ spectral components laying symmetrically on both sides of main diagonal, selected so that it contains components with coordinates (1,1), (2,1), (1,2), (3,1), (2,2), (1,3), (4,1), (3,2), (2,3), (1,4), etc. Parameter d is a length of side of square located in left upper corner of spectral matrix.

3. We perform minimum distance classification using metrics L_1 and result rank equal 1.

Based on above procedure, the model of computer experiment is:

$$\mathbf{CUFS(100/1/1)\{2D\ PCA:}\ M \times N \longrightarrow d(d+1)/2\}[\mathbf{MDC/L1/rank = 1}], \tag{1}$$

where: $M = 250$; $N = 200$: $d = 30$ and parameter “d” is defined by solving the variational problem. Result obtained is **71% with rank = 1**.

Including the preprocessing operation of selecting the central area of face from the whole image, result obtained was **97% with rank = 1**.

Table

No.	Art Sketch, 3rd stage					Viewed Sketch, 3rd stage				
Exp	1	2	3	4	5	1	2	3	4	5
1	88	84	92	88	92	96	99	97	99	97
2	90	90	90	90	91	98	98	99	98	100
3	88	91	89	86	89	100	99	98	97	97
4	89	87	90	86	92	99	99	100	98	100
5	90	90	84	86	91	99	100	99	98	99
6	87	86	91	87	93	96	96	99	100	100
7	90	88	90	85	89	99	99	100	100	99
8	89	92	86	87	89	99	99	100	100	99
9	88	89	85	86	90	100	100	98	97	98
mean	88.6667					98.689				

Model of computer experiment in this case is:

$$\textbf{CUFS(100/1/1)\{Cropping + 2D PCA: } M \times N \longrightarrow d(d+1)/2\textbf{\}[MDC/L1/rank = 1],} \qquad (2)$$

where the operation "**Cropping**" consist in cutting from input image a square of 20 pixel side length, and leaving without changes remaining part of image.

Performing the same experiments with the data set «training» from the base CUFS the amount of correctly classified sketches (rang = 1) was 85 out of 88, it is 96.9%.

For "Art Sketch", modified in third step of express-method, average outcome in the frame of model (2) was in the range 89% to 81% at rank = 1, depending on selected modification parameters. Reduction in recognition rate can be justified by changes in local structure of these sketches. Conducted two times of 5 groups of experiments with 9 changes of modification parameters in each experiment—total 90 of experiments. Analogous experiments were conducted with sketches synthesized by express-method. Some better results shown in table.

In Fig. 13 presented original data and recognition results concerning our base of sketches, obtained with above described express-method in stage 2. All experiments were conducted according to models (1) and (2). Results obtained in both cases amounted to 100% at range = 1.

For own sketch base, obtained in stage 3, average results for 90 experiments for models (1) and (2) amounted from 98.7% to 99.8% at rank = 1.

Figure 14 presents structure of modeled FaReS, used in all experiment. FaReS consists of: 1—block of selecting ROI; 2 and 3—2D PCA blocks; 4—base of templates (original images and their vector representations); 5—classifier.

SUMMARY

Proposed novel method of automatic sketch synthesis, that can be used for sketch recognition tasks research and retrieval of corresponding photo. These methods were applied to two popular benchmark face databases and obtained results were discussed. It was

250 × 200   100/100 = 100%   210 × 160   100/100 = 100%

Fig. 13. Input data and results for own sketch base.

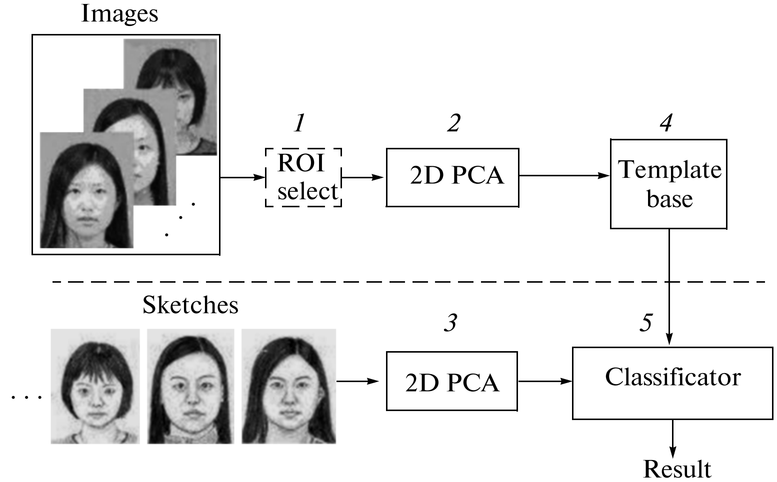

Fig. 14. FaReS structure.

shown that for recognition of sketches very simple systems can be used. Presented application example is one of possible variant of such system. It has many clearly visible advantages compared to systems presented in [3–5, 8–11], in particular simple implementation and accuracy of sketches recognition.

It seems that methods of matching sketch with corresponding photo should be directed by specific application scenario. Therefore future investigation shall be connected with analysis of different scenarios, taken from real situations. We are going to apply new variants of sketch synthesis and methods of recognition, including sketches for database FERET.

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Georgy Alexsandrovich Kukharev Born in Leningrad, Russia. Received Ph.D. degree (1997) from the Fine Mechanics and Optics Institute (Leningrad, Russia) and Doctor of Technical Science degree (1986) from the Institute of Automatics and Computer Facilities (ABT, Riga, Latvia). Since 2006, full professor at Szczecin University of Technology, Faculty of Computer Science & Information Systems (Poland), and at Saint Petersburg State Electrotechnical University LETI, Department of Computer Software Environment. In 2001–2003 visiting professor of Ecole Centrale de Lyon, Department of Mathematics & Computer Science. Since 2005 visiting professor of Hanoi University of Technology, Department of International Training Programmer. Author of ten monographs, over 100 scientific papers, and over 40 patents in the areas: computer architecture of signal processing, image processing, and pattern recognition. Current interests: biometrics, including face detection and face recognition; Visitor Identification and access control systems, task Name It, and Face Retrieval.

Katarzyna Magdalena Buda was born in 1987. Received master's degree at the Faculty of Computer Science & Information Systems at Szczecin University of Technology (Poland) in 2013. Now she is doctoral. Research interests: face recognition, sketch and image processing. Co-author of 4 publications.

Nadegda Lvovna Shchegoleva was born in Komsomolsk-on-Amur, Russia. Received Ph.D. degree (2000) in Saint Petersburg Electrotechnical University (LETI). 2001–2006 Senior Researcher in Okeanpribor Concern Open Joint-Stock Company. Since 2007 Associate Professor of the Computer Software Department in Saint Petersburg Electrotechnical University "LETI". Co-author of two monograph, patent, more than 40 scientific articles. Current interests: the biometric identification systems and access control systems, face detection and face recognition, building and modeling of the recognition systems.