PALM SHAPE COMPARISON FOR PERSON RECOGNITION

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Abstract: The article presents a new method for palm comparison based on the alignment of palm shapes. The proposed approach allows comparison and recognition of palms with sticking fingers. The existing methods do not work correctly in this case, while it frequently appears in real environments (mostly among elderly people). The idea of the proposed method is to model a ”posture” of test palm on reference palm. The form of flexible object is used for palm modeling. This representation provides a convenient tool for applying palm transformations and allows us to perform them in real-time mode. Low resolution webcams can be used for palm image acquisition. The article also introduces the application of person recognition based on the proposed comparison. At the end of the article the problem of improving recognition characteristics of palm is addressed. Particularly, it provides a bimodal approach that employs palm and voice features.

1 INTRODUCTION

The article presents a new method for palm comparison based on its shape. Comparison is performed between reference and test palms. Reference palm is a model of person's palm stored in the form of flexible object (Mestetskiy, 2009). This representation of reference palm is constructed for a ”good” image of palm, i.e. it doesn't contain sticking fingers, long nails, rings or bracelets. Contrarily, test palm is a binary image of palm, which can contain sticking fingers, like on Figure 1. Such case appears while dealing with elderly people as sometimes it is difficult for them to separate fingers. The proposed method employs only palm shape information, interior is of no interest. So, non-expensive webcams can be used to obtain palm images.

The proposed method for palm comparison suggests analyzing shapes of transformed reference palm and test one. Transformation is performed for reference palm because it is a model of palm and we know its structure; while it isn't true for a test one. Generally, when person presents his/her palm for recognition, he/she does some or all of the following movements: shifts and rotations of palm; rotations of fingers. The used representation of reference palm allows these movements to be modeled and, finally, test and reference palms to be compared in the same ”posture”. The article continues the work, introduced in (Bakina and Mestetskiy, 2009). Most existing approaches to palm recognition require to show palm the way all fingers are well separated. The proposed method for palm shape comparison can operate in common cases with well separated fingers and, moreover, it suits for cases with sticking fingers.

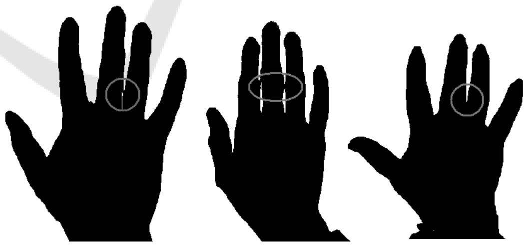

Figure 1: Examples of sticking fingers.

Palm shape isn't really unique among people. So, one-to-many comparison (or identification) doesn't provide good recognition accuracy. However, the reducing of identification problem to verification one may help. The possible way of doing this is combining palm shape features with other biometric data. As an example, a fusion of palm and voice features is considered in the article.

The article is organized as follows. Section 2 considers the background. In Section 3 the used model of palm is described, and the construction of such model is presented. In the next Section 4 comparison of palms and similarity measure are introduced. Section 5 describes the recognition system based on palm shape comparison. Section 7 introduces the bimodal

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approach. Also, Sections 6 and 7 present the results of the experiments carried out. Conclusion and future work are considered in Section 8.

2 BACKGROUND

There are a lot of approaches to person recognition based on palm features. The first one, which is widely used nowadays, employs hand geometry features such as palm width, perimeter, area, lengths and widths of fingers, distances between finger joints, etc. This approach is introduced in several works—(Jianxia et al., 2005), (Gonzalez et al., 2003), (Morales et al., 2008), (Boreki and Zimmer, 2005), (Wong and Shi, 2002), (Covavisaruch et al., 2005), (Varchol and Levicky, 2007), etc. Generally, the works differ in a set of hand geometry features used, distance functions and classifiers applied. For example, in (Morales et al., 2008) information about width (measured at 40 locations) of index, middle and ring fingers is considered. In (Covavisaruch et al., 2005) feature vector is composed of 21 components—length of fingers, width of each finger at 3 locations, width of the palm. Also, several distance functions are compared. In addition to common hand geometry features special comparison is performed for finger tips in (Wong and Shi, 2002).

Another approach to person recognition based on palm features suggests transforming palm to predefined position and extracting shape-based features (Yoruk et al., 2006), (Jain and Duta, 1999), (Mestetskiy, 2007), (Su, 2008). In this case a contour of palm is taken as a signal, to which independent component analysis, wavelet, cosine or other transforms are applied. But most of the existing approaches can operate only in situations when person presents his palm in a such manner that obtained image is good. At least it means that fingers are well separated, i.e. don't touch each other. For a "good" palm it is possible to calculate features correctly and, then, apply some classifier to perform recognition.

Hand geometry features don't suit for person recognition in the case of sticking fingers, because we don't know the exact position of fingers and, therefore, can't calculate their characteristics. However, shape-based approach gives hope to us, because the shape of palm is known, even when there are fingers touching each other.

Shape-based approach was introduced in several works. In (Yoruk et al., 2006) it is proposed to apply transform features for a normalized palm for recognition purposes. Normalization includes initial orientation of whole palm, orientation of fingers by their eigen values (rotation of fingers at their pivot points) and alignment of two palms by their centroids and pivot lines. The authors compare recognition accuracy for modified Hausdorff distance and two architectures of the Independent Component Analysis. The obtained correct identification and verification accuracies were about 98 – 99% depending on the size of feature vector for the Independent Component Analysis.

Another approach is introduced in (Jain and Duta, 1999). In this work it is suggested extracting five pairs of corresponding fingers and aligning them separately. Alignment for each pair of fingers is based on quasi-exhaustive polynomial search of point pair matching between the two sets of points. Least-squares type distance is used to provide analytical solution to the alignment problem. The average distance between the corresponding points is used as measure of similarity of two palms. Threshold rule is applied for verification. *FAR* (False Accept Rate) and *FRR* (False Reject Rate) curves are presented for different values of a threshold. For the threshold equal to 1.8 the obtained *FAR* is about 2%, while *FRR* is near to 3.5%.

In (Mestetskiy, 2007) reference and test palm to be compared are transformed to a predefined position, where angles between fingers are fixed. This is done by performing rotations of fingers at their bending points. Then, the palms are aligned. After that normalized symmetric difference of their superposed silhouettes is calculated. Nearest neighbor approach and threshold rule are applied for classification. The obtained *EER* (Equal Error Rate) is about 5%.

In all these approaches reference and test palms are supposed to be of the same nature (set of contour points, flexible objects, etc). Generally, transformations are performed or can be performed for both of them. However, these approaches require no sticking fingers and long finger nails. Ring removal technique is introduced only in (Yoruk et al., 2006).

The approach to palm shape comparison, proposed in this article, can be used in cases of sticking fingers. It is based on the same idea of alignment of palm shapes for comparison. We assume that reference palms don't have fingers that touch each other, while test ones can have them. Transformations reflect possible movements of palm. They are performed for a reference palm to provide the best alignment with a test palm.

3 MODEL OF PALM

The model of palm, which is constructed for a reference palm, is proposed in (Mestetskiy, 2009). It is the form of flexible object, based on the circular decomposition of binary image. Further, we consider some definitions, which are used in the article.

3.1 Basic Definitions

Consider a set of points T on the Euclidian space $\mathbb{R}^2$ such that it is connected planar graph. The graph contains a finite set of vertices and continuous edges. Edges can intersect only at graph vertices. Each point $t \in T$ is associated with circle c_t with the center at this point.

Family of circles $C = \{c_t, t \in T\}$ is called the *circular graph*. Graph T is called the *axial graph* or *skeleton* of a circular graph. The union of circles $S = \bigcup_{t \in T} c_t$ with their interior is called the *silhouette* of a circular graph. So, silhouette of a circular graph is a close connected set of points on the Euclidian space $S \subset \mathbb{R}^2$. The boundary of a circular graph is the envelope of all circles in the family C. The allowed set of transformations of a circular graph that preserve its topological structure and make the group, is called *deformations*. Denote a set of deformations by V. *Flexible object* $G = \{C, V\}$ is a circular graph and its set of deformations.

In the proposed approach to palm comparison it is possible to apply such transformations of flexible object that don't preserve its topological structure. So, let a set of deformations V be a set of transformations that make a group.

Figure 2 (on the left) shows an example of flexible object. It contains its axial graph T and family of circles C (only circles associated with graph vertices are present).

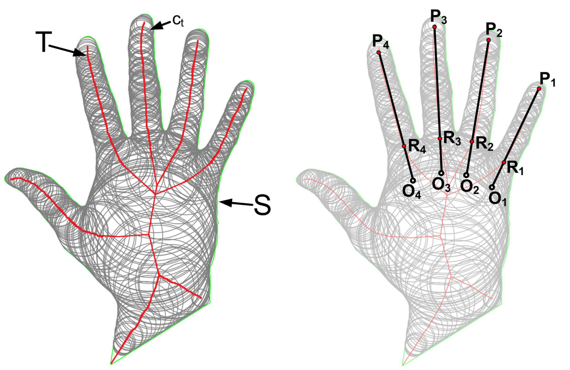

Figure 2: Example of flexible object (on the left) and its marking (on the right).

Thus, to define the flexible object of palm it is necessary to describe the allowed set of transformations T.

3.2 Palm Transformations

In the proposed system person shows his/her palm by positioning it on a horizontal surface. So, basic movements of palm can only include, as it was described earlier, shifts and rotations of palm, rotations of fingers. Thus, a set of transformations to be defined should allow all these movements to be modeled.

First, *rotation points* of four fingers (index, middle, ring and little) are calculated. This points are the roots of finger proximal phalanges. Fingers are rotated at this points. Thumb finger isn't considered, as its movements are more complex and can result in the significant change of palm shape (for example, skin changes between index and thumb fingers).

The procedure of extracting tips, roots and rotation points of fingers is described in (Bakina and Mestetskiy, 2009). It is assumed that the rotation point of a finger lies on its axe, and the distance between rotation point and root of the finger is 30% of the finger length. Here, *axis* of a finger is a line that connects its tip and root. On Figure 2 (on the right) rotation points are marked as O_1, O_2, O_3 and O_4. Points R_1, R_2, R_3 and R_4 are root points of fingers; points P_1, P_2, P_3 and P_4 are tips of fingers; lines O_1P_1, O_2P_2, O_3P_3 and O_4P_4 are axes of fingers.

It should be noted that tips and roots of fingers are detected automatically by analyzing the palm circular graph. In short, the branch of the circular graph is considered from its branchpoint to leaf node. The first vertex to fulfil the restrictions on radius r of the circle and angle φ between two segments connecting the center of circle with its tangency points is treated as the root of a finger. Then, the branch is analyzed in opposite direction and similar restrictions are applied to extract the tip of a finger.

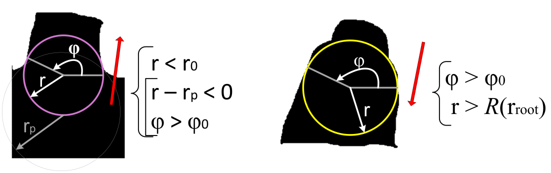

Figure 3: Detection of root (on the left) and tip (on the right) of a finger.

Figure 3 illustrates the restrictions applied. Here, r is the radius of the current circle on the branch; φ is the angle between two segments connecting the center of a circle with its tangency points; r_p is the radius of the previous circle; r_0 and φ_0 are restrictive constants; r_{root} is the radius of the found root vertex; $R(x)$ is a function. In the current work $R(x) = 0.65x$.

So, the allowed set of transformations includes shifts and rotations of whole palm, and rotations of fingers at points O_1, O_2, O_3 and O_4. It is assumed that the structure of polygon $O_1O_2O_3O_4$ is fixed.

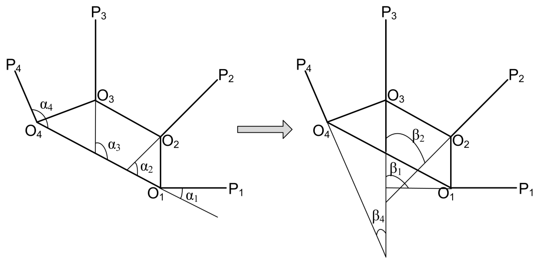

Figure 4: Parametrization of palm: initial (on the left) and assumed (on the right).

Let a vector $\overrightarrow{\alpha} = (\alpha_1, \alpha_2, \alpha_3, \alpha_4)$ be a set of angles between finger axes and line O_1O_4. This angles are shown on Figure 4 (on the left). Then, by $v(\overrightarrow{\alpha})$ define the transformation that rotates the fingers to the angles $\overrightarrow{\alpha}$. E_i is the initial (not transformed) reference palm, where $E = \{E_i\}_{i=1}^{n}$ is the set of reference palms in the database; by $v(E_i, \overrightarrow{\alpha})$ define the flexible object, which is the result of transformation $v(\overrightarrow{\alpha})$ applied to E_i. The allowed values of $\overrightarrow{\alpha}$ define the set $D_i \subset \mathbb{R}^4$ and group of transformations $V_i = \{v(\overrightarrow{\alpha})\}_{\overrightarrow{\alpha} \in D_i}$; $D = \bigcup_{i=1}^{n} D_i$, $V = \{V_i\}_{i=1}^{n}$.

4 PALM SHAPE COMPARISON

Palm shape comparison is performed for reference and test palms. Reference palm is in the form of flexible object, while test palm is a binary image. The idea is to transform reference palm to provide the best alignment with test one.

Let F be a test palm and $\mu(E_i, F)$ a measure, which defines the distance between reference palm E_i and test palm F. So, we have the minimization problem:

$$\overrightarrow{\alpha}^{*} = \underset{\overrightarrow{\alpha} \in D_i}{\operatorname{argmin}}\, \mu(v(E_i, \overrightarrow{\alpha}), F) \qquad (1)$$

Here, $\overrightarrow{\alpha}^{*}$ corresponds to transformation, which produces the best alignment of palms.

Further, we assume that angle α_3 between axe of middle finger O_3P_3 and O_1O_4 is fixed (as person rarely moves his middle finger). Thus, optimization problem (1) can be reduced to minimization by three parameters: $\overrightarrow{\beta} = (\beta_1, \beta_2, \beta_4)$, where $\beta_1 = \alpha_3 - \alpha_1$, $\beta_2 = \alpha_3 - \alpha_2$ and $\beta_4 = \alpha_3 - \alpha_4$, which are shown on Figure 4 (on the right). The optimization problem (1) is solved by setting the initial approximation for $\overrightarrow{\beta}$ and, then, by finding the optimal value $\overrightarrow{\beta}^{*}$ in a small local region.

For the initial approximation of $\overrightarrow{\beta}$ the angles between fingers on a test palm are taken. Certainly, these angles can be easily calculated for a reference palm. However, we can obtain approximate values of them for a test palm too. To do this, firstly, circular decomposition of test palm is created. Then, approximate position of fingers axes are extracted by the same procedure as for a reference palm. This axes are approximate, because in the case of sticking fingers we can't calculate finger roots correctly.

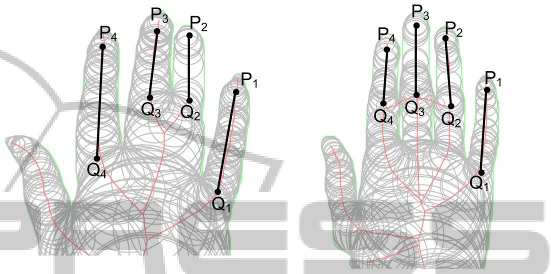

Figure 5: Extraction of approximate finger axes for test palms.

Figure 5 illustrates the extraction of finger axes for a test palm. Points Q_1, Q_2, Q_3 and Q_4 were marked as supposed finger roots. Approximate axes are Q_1P_1, Q_2P_2, Q_3P_3 and Q_4P_4.

So, initial approximate value $\overrightarrow{\beta}^{0}$ for $\overrightarrow{\beta}$ is set. To compare the reference palm E_i with the test palm F we apply transformation $v(\overrightarrow{\beta}^{0})$ to the reference palm and superpose middle fingers of both palms (i.e. tips and axes of middle fingers). Then, the region of palms that lies under line O_1O_4 of reference palm is cut on both palms. Wrist regions of palms have different structure, explained by the presence of long sleeves, watches, etc. So, only the region that corresponds to four fingers is analyzed. Figure 6 shows initial alignment of palms (on the left). Only region above line O_1O_4 is taken into account.

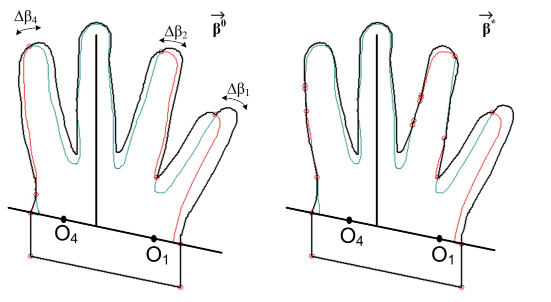

Figure 6: Initial (on the left) and optimal (on the right) alignment of palm regions.

The distance between palms is defined as symmetric difference of regions of their matched silhouettes:

$$\mu(E_i, F) = \mathrm{Area}(E_i \setminus F) + \mathrm{Area}(F \setminus E_i) \qquad (2)$$

Function ”Area” in (2) calculates area of region above O_1O_4.

The proposed alignment of palms allows us to consider parameters β_1, β_2 and β_4 independently. The local region, in which optimal value of $\overrightarrow{\beta}$ is searched, is spacial parallelepiped: $\beta_i \in [\beta_i^0 - \Delta\beta_i; \beta_i^0 + \Delta\beta_i]$, $i = 1, 2, 4$. Basically, $\Delta\beta_i$ reflects the error of calculating angles between fingers on a test palm. The allowed values were set to $\Delta\beta_1 = \Delta\beta_2 = \Delta\beta_4 = 5^\circ$. The experimental results have shown that deviation of 5° is enough to achieve the best alignment of palms.

The optimal value of β_i in the segment $[\beta_i^0 - \Delta\beta_i; \beta_i^0 + \Delta\beta_i]$ is found by iteration procedure. Angles from $\beta_i^0 - \Delta\beta_i$ to $\beta_i^0 + \Delta\beta_i$ with step of 2° are examined. The angle to produce the best alignment of palm regions is taken as optimal. So, the optimal vector $\overrightarrow{\beta^*}$ is found. Figure 6 (on the right) shows the obtained optimal alignment of palms.

5 PERSON RECOGNITION

The described above method for palm shape comparison is employed in the proposed recognition system. This system works as follows.

Person positions his/her palm on a monochrome horizontal surface for recognition. Webcam, which is situated above person’s palm, makes image of it. Figure 7 shows the proposed system.

Figure 7: Person recognition system.

The acquired palm image, or test palm, is transformed to binary image and compared to database of reference palms. Database of reference palms consists of persons’ palms in the form of flexible object, and can include several models for each person. When test palm is compared to reference palms of a particular person, the closeness of ”reference” and ”test” person is defined as the minimal distance between test palm and each of the existing reference palms of this particular person.

Then, simple threshold rule is applied to determine, if the presented test palm belongs to one of the users. In the case when database contains more than one similar person preference is given to the nearest one. If person isn’t recognized as an insider within several seconds (while several palm images are made and passed for recognition), this person is treated as an outsider.

The acquired palm images are scaled for recognition. So, additional camera calibration is required.

6 EXPERIMENTS

Experimental data contained 255 palm images of 54 persons. These images were divided into two groups—reference and test data. Reference data was composed of 108 palms ($1-3$ images for every user); so, test data contained 147 images.

Firstly, the distance between each test palm and each user (the minimal distance between test palm and each of the existing reference palms of this particular user) was calculated. It was done for different values of threshold. After that densities of distribution for intra- and inter-class distances were estimated. Every class is composed of all palms for a particular person. So, when test and reference palms belonged to the same person, the distance was considered to be intra; otherwise, it was inter-class distance. There were 147 intra-class and 7791 inter-class distances. The distance is measured in square pixels.

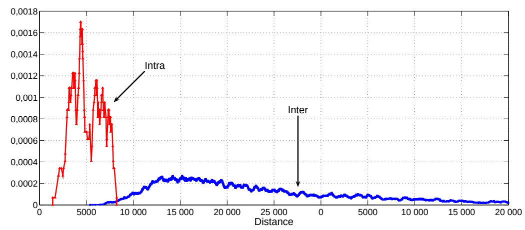

Figure 8: Density of distribution for intra- and inter-class distances.

As a result, intra- and inter-class distances turned out to be really separable (see Figure 8). In the next experiments recognition accuracy was estimated—*FAR* and *FRR* were calculated for verification and identification processes.

6.1 Verification

For each test palm verification was executed for different values of threshold. Incorrect verification was registered during *FRR* estimation, if the minimal distance between person's test palm and his/her reference palms was greater than the considered threshold. Incorrect verification was registered during *FAR* estimation, if the minimal distance between test palm and reference palms of another person was less than the considered threshold. Figure 9 shows the obtained values of *FAR* and *FRR*.

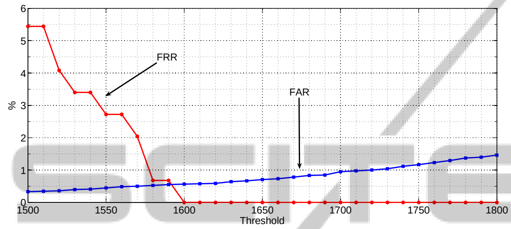

Figure 9: *FAR* and *FRR* in verification process.

The results show that the proposed method can produce verification accuracy near to 99% when threshold value is about 1600 – 1700. To make a comparison, total palm area is about 40000 square pixels, so, the threshold value of 2000 allows the deviation of 5% between palm silhouettes. The obtained value of *EER* (Equal Error Rate) is 0.5%.

6.2 Identification

Identification was executed for all test palms for different values of threshold. Incorrect identification was registered during *FRR* estimation, if the nearest reference palm, which met the threshold, didn't belong to the same person. Incorrect identification was registered during *FAR* estimation, if the list of nearest reference palms, which met the threshold, contained palms of other persons.

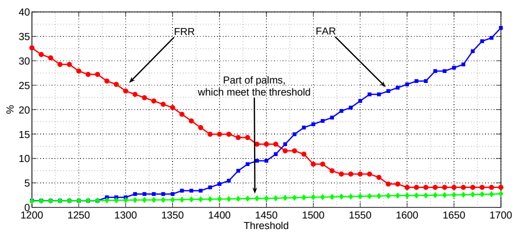

Figure 10: *FAR*, *FRR* and relative amount of reference palms, which meet the threshold in identification process.

Figure 10 shows the obtained results. The minimal value of *FRR* is about 5%, and it is explained by the presence of really similar palms in database. The exclusion of similar palms produced better results with *FRR* about 0%.

Nevertheless, *FAR* remains high. Even when the nearest person from the database for the test palm is recognized correctly, there is amount of reference palms similar to test one (i.e. distances meet the threshold). And, mostly, it is the nature of this modality. Only palm shape isn't enough to produce reliable decision about person's identity. There can be different solutions to the problem of high *FAR*. One of them is combining different modalities.

7 COMBINING MODALITIES

We propose combination of palm and voice features to decrease the *FAR* value. In addition to presenting palm for recognition purposes, person is required to say a password. So, text-dependent person recognition can be applied (Theodoridis and Koutroumbas, 2003).

Each person in the database is described by several reference models of palm and several records of password. Combination of modalities implements cascade model, where voice features serve as filter of knowingly unlike persons; and, then, recognition is performed over palm shape within a small group. Voice features are composed of cepstral coefficients, calculated for audio signal of password. DTW (Dynamic Time Warping) technique is used to compare passwords.

At first, test record of password is compared to records for each person in the database; and the list of *k* most similar persons is constructed. Then, identification is performed for test palm within the group of these persons.

Table 1: *FAR* and *FRR* for bimodal recognition.

k	m	*FRR*, %	*FAR*, %
3	1600	6.7	0
4	1600	6.7	0
5	1600	6.7	0
3	1700	4.2	0
4	1700	4.2	0
5	1700	4.2	0
3	1800	3.4	0
4	1800	3.4	5
5	1800	3.4	6.7
3	1900	1.7	1.7
4	1900	1.7	6.7
5	1900	1.7	8.4

Experiments for bimodal recognition were carried out for a smaller group of users, as reference and test records of passwords were existed only for 20 people. As a result, there were 38 reference persons and 117 test objects. Experiments were carried out for different values of parameter k and threshold m. Table 1 shows the best obtained values of FAR and FRR for bimodal recognition.

As it is expected, bimodal approach shows better results than unimodal. Combination of two modalities allowed us to reduce the high value of FAR. For example, for several values of k and m it is equal to 0%. Also FRR is less than it was for unimodal identification. For $k = 3$ and $m = 1900$ we have $ERR = 1.7\%$.

8 CONCLUSIONS

The new method for person recognition by palm shape was proposed. The choice of palm shape is explained by the fact that there are people, who tend to show palm "poorly". In such cases (presence of sticking fingers, incomplete wrist, etc.) sometimes it is impossible to measure or generate palm features for future comparison. The proposed method allows reference palm (stored in the form of flexible object) and test palm (which is a binary image, or a flexible object too) to be compared. The idea is to transform reference palm to provide the best alignment with test one.

Verification accuracy in terms of EER was shown to be about 0.5%. For identification purposes person palm shape isn't really unique, so FRR was near 5%. FAR remains high and can be reduced by combining palm shape features with other biometric data. One of the possible combinations, with voice features, was illustrated. The best recognition accuracy for bimodal recognition was $EER = 1.7\%$.

The experiments were carried out on the prototype of the system. It is a real-time application, the "Time & Attendance" system, which traces the presence of students at the classes.

In the future it is supposed to implement alignment of two palms, which will consider possible rotations of middle finger and, moreover, which will model the complex movements of thumb. Also, other decision rules should be studied (instead of simple threshold rule applied). The presence of some artificial things on palm (such as rings, bracelets, etc.) should be investigated.

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REFERENCES

Bakina, I. and Mestetskiy, L. (2009). Palm comparison in the presence of artifacts (in russian). In *Proceedings of the 14th Russian Conference of Mathematical Methods of Pattern Recognition, Suzdal, September 21-26, 2009*, pages 301–304.

Boreki, G. and Zimmer, A. (2005). Hand geometry: A new approach for feature extraction. In *Proceedings of the 4th IEEE Workshop on Automatic Identification Advanced Technologies*, pages 149–154.

Covavisaruch, N., Prateepamornkul, P., Ruchikachorn, P., and Taksaphan, P. (2005). Personal verification and identification using hand geometry. In *ECTI Transactions on Computer and Information Technology*, volume 1, pages 134–140.

Gonzalez, S., Travieso, C. M., Alonso, J. B., and Ferrer, M. A. (2003). Automatic biometric identification system by hand geometry. In *Proceedings of the 37th Annual International Carnahan Conference on Security Technology*, pages 281–284.

Jain, A. K. and Duta, N. (1999). Deformable matching of hand shapes for verification. In *Proceedings of ICIP '99, Kobe, Japan*, pages 857–861.

Jianxia, W., Wanzhen, Z., Xiaojun, W., and Min, Q. (2005). The feature parameter extraction in palm shape recognition system. In *Journal of Communication and Computer*, volume 2, pages 25–28.

Mestetskiy, L. (2007). Shape comparison of flexible objects. In *VISAPP*, volume 1, pages 390–393.

Mestetskiy, L. (2009). *Continious morphology of binary images: figures, skeletons, circulars (in Russian)*. FIZMATLIT, Moscow.

Morales, A., Ferrer, M. A., Diaz, F., Alonso, J. B., and Travieso, C. M. (2008). Contact-free hand biometric system for real environments. In *Proceedings of the 16th European Signal Processing Conference (EUSIPCO)*.

Su, C.-L. (2008). Index, middle, and ring finger extraction and identification by index, middle, and ring finger outlines. In *VISAPP*, volume 1, pages 518–520.

Theodoridis, S. and Koutroumbas, K. (2003). *Pattern Recognition*. Elsevier, 2nd edition.

Varchol, P. and Levicky, D. (2007). Using of hand geometry in biometric security systems. In *Radioengineering*, volume 16, pages 82–87.

Wong, A. L. and Shi, P. (2002). Peg-free hand geometry recognition using hierarchical geometry and shape matching. In *Proceedings of IAPR International Conference on Machine Vision Applications*, pages 281–284.

Yoruk, E., Konukoglu, E., Sankur, B., and Darbon, J. (2006). Shape-based hand recognition. In *Image Processing, IEEE*, volume 15(7), pages 1803–1815.