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Personal Authentication Based on Hands Natural Layout

Miguel Adán, Antonio Adán, Roberto Torres, Andrés S. Vázquez, Gloria Bueno
Escuela Superior de Informática. UCLM. Spain
{Miguel.Adan, Antonio.Adan, Roberto.Torres, Andres.Vazquez, Gloria.Bueno}@uclm.es

Abstract

This work is addressed to develop a hands biometric system for verification and recognition goals. The method is based on three keys. First we use a hand's natural layout as intrinsic properties of each individual. Consequently, neither hand-pose training nor a pre-fixed position is required in the registration process. Secondly, we define a set of features without using typical image processing (i.e. segmentation, filtering, etc) because these are defined on a part of the hand's contour. Thirdly, instead of common methods that register one hand, we use left and right hands in our approach. As a consequence of this, ratios FAR and FRR improves meaningfully. The paper shows the experimentation and results of the method for more than 4200 real samples taken in a secondary school. The results are good enough to consider this biometric system for future security/control applications.

1 Hand-based biometric

Unfortunately, security issues are becoming more and more of increasing interest in today's society. The identification of individuals based on biometrics is an important component towards this goal. Besides, most biometric systems depend on passwords and codes one of the most reliable methods. This is due to the fact that they are based on each individual's inherent characteristics. Currently, there is a large number of biometric systems making use of face recognition, voice analysis, iris pattern, fingerprints, hand geometry, etc.

Hand-based biometric technologies are getting very popular for control purposes, such as access to buildings, airports, nuclear plants, and Olympic stadiums. They are suitable for massive use because of their low processing time and real time response. Unlike biometric systems based on fingerprints recognition and iris pattern, users are not reluctant to hand biometric ones. Most features related to a human hand are relatively invariant and peculiar (although, not unique) to each individual. That is why these systems have been commercially used more for verification than for identity recognition. These systems make use of only one hand, usually the right one, from which the features are obtained by different methods, such as hand geometry, [1], [2], palm-prints [3], [4], [5], finger crease [6] and deformable model, [7]. Moreover, the image acquisition is usually accomplished in controlled environments. These environments are formed by a platform composed of a set of pegs, which enable the hand position to be fixed, and a mirror to obtain the up side of the hand [1], [8], [9], [10]. The main drawbacks of these systems are: a) the required upkeep due to damage, spoiling and dirtiness of the platform and mirrors and b) the required training and co-operation of the individuals to place the hand in the position constrained by the pegs. These systems are improved by those based on 3D reconstructions [11] albeit of using expensive and complicated sensor systems.

Our project explores, in a novel way, the analysis of both hands geometry data. As far as we are concerned, systems that make use of right and left hands do not exist. Furthermore, the hand pattern is related to the implicit axis within the natural hand layouts, which allows us to design a simple and affordable system free of pegs and easy to use where the user does not have to be trained. The only requirement is to place the hands with outstretched fingers.

The following sections present: features extraction based on the natural hand layout (section 2), similarity measure (section 3), verification results (section 4), conclusions and further work (section 5).

2 Pattern definition in a Natural Reference System

In most hand biometric systems the hand is placed at a pre-fixed position [1], [9], [12]. It can be said that the hand is positioned with respect to a universal reference system (i.e. image reference system). Contrary to this idea, the hand features that we define are relative to their own reference axes called *Natural Reference System (NRS)*. This reference system is based on two invariant points of the extended hand: the positions of the middle and thumb ends (see Figure 1 a).

Let $\{O,X,Y\}$ be the image coordinate system, *O* being the centre of the image and suppose an image containing an extended hand D. Let 1, 2, 3, 4, 5 be the labels of pinkie, ring finger, middle finger, index finger and thumb respectively. The Natural Reference System of D is defined after the following steps: I) Find the straight line $r = r(\rho,\theta)$ fitted to the skeleton of 3. II) Set $\{O',X',Y'\}$ with *O'*=*O*, *Y'* being parallel to *r* and passing by *O'* and *X'* being normal to *Y'* by *O'*. III) Find $P = (x_0, y_0)$, $x_0 = Min\{x' : (x',y') \in D\}$ on 5 in the system $\{O',X',Y'\}$. IV) Move $\{O',X',Y'$ to $O'' = (0, y_0)$ obtaining the *Natural Reference System* $\{O'',X'',Y''\}$.

Natural placing of the fingers on a completely extended hand is theoretically invariant and personal. Figure 1 b) illustrates three different samples for a hand, where the relative placing of the fingers remains invariant. Note the particular position for both index and ring fingers. On the other hand, even though two hands look apparently similar, their corresponding reference systems could be very distant. In this case, the new images translated to a common coordinate system would be very distant as well (Figure 1 a).

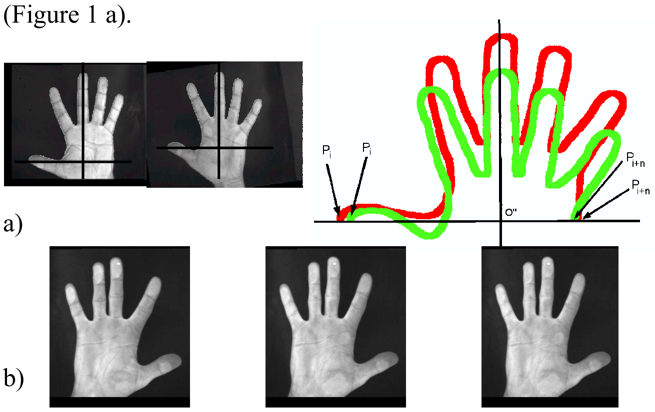


Figure 1. a) Reference systems defined in hands apparently similar and corresponding contours plotted on a common coordinate system b) Invariance of the natural position of the fingers.

In hand-based biometrics only a kind of hand (right or left) is usually registered. Obviously the inclusion of both hands would yield an increase of information and effectiveness in the verification system. In this question, our strategy goes beyond this idea. One of the characteristics of the human body is the axial symmetry. Based on this property the hands cross comparisons could be a new way of identification. In our case we have turned the left hand into the right hand through its mirror-image. Next comparisons L/W and W/L have been introduced in the identification decision process.

In order to avoid errors due to external objects that occlude the hand (watches, clothes, bracelet, etc) only a part of the hand contour has been used in our method. This part is illustrated in Figure 1 a). On the other hand, the users must not take off anything, which offers a remarkable advantage with respect to previous methods. Next we will present the normalized-polar representation of such a contour and we will fix a set of points marked on it.

Let $I = \{P_{i+1}, P_{i+2}, \ldots, P_{i+n}\}$ be a series of pixels belonging to the contour of the hand D referenced to its NRS, where: $P_i = (x_i, 0)$, $P_{i+n} = (x_{i+n}, 0)$ $x_i = \mathrm{Min}\{x : (x, y) \in D\}$ and $x_{i+n} = \mathrm{Max}\{x : (x, y) \in D, y = 0\}$.

The series I goes on fingers 2, 3 and 4, and partially on fingers 1 and 5. In order to handle a normalized representation, I is normalized to a fixed number of pixel through a resampling process, obtaining I_N (in our case N=1000). Note that this information is not ambiguous at all in the image and it is invariant to affine transformations as well. Finally, the polar representation of I_N consist of modulus function f and phase function g. Note that to obtain this representation, elementary image processing (binarization and contour extractions) is required. This circumstance avoids the high computational cost associated with segmentation algorithms.

Our hand-pattern is defined through a set of features computed inside f and g. Firstly, we fix the following key points in f:

- *Relative Maximum Points* : $\{P_{a1}, P_{a2}, P_{a3}, P_{a4}\}$
- *Middle Points*: $\{P_{m1}, P_{m2}, \ldots P_{m8}\}$, which verify:

$$f(P_{mk}) = (1/n)\sum_{j=1}^{n} f(P_{i+j}) \quad \text{j=1,2,…,8}$$

- *Relative Minimum Points*: $\{P_{b1}, P_{b2}, \ldots P_{b5}\}$, where P_{b1} and P_{b5} verify:

$$\overline{P_{b1}P_{m1}} = \overline{P_{b2}P_{m2}} \quad , \quad \overline{P_{b5}P_{m8}} = \overline{P_{b4}P_{m7}}$$

- *Inter-Middle Points*: $\{P_{m12}, P_{m34}, P_{m56}, P_{m78}\}$
- *Inter-Minimum Points*: $\{P_{b12}, P_{b23}, P_{b34}, P_{b45}\}$

Figure 2 a) illustrates the position of such key points whereas b) plots their approximate location on the hand's contour I_N. It is important to remark that this location does not have to coincide with typical hand geometrical points, i.e. finger crest, maximum curvature points, etc, because the key points are defined in f.

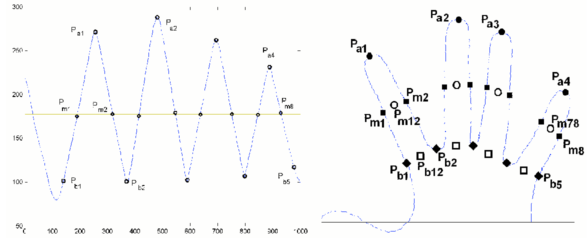
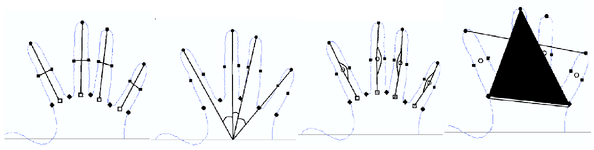


Figure. 2. (a) Location of the key points in f (b) Visualization of the approximate location of the points on the contour I_N .



a) b) c) d)

Figure 3. Visualization of features. a) v_1 and v_2, b) v_3, c) v_4 , d) s and r

After fixing the set of points, the following set of features defines the hand pattern (Figure 3):

- *Lengths*: $\vec{v}_1 = \{ l_j : \ l_j = \overline{P_{aj}P_{b,j(j+1)}}, \quad j = 1,2,3,4 \}$
- *Widths*: $\vec{v}_2 = \{ a_j : \ a_j = \overline{P_{m(2j-1)}P_{m(2j)}}, \quad j = 1,2,3,4 \}$
- *Gaps*: $\vec{v}_3 = \{ q_j : \ q_j = g(P_{aj}) - g(P_{a,(j+1)}), \quad j = 1,2,3 \}$
- *Curvatures*: $\vec{v}_4 = \{ c_j : c_j = \angle(P_{aj}, P_{m(2j-1)(2j)}, P_{bj(j+1)}, \quad j = 1,2,3,4 \}$
- *Coordinate Matrix:* $m = (m_{ij}),\ i = 1..25,\ j = 1,2$
- *Area and Opening*: $s = \Delta(Pa_2, Pb_1, Pb_5)$, $r = \dfrac{\overline{P_{a1}P_{a4}}}{\overline{P_{b1}P_{b5}}}$

3 Similarity Measure and Verification

The similarity measure is based on a set of distances between right hands(R/R), left hands (L/L), right-left hands (R/L) and left-right hands (L/R). Let M, M', $M, M' \in \{R, L\}$ two hands. Taking into account the pattern $\{\vec{v}_1, \vec{v}_2, \vec{v}_3, \vec{v}_4, m, s, r\}$, thirteen distances are defined as follows:

$$d_i(M,M') = |l_i(M) - l_i(M')|, \quad i = 1,2,3,4.$$

$$d_{4+i}(M,M') = |a_i(M) - a_i(M')|, \quad i = 1,2,3,4.$$

$$d_9(M,M') = |\vec{v}_3(M) - \vec{v}_3(M')|$$

$$d_{10}(M,M') = |\vec{v}_4(M) - \vec{v}_4(M')|$$

$$d_{11}(M,M') = \frac{1}{25}\sum_{i=1}^{25}\sqrt{(m_{i1}(M) - m_{i1}(M'))^2 + (m_{i2}(M) - m_{i2}(M'))^2}$$

$$d_{12}(M,M') = |s(M) - s(M')|$$

$$d_{13} = |r(M) - r(M')|$$

Our biometric system stores a hands database B consisting of h samples R/L for r individuals. $B = \{(R^j{}_q, L^j{}_q), j = 1..h, q = 1..r\}$. Suppose that an input-sample R_q/L_q belonging to the q-*th* individual is introduced for verification. The method consider all possible comparison couples:

$$\{(R_q, R^j{}_k), (R_q, L^j{}_k), (L_q, R^j{}_k), (L_q, L^j{}_k), \quad j = 1..h, k = 1..r\}$$

For each couple, which we will call (M_q, M_k), $M \in \{R, L\}$, the Normalized Similarity Measure is defined as:

$$G(M_q, M_k) = \frac{G_{q,k} - \underset{k}{mean}\{G_{q,k}\}}{\underset{k}{std}\{G_{q,k}\}}, \quad G_{q,k} = \sum_{i=1}^{13} \frac{A_{i,q,k} - B_{i,q}}{C_{i,q} - B_{i,q}}$$

where $G_{q,k}$ is the sum of thirteen normalized values between [0,1], $A_{i,q,k} = \min_j \{d_i(M_q, M^j{}_k)\}$ (minimum distance for the individual *k*) and $B_{i,q} = \min_k \{A_{i,q,k}\}$, $C_{i,q} = \max_k \{A_{i,q,k}\}$ (minimum and maximum distances for *k* index). The major $G(M_q, M_k)$ is the most similar two hands are.

After comparing two hands, the verification decision will depend on whether the similarity measures pass or not a specific threshold that is empirically prefixed. Therefore, the threshold value depends on the database and must be computed and updated when this changes. The next phase labels each matching (M_q, M_k) as suitable or unsuitable, this election being based on the prefixed threshold μ. Formally we define the matching function:

$$p_\mu(M_q, M_k) = \begin{cases} 1 & si \quad G(M_q, M_k) < \mu \\ 0 & si \quad G(M_q, M_k) \geq \mu \end{cases}$$

Finally the verification decision (acceptance or rejection) or the hypothesis "the sample q belongs to the individual k" is established following the next criterion:

$$M_q \equiv M_k \quad \Leftrightarrow \quad \sum_{M \in \{D,I\}} p_\mu(M_q, M_k) \geq 1$$

Note that it is sufficient that only one matching (M_q, M_k), $M \in \{R, L\}$ was suitable for accepting the hypothesis.

4 Experimentation of the method

A mobile experimental prototype with 2 CCD cameras has been built. The hands are placed onto a robust platform that includes its own illumination system with diffuse light. This system allows the users to place their hands in a comfortable way on the top of the crystal platform situated over the cameras and light. The prototype is closed to avoid possible disturbance from the surrounding light (Figure 4).

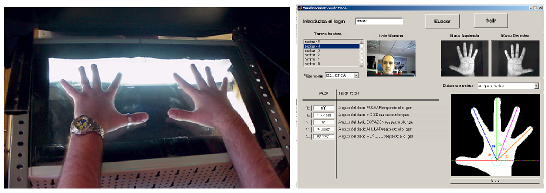


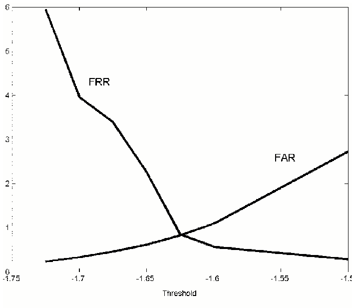
Figure 4. a) Natural hands layout. a) Software tool developed.

In order to prove the performance of the system we have carried out a similarity study and a verification test for 353 individuals corresponding to men and women of 17-20 years old. This experiment was developed in a secondary school centre with attendance control objectives. Therefore, the test was accomplished on a homogeneous sampling where most teenagers were not motivated enough to make the register phase conveniently.

So far 4200 samples have been recorded, taking 6 acquisitions per user and for both hands. We collected the images at an interval of around two months. Samples 1 to 5 constitute the database *B* whereas samples 6 are taken as test-samples (or input-sample) establishing the test set $B' = \{(R_q, L_q) : q = 1,2,..353\}$.

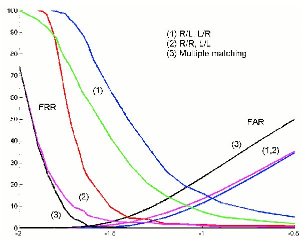
In order to carry out the verification process, the procedure explained in the last section is applied to each q-th sample of *B'*. As a result of that, we obtain a set of potential users $\Theta(q)$ which verify the verification hypothesis (in other words, it verifies $M_k \equiv M_q$).

The well known *FAR* versus *FRR* balance depends on the environment specifications and the kind of application imposed. In our case, the best values are for μ=-1.6250, obtaining ratios *FAR*=0.8257 %, *FRR*=0.8499 % and for μ=-1.6000, obtaining ratios *FAR*=1.0897 %, *FRR*=0.5666 %. In Figure 5 a) a detail of *FAR* and *FRR* curves are shown.

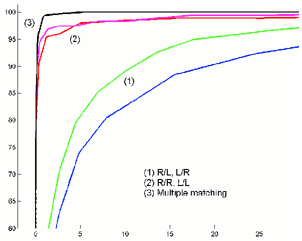


a)

Threshold	FAR (%)	FRR (%)
-1.7000	0.3300	3.9660
-1.6750	0.4547	3.3994
-1.6500	0.6124	2.2663
-1.6250	**0.8257**	**0.8499**
-1.6000	1.0897	0.5666
-1.5000	2.7274	0.2833
-1.4000	5.2826	0.0000



b)



c)

Figure 5 a) *FAR* and *FRR* curves for the method proposed in the paper. b) Comparison with simple matching strategies. c) *ROC* curves.

A performance analyse of the method for each kind of matching R/R, L/R, R/L, L/L, is illustrated in figure 5 b). In this, *FRR* and *FAR* curves have been plotted for all cases. Looking at this figure it is evident that our method (3) based on multiple comparisons obtains better results than the methods based on single comparisons (1 and 2). As was to be expected comparisons R/R, L/L (case 2) provide better results than R/L, L/R ones (case 1) as well.

Figure 5 c) shows the *Receiver Operating Characteristic* (*ROC)* curves for previous cases (1), (2) and (3). *ROC* curve represents *FAR* versus 100-*FRR*. It can be seen that our method yields the best results. The system can operate at a 96 percent genuine acceptance rate and a 0,3 percent false acceptance rate for μ=-1.7000. These results are comparable with previous hand-based approaches [1, 2, 3, 4, 7, 10].

5 Conclusions

In this paper we present a new hand biometric system for verification/recognition goals. The method is described by the following properties:

- It uses the natural hands layout and extracts a set of new invariant features defined over a personal reference system. Consequently, neither a prefixed pose nor training phase is required by the system. The individuals just have to extend their hands.
- It computes the hand pattern avoiding segmentation processes and other usual image processing (smoothness, filtering, etc) because only a part of the hand contour is used.
- Right and left hands are taken into account for carrying out verification/recognition applications.
- The designed system is very easy to use and is free of pose restrictions. Furthermore people do not have to remove their wristwatch, bracelet or similar items.

An experimental test has been carried out in a secondary school centre for attendance control purposes. We have registered over 350 students obtaining a database of more than 4200 real images. After analysing the verification results it can be said that acceptable good ratios of *FAR* and *FRR* have been achieved.

Our future work is addressed in two ways. Firstly, we are encouraged by the decrease in *FAR* and *FRR* values by improving the prototype, the registration phase and the software that control it. Secondly, with the goal of refining the whole system, we want to increase the database and check the method daily for a period of time.

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