Further Developments in Geometrical Algorithms for Ear Biometrics

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Abstract. The paper presents new geometrical methods of feature extraction from ear images in order to perform human identification. Geometrical approach is motivated by the actual procedures used by police and forensic experts. In the article novel algorithms of ear feature extraction from contour images are described in detail. Moreover, identification results obtained for each of the methods, based on the distance of feature vectors in the feature space, are presented.

1 Introduction and Previous Work

Ear biometrics seems to be a good solution for passive human identification systems. Ear images can be acquired from the distance even without the knowledge of the examined person. Ear biometrics is also highly accepted as single or hybrid (e.g. with face) biometrics by users in possible access control applications. According to users, ear biometrics is less stressful than fingerprinting. Moreover, our test users admitted that they would feel less comfortable while taking part in face images enrolment (people tend to care how they look on photographs). Furthermore, in ear biometrics there is no need to touch any devices and therefore there are no problems with hygiene.

Even though ear biometrics have not been implemented commercially so far, there are some known methods of feature extraction from ear images [1][2][3]. Those methods were discussed in our previous articles, in which we had also proposed our own new methods of feature extraction: concentric circles based method (CCM) and contour tracing method (CTM) [4][5]. Recently, various approaches towards 3D ear biometrics has been developed and published [6][7].

Hereby we introduce our further developments in feature extraction for human identification based on ear images. In Section 3 contour selection algorithm, geometrical parameters extraction method (GPM) consisting of the shape ratio ($GPM - SRM$) and the triangle ratio methods ($GPM - TRM$), as well as angle-based method (ABM) are presented in detail. In Section 4 identification results are presented and discussed. Conclusion and references are given next.

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2 Motivation for Geometrical Approach

Our methods based on geometrical feature extraction are motivated by actual procedures used in police and forensic evidence search applications. Nowadays, human ears and earprints are standard features of identity taken into account by forensic specialists and criminal policemen. In reality, well-established procedures of handling ear evidence (so called *ear otoscopy*) are based on geometrical features such as size, width, height and earlobe topology [8][9].

Therefore, by analogy to ear otoscopy, we decided to compute geometrical parameters of ear contours extracted from ear images. Such approach gives information about local parts of the image, which is more suitable for ear biometrics than global approach to image feature extraction. Moreover, geometrical features of extracted contours are more adequate for ear identification than color or texture information, which is not distinctive enough within various ear images [10].

3 Methods Based on Geometrical Parameters - *GPM*

In the proposed method of feature extraction from ear images in order to perform human identification, we use the geometrical parameters and properties of ear contour images. The first step of the method is the extraction of contours from ear images in such way, that the extracted contours contain distinctive information about shape and geometrical properties of given ear. Then for each of the extracted contours we construct the feature vector on the basis of the proposed geometrical parameters.

3.1 Contour Image Processing

We presented ear contour detection algorithm in our previous work [4][5]. Hereby it is enhanced by contour processing procedure. The aim of contour image processing is the selection of contours containing the most distinctive information characterizing human ear images. For each extracted contour c, we calculate its length:

$$L_c = \sum_{q=1}^{Q-1} \sqrt{(x_{q+1} - x_q)^2 + (y_{q+1} - y_q)^2}, \tag{1}$$

where:

- Q - number of contour points,
- c - number of contours, for $c = 1, \ldots, C$,
- (x, y) - coordinates of contour points,
- q - indexation of the current contour point.

After evaluation of ear images from our database we defined so called *short contours*, which are eliminated. We eliminate the contours for which:

$$L_c \leq t \times L_c max, \tag{2}$$

where t is a sensitivity parameter (we use the value $t = 0.2$). In result of such processing we obtain images with the limited number of contours (Fig. 1).

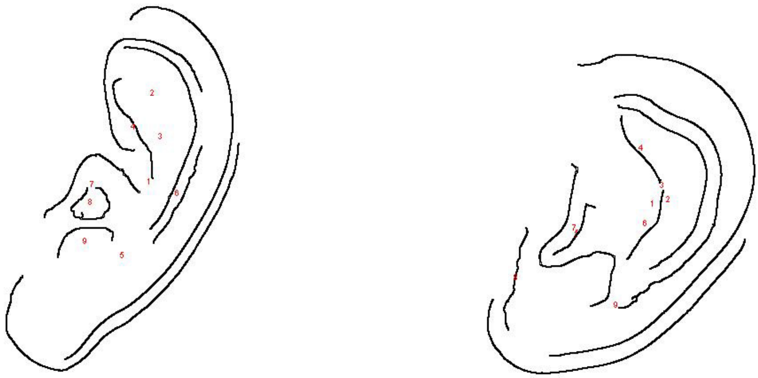

Fig. 1. Selected (longest) and numbered contours in test images 'macfir' (left) and 'szysob' (right), respectively

3.2 GPM - Triangle Ratio Method

The aim of the triangle ratio method is to extract invariant geometrical features which describe contours in ear image. Hereby we consider only the longest contour, but the method is applied to all the selected contours of the earlobe.

The method is based on finding the maximal chord of the contour and the intersection points of the contour with the longest line perpendicular to the maximal chord.

Maximal chord is denoted by $Chord_{\max}$ and is determined according to the following algorithm:

- we search for the first point of the longest contour l_{cmax} - let it be the point p_c with the coordinates (i_c, j_c). Let (i_b, j_b) be the coordinates of the current contour point p_b,
- we calculate the distances between the point p_c and the consecutive points p_b,
- the maximal chord is defined by:

$$Chord_{\max} = \max\left\{\sqrt{(i_c - i_b)^2 + (j_c - j_b)^2}\right\} \tag{3}$$

for: $b = 1 \ldots N$, where N is the number of contour points.

Then we extract ear contour features. In our case we use the properties of the triangle sidelines created in the following way:

1. extraction of the longest contour L_{cmax} within the ear image, contour length is calculated according to (1),
2. calculation of the maximal chord according to (3),
3. having computed the coordinates of the maximal chord and its length, for the current points of the contour we calculate:

$$A_b = i_c j_b - i_b j_c + i_b j_{bmax} - i_{bmax} j_b + i_{bmax} j_c - i_c j_{bmax} \tag{4}$$

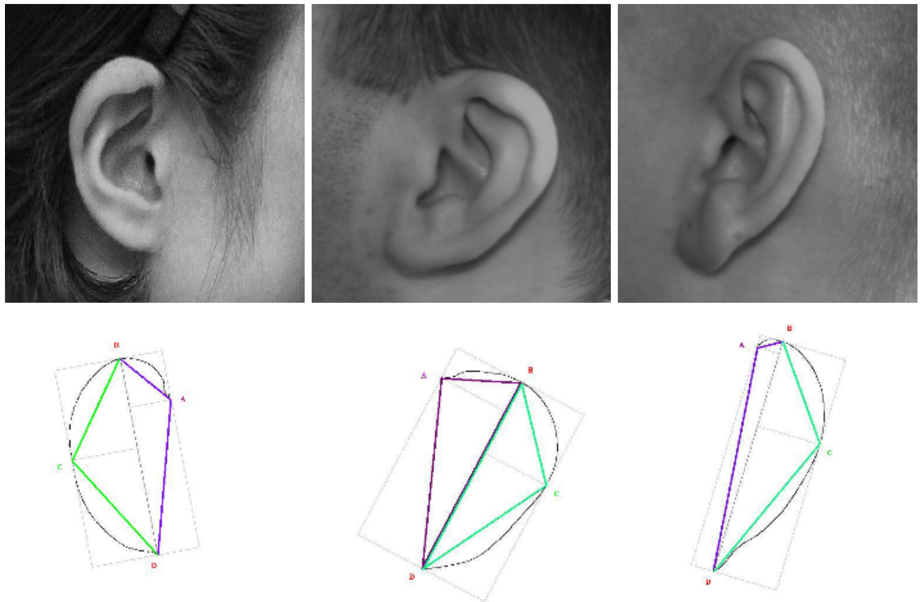

Fig. 2. Triangle ratio method for sample ear images 'prapod', 'szysob' and 'macfir', respectively. The images show the extracted longest ear contour with the triangles based on points $ABCD$.

and the maximal distance of the current point from the maximal chord:

$$r_b = \frac{A_b}{Chord_{\max}}, \tag{5}$$

4. point for which $r_b = \max$ when $j_b \leq j_c$ determine the point B in the ear contour, while the current point for which $j_b \geq j_{bmax}$ determine the point C in the ear contour,
5. two triangles are created: the triangle ABD and BCD (the presented conditions (inequalities) are true for left images, for right ears inequalities are reverse),
6. we calculate the length of the line connecting the points A and C (those lines are heights of the triangles ABD and BCD respectively), those lengths are denoted as h_m and h_d,
7. we calculate the parameter b as the sum of the lengths of two lines connecting points A and C with the diameter under the angle of $90°$, that is $b = h_m + h_d$,
8. we calculate the lengths of the sides ab and ad of the triangle ABD and the lengths of the sides bc and cd of the triangle BCD,
9. we calculate the values of parameter $w1$ such as $w1 = ab + ad$ and, by analogy, $w2$ such as $w2 = bc + cd$,
10. we calculate the ratio $w = w1/w2$,
11. we calculate the triangles ratio according to (7).

Table 1. The parameters computed for the longest ear contours extracted from 3 test ear images 'prapod', 'szysob' and 'macfir' from Fig. 2

Parameter	$'prapod'$	$'szysob'$	$'macfir'$
$\|AB\|$	112.3	138.2	45.1
$\|AD\|$	267.0	329.6	387.1
$\|BC\|$	193.7	181.9	188.2
$\|CD\|$	218.8	256.0	280.2
$w1$	379.3	467.8	432.2
$w2$	418.5	437.9	468.4
w	0.906	1.068	0.923
$Chord_{max}$	343.0	362.4	411.3
b	186.4	245.8	151.4
db	1.840	1.474	2.730
h_m	72.2	125.7	39.6
h_d	114.0	119.9	111.7
tr	0.574	1.120	0.327

The parameter b is the sum of two lines connecting the points A and C with the maximal chord $Chord_{max}$ under the angle of 90°.
The parameter db is the length ratio calculated as:

$$db = \frac{Chord_{\max}}{b}. \tag{6}$$

On the basis of the previous calculations we can compute the triangles ratio tr, such as:

$$tr = \frac{h_m w_1}{h_d w_2}. \tag{7}$$

The results of the presented method for 3 test ear images are shown in Figure 2. The calculated values of the presented lines, parameters and ratios w and db for 3 ear images are shown in the Table 1.

3.3 GPM - Shape Ratio Method

Another proposed ear contours' feature is the shape ratio. We compute it for the meaningful contours in ear image selected by the method described in section 3.1. The shape ratio denoted as kk is computed according to (8):

$$kk = \frac{L_c}{d_{kp}}, \tag{8}$$

where:

- L_c is the contour length given by (1),
- d_{kp} is the length of the line connecting the ending points of each contour given by (11).

Table 2. Values of parameters computed for 9 selected contours in test image 'macfir'. L_c - contour length; d_{kp} - length of the line connecting the endpoints, kk - shape ratio; $Chord_{max}$ - the longest chord of the contour; b - length of perpendicular lines connecting most distant points with $Chord_{max}$; db - length ratio; cc - number of d_{kp} intersections with the contour; in some cases d_{kp} may be equal to $Chord_{max}$.

c	L_c	d_{kp}	kk	$Chord_{max}$	b	db	cc
1	572.6	387.1	1.479	411.3	151.4	2.730	0
2	280.8	103.4	2.019	126.5	109.1	1.159	0
3	282.6	207.0	1.365	207.0	68.9	3.004	0
4	138.2	118.3	1.168	118.3	19.6	6.036	1
5	509.3	285.9	1.781	339.7	121.3	2.801	0
6	132.8	121.6	1.092	121.6	7.8	15.590	0
7	175.8	110.9	1.585	110.9	54.9	2.020	0
8	128.8	10.4	12.385	43.9	36.6	1.120	0
9	97.4	64.2	1.517	68.0	28.7	2.369	0

Table 3. Values of parameters computed for 9 selected contours in test image 'szysob'. L_c - contour length; d_{kp} - length of the line connecting the endpoints, kk - shape ratio; $Chord_{max}$ - the longest chord of the contour; b - length of perpendicular lines connecting most distant points with $Chord_{max}$; db - length ratio; cc - number of d_{kp} intersections with the contour; in some cases d_{kp} may be equal to $Chord_{max}$.

c	L_c	d_{kp}	kk	$Chord_{max}$	b	db	cc
1	643.8	329.6	1.953	362.4	245.8	1.474	0
2	401.6	238.1	1.687	240.8	127.9	1.883	0
3	284.7	187.7	1.517	187.7	84.8	2.213	0
4	95.4	86.5	1.103	86.5	10.5	8.238	1
5	303.9	161.7	1.879	161.7	84.4	1.916	2
6	94.6	87.2	1.085	87.2	10.7	8.150	0
7	87.4	70.9	1.233	70.9	16.1	4.404	1
8	132.5	116.7	1.135	116.7	12.0	9.725	1
9	429.5	292.0	1.471	308.2	114.5	2.692	0

The shape ratio value is always $kk > 1$. Shape ratio allows contours classification into 2 classes:

1. linear contours for which $kk \cong 1$,
2. circular contours for which $kk >> 1$.

The example of the circular contour is the contour number 8 extracted in the ear image in Fig. 1 (left). Its value in the Table 2 is $kk_8 = 12.385$.
The examples of the linear contours are:

– contour number 6 extracted in the ear image in Fig. 1 (left); its shape ratio is $kk_6 = 1.092$ (Table 2),

– contour number 6 extracted in the ear image in Fig. 1 (right), its shape ratio is $kk_6 = 1.085$ (Table 3).

The ratio cc is also proposed. It is computed as the number of intersections between the each maximal chord $Chord_{max}$ and corresponding contours c.
It allows contour classification into 2 classes:

– simple contours, for which $cc = 0$,
– complex contours, for which $cc \geq 1$.

Most of the contours are classified as simple contours. The example of the complex contour is the contour number 5 extracted in the ear image in Fig. 1 (right). The combined feature vector containing the parameters computed by the proposed methods $GPM - TRM$ and $GPM - SRM$ for $c = 1, ..., C$ extracted contours is given by:

$$FV = \left\{ (L_c, d_{kp}, kk, d, b, db, cc)_c \right\}. \tag{9}$$

3.4 Angle-Based Contour Representation Method - *ABM*

Each extracted contour is treated as an independent open curve. Each curve is represented by two sets of angles [11]:

$$\begin{aligned} \Phi &= \Phi_w; 1 \leq w \leq \epsilon \\ \Psi &= \Psi_w; 1 \leq w \leq \epsilon \end{aligned} \tag{10}$$

corresponding to the angles between the vectors centered in the point p_0.
For each contour (curve) we search for the point p_0, which becomes the center of the concentric circles. The point p_0 is defined in the following way:

1. two ending points (i_p, j_p) and (i_k, j_k) of each curve are localized,
2. the equation of the line passing through those extracted points is $j = b_1 \times i + b_0$, where: $b_1 = \frac{j_k - j_p}{i_k - i_p}$ $b_0 = \frac{j_p \times i_k - j_k \times i_p}{i_k - i_p}$,

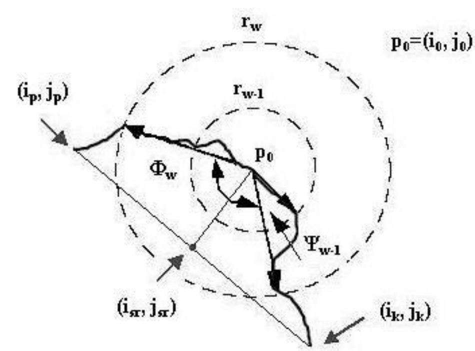

Fig. 3. Visualization of the *ABM* method for a chosen ear contour and 2 radii (concentric circles) with a centre in p_0

3. the distance between the ending points is computed:

$$d_{kp} = \sqrt{(i_k - i_p)^2 + (j_k - j_p)^2}, \tag{11}$$

4. the center point i_{sr}, j_{sr} of the line between (i_p, j_p) and (i_k, j_k) is computed in the following way. Let $\tan\gamma = \frac{j_k - j_p}{i_k - i_p}$ and $\triangle j = \frac{d_{kp}}{2} cos\gamma$. Then $j_{sr} = j_k + \triangle j$,
5. knowing j_{sr} and the line equation we can determine i_{sr},
6. the line $j = \frac{1}{b_1}(i_{sr} - i) + j_{sr}$ perpendicular to the line between the contour ending points and passing through the computed center point (i_{sr}, j_{sr}) intersects the contour in the point p_0 with the coordinates (i_0, j_0).

The length of the maximal radius is determined by:

$$r_m = \sqrt{(i_k - i_0)^2 + (j_k - j_0)^2}. \tag{12}$$

For each contour we consider ϵ concentric circles with the radii $r_w = w \times \frac{r_m}{\epsilon}$ $(w = 1, \ldots, \epsilon)$. For each contour the point p_0 becomes the center of the local polar coordinate system.
For each radius r_w we compute the angles:

$$\Phi_w = (\theta_{max} - \theta_{min})_w \tag{13}$$

$$\Psi_{w-1} = ((\theta_{max})_w) - ((\theta_{max})_{w-1}). \tag{14}$$

Having assumed that there are $c = 1, ..., C$ contours in the ear contour image, and that each contour is analyzed by w concentric circles, the feature vector is given by:

$$W = \{(\Phi_w, \Psi_{w-1})_1, \ldots, (\Phi_w, \Psi_{w-1})_c, \ldots, (\Phi_w, \Psi_{w-1})_C\}. \tag{15}$$

4 Experiments and Results

The experimental scenario involves the finite ear images database. One of the users, who took part in the enrollment process and his ear image is surely stored in the database, is chosen randomly. The acquisition of the user's test ear image is performed. Next, we compute the feature vectors for the test user and we search for the corresponding image from the database. In result of such scenario we obtain one ear image for which the computed feature vectors are the closest to test image feature vectors in terms of distance in the feature space.

Since there are no standard ear image databases, we performed all the tests on our own ear image database. We used images from 80 people so that we had an experimental database of 800 images (5 positions and 2 illumination values for a person). The input (query) images were taken for randomly chosen users in the conditions similar to those during the first enrollment. The feature vectors were calculated and the recognition decision was made based upon the proposed features. For each of the proposed method the classification formula was created on the basis of the distance in the feature space.

In the process of ear identification by Geometrical Parameters Method - GPM we calculate the distance between the feature vectors FV (9). The minimal distance difference between the test feature vector FV_{test} and the vectors from the database FV_{ref} is given by:

$$ans4 = \min \left\{ \sqrt{\left(FV_{test}^2 - FV_{ref_{c=1}}^2 \right)_{z=1} + \cdots + \left(FV_{test}^2 - FV_{ref_C}^2 \right)_Z} \right\}. \tag{16}$$

The image for which (16) is fulfilled is the obtained result for the test user. In 104 tests we obtained the correct identification result in all the tests.

In the process of identification by ABM method, the feature vectors W (15) are compared. The minimal distance difference between the test feature vector W_{test} and the vectors from the database W_{ref} is given by:

$$ans3 = \min \left\{ W_{test} - (W_{ref})_z \right\} = \min \left\{ dif2_1, \cdots, dif2_z, \cdots, dif2_Z \right\}, \tag{17}$$

for the value of the feature vectors difference in the feature space calculated as:

$$dif2_z = \sqrt{\sum_{c=1}^{C} \left\{ \sum_w \left[(\Phi_w)_{test} - (\Phi_w)_b \right] + \sum_w \left[(\Psi_{w-1})_{test} - (\Psi_{w-1})_Z \right] \right\}}. \tag{18}$$

for $z = 1, ..., Z$, where z denotes the consecutive feature vector in the ear image database and Z is the number of ear images.

The image for which (17) is fulfilled is the obtained result for the test user. In 104 tests we obtained the correct identification result in 94 cases.

The cumulative results for all the methods (methods CCM and CTM were introduced in our previous work [4][5]) are presented in the Table 4.

Table 4. The cumulative results of the presented identification methods (CCM and CTM were introduced in our previous articles [4][5]). The presented parameter is Rank-one-recognition.

method	number of tests	correct acceptances	false rejections	Rank-1
CCM	104	94	10	90.4
CTM	104	98	6	94.2
ABM	104	94	10	90.4
GPM	104	104	0	100.0

5 Conclusion

In the article we presented our further, novel developments in geometrical feature extraction methods for ear biometrics. The major contributions are the new methods: $GPM - TRM$, $GPM - SRM$ and ABM. Moreover, the method of ear contour image processing in order to select only the most meaningful contours was presented. The experiments and the achieved results were also discussed.

After experiments we came into conclusion that the proposed geometrical methods, which had been motivated by the manual process of feature extraction used in criminology, allow effective person identification on the basis of features extracted from ear images. The best results were achieved by the GPM method.

Further research is now being conducted in order to extract more geometrical and global (Gabor-based) features and weigh them properly in the multidimensional process of identification. Further experiments and evaluation of all the methods are also being performed. Furthermore, we examined user interaction in the enrolment step and we concluded that ear images acquisition is accepted by more users than other biometrics human identification methods, even face recognition.

References

1. M. Burge, W. Burger *Ear Biometrics*, in: *Biometrics: Personal Identification in Networked Society (Eds: A.K. Jain, R. Bolle, S. Pankanti)*, 273-286, 1998.
2. D.J. Hurley , M.S. Nixon, J.N. Carter, "Force Field Energy Functionals for Image Feature Extraction," Image and Vision Computing Journal, vol. 20, no. 5-6, pp. 311-318, 2002.
3. K. Chang, B. Victor B., K.W. Bowyer, S. Sarkar, "Comparison and Combination of Ear and Face Images in Appearance-Based Biometrics," IEEE Trans. on PAMI, vol. 25, no. 8, pp. 1160-1165, 2003.
4. M. Choraś, "Ear Biometrics Based on Geometrical Method of Feature Extraction", in: *F.J Perales and B.A. Draper (Eds.): Articulated Motion and Deformable Objects,* LNCS 3179, Springer-Verlag, pp. 51-61, 2004.
5. M. Choraś, "Ear Biometrics Based on Geometrical Feature Extraction," Journal ELCVIA (Computer Vision and Image Analysis), vol. 5, no. 3, pp. 84-95, 2005.
6. H. Chen, B. Bhanu, "Contour matching for 3D ear recognition," Proc. of Workshop on Applications of Computer Vision (WACV), 123-128, 2005.
7. P. Yan, K. W. Bowyer, "ICP-based approaches for 3D ear recognition," Proc. of SPIE Biometric Technology for Human Identification, 282291, 2005.
8. J. Kasprzak, *Forensic Otoscopy (in Polish)*, University of Warmia and Mazury Press, 2003.
9. J. Kasprzak, "Polish Methods of Earprint Identification", The Information Bulletin for Shoeprint/Toolmark Examiners, vol. 9, no. 3, 20-22, 2003.
10. M. Choraś, "Human Identification Based on Ear Image Analysis" (in Polish), Ph.D. Thesis, ATR Bydgoszcz, 2005.
11. F. Kamangar, M. Al-Khaiyat, "Planar Curve Representation and Matching," *Proc. British Machine Vision Conference,* pp. 174-184, 1998.