PATTERN RECOGNITION ALGORITHMS FOR EAR BIOMETRICS

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ABSTRACT

In this article we present geometrical Parameter algorithms for ear Biometrics by representing the Ear image as contours, feature extraction and recognition. The proposed algorithms were developed for ear biometrics, but they can be applied in other contour image processing applications. Firstly we present mathematical and algorithmic foundations of geometrical feature extraction methods. We also discuss their application and the achieved results for ear contour image analysis and recognition. The human ear is a perfect source of data for passive person identification in many applications. In the growing need for security in various public places, ear biometrics seems to be a good solution, since ears are visible and their images can be easily taken, even without the examined person's knowledge. The robust feature extraction method can be applied to determine personality of individuals. The growing interest in ear biometrics can be evidenced by many publications over the last few years. More importantly research groups developed different approaches to a problem of feature selection and extraction for ear biometrics.

Keywords: *Ear Biometrics, Recognition, Feature Extraction, Ear Contour Representation.*

1. EAR BIOMETRICS- INTRODUCTION

Biometrics identification methods proved to be very efficient, more natural and easy for users than traditional methods of human identification. In fact, only biometrics methods truly identify humans, not keys and cards they posses or passwords they should remember.

The future of biometrics surely leads to systems based on image analysis as the data acquisition is very simple and requires only cameras, scanners or sensors [1]. More importantly, such methods could be passive, which means that the subject does not have to take active part in the whole process or, in fact, would not even know that the process of identification takes place.

There are many possible data sources for human identification systems, but the physiological biometrics has many advantages over methods based on human behavior. The most interesting human anatomical parts for passive, physiological biometrics systems based on images acquired from cameras are face and ear [2]. Both of these methods contain large volume of unique features that allow identifying humans.

Human ears have been used as major feature in forensic science for many years (for example in airplane crashes). Ear prints, found on the crime scene, have been used as a proof in over few hundred cases in the Netherlands and the United States [3].

Nowadays, police and forensic specialists use ear prints as a standard proof of identity [4] [5] [6] [7]. An otoscopic (ear based) forensic opinion has a status of scientific evidence and, as such, is admitted by Polish Courts [8]. In most countries ears have to be visible while preparing photographs for passports and other ID documents.

Fig.1. some examples of various ear images from our database

The Geometrical methods of open contour representation and feature extraction which can be applied to ear image analysis. Our geometrical contour processing methods dedicated for ear biometrics are motivated by procedures used in police and forensic evidence search applications. In reality, well-established manual procedures of handling ear evidence (ear images or ear prints) are based on geometrical features such as size, width, height and earlobe topology (so called ear otoscopy) [9]. Therefore 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 colour or texture information, which is not distinctive enough for various ear images. Contours corresponding to earlobes are much diversified and contain enormous amount of information allowing ear identification.

Recently ear biometrics has gained attention in computer vision community due to large interest in passive human identification systems. In previous work [10] we overviewed different approaches of 2D ear image analysis. Recently, various approaches towards 3D ear biometrics have been developed and published [11] [12].

Typically, a biometric image analysis system, and therefore ear images analysis system consists of the following components: image acquisition and enrolment, preprocessing, feature extraction and classification (Figure 2).

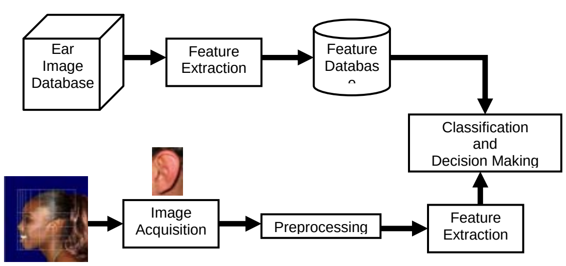

Fig.2. Ear image analysis system.

Preprocessing reduces image into more compact representation suitable for further processing. Ear images preprocessing consists of threshold, edge detection, contour selection and size normalization operations. The result of the preprocessing stage is the binary image with 7-10 longest ear contours (Fig. 3).

Fig.3. Ear Contour Representation

Feature extraction consists of binary contour image analysis and measuring the contour features. The features are the parameters that can be obtained on the basis of discrete geometry computations. Classification is used to quickly identify object on the basis of its image features. The aim of this stage is to compare input ear image, represented as a feature vector with the library models (archetypical vectors in database).

In this article we focus on presenting the geometrical feature extraction methods developed for ear biometrics applications. In Section 2 geometrical methods of ear contours feature extraction are presented. In Section 3 results and conclusion are given.

2. GEOMETRICAL APPROACH TO FEATURE EXTRACTION

Hereby we present geometrical methods of feature extraction from ear images. Even though such approach seems to be most natural for ear shape representation, it is almost impossible to develop invariant feature extraction methods. In the feature extraction methods binary contour images with the selected number of contours and normalized coordinates are processed. The local contour extraction and contour selection algorithms had been presented in the work [10] [13].

Even though such approach seems to be most natural for ear shape representation, it is almost impossible to develop invariant feature extraction methods.

A. Voronoi Diagrams

The geometrical method proposed by Burge and Burger [14] [15] was based on building neighborhood graphs and Voronoi diagrams of the detected edges. Voronoi diagram of detected ears describes contour segments in ear image.

The proposed algorithm consists of the following steps:

1) Ear image enrolment.
2) Ear detection by the Lai and Chin active snake method [16].
3) Edge detection by canny operator [17].
4) Curve extraction by Hancock and Kittler method. Larger curves and segments are detected while shorter contours are eliminated [18].
5) Neighborhood graph is built and Voronoi diagram is created. The sample ear image with the corresponding Voronoi diagram and neighborhood graph is presented in Figure 4.

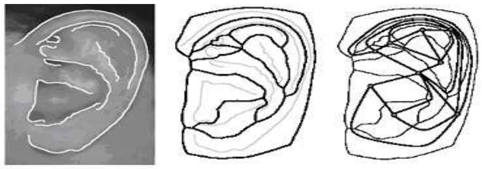

Fig. 4 .Sample ear image with the constructed Voronoi diagram and the corresponding neighborhood graph

Digital images consist of a finite number of discrete pixels arranged in a square grid. A pixel may be considered as an element of Z^2; hence a digital image is a subset of Z^2. A path P from p to q is a sequence of pixels $t_0, t_1, t_2 \ldots t_n$, such that $t_0 = p$, $t_n = q$ and for all $i: 0 \le i \le n$, t_i is a neighbour r_{i-1}:

$$P = \{ti \mid 0 \le i \le n\} \quad (1)$$

Where n is the length of the path.
A neighbour of pixel p is a pixel q such that $d(p, q) = 1$. If $p = (x_p, y_p)$ and $q = (x_q, y_q)$, then:

$$d(p, q) = \max(|x_p - x_q|, |y_p - y_q|) \quad (2)$$

We assume that we have a contour given as an ordered set of points in the image plane $C = \{t_i \mid i = 1 \ldots n\}$, $t_i = (x_i, y_i)$. The contour is usually an open curve.

B. Concentric Circle Based Method – CCM

The CCM method is based on concentric circles centered in the obtained centroid point. The centroid of binary ear contour (after the normalization) is placed in the point (0, 0) of the coordinates system. The centroid also becomes the centre of the concentric circles of the radius ri.

The algorithm uses the surrounding circle of contour image C for partitioning it to o radial partitions. The intersection points of ear contours with the created concentric circles of radius r_i are calculated as:

1. We define the maximal possible radius r'_{max} and the distance between the consecutive circles Δr,
2. We calculate the number of circles o, such as:

$$O = \left\lfloor \frac{r^l \max}{\Delta r} \right\rfloor \quad \textbf{(3)}$$

and ⌊⌋ is the maximal integer number less than o,

3. For each contour point (i, j) we calculate polar coordinates $(p, \emptyset)$

$$p(i, j) = \sqrt{i^2 + j^2}; \phi = \arctan\frac{j}{i} \quad \textbf{(4)}$$

which are stored in the record T with the elements $(i, j, p, \emptyset)$.
4. For $r_l = l * \Delta r$, $(l = 1, \ldots, o)$, basing on the record T we store the number of elements l_l, for which $r_l = p$ and we create the vectors:

$$V_l = \{(l_l)_1 \ldots (l_l)_s \ldots, (l_l)_o\}, \quad \textbf{(5)}$$

$$VZ = \{(i_1, j_1, \rho, \varphi_1), \ldots, (i_s, js, \rho, \varphi_s), \ldots, (i_u, j_u, \rho, \varphi_u)\} \quad \textbf{(6)}$$

5. let (i_s, j_s) and (i_u, j_u) be the coordinates of the intersection points, for which we have stored φ_s and φ_u .for $\varphi = 0°, \ldots, \mathrm{mod}(360°)$ we calculate the distances:

$$d_{su} = \sqrt{(i_s - i_u)^2 + (j_s - j_u)^2} \quad \textbf{(7)}$$

The sum of the distances between all the points s, u, for which $\rho = r_l$ is equal to

$$D_t = \sum_{s,u} d_{su} \quad \textbf{(8)}$$

6. The algorithm finishes creating vectors for $l = o$.
The feature vector created on the basis of the presented feature extraction algorithm can be formulated as:

$$V = \{V1, D_1, \ldots, V_l, D_l, \ldots, V_o, D_o\} \quad \textbf{(9)}$$

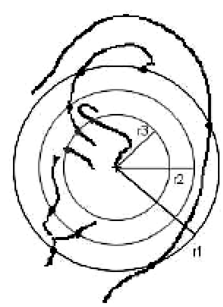

Fig. 5 .The Symbolic representation of algorithm for $N_r = 3$

C. Contour Tracking Method – CTM

We consider the binary ear image containing a number of contours. For each contour-line we specify following characteristic points:

- contour ending points,
- contour bifurcations,

- points of contour intersections with the concentric

Circles denoted as l_l. Those points were defined and included in (9).

Let g_o , denote the current point of the contour line, so that $g_o = g(i,j) = 1$. Contour line points are classified on the basis of the coefficient N^8_c

$$N_c^8 = \sum_{K=s} \left(g\dddot{k} - g\dddot{k}\, g\dddot{k} + 1 g\dddot{k} + 2 \right) \quad \textbf{(10)}$$

Where $S = (1, 3, 5, 7)$.

The first steps of the contour tracing algorithm are analogous with the algorithm of determining intersection points with the concentric circles presented in section B. We modify the fourth step of the algorithm by calculating the additional coefficient N_8^c. Therefore the modified record table T " with the elements (i, j, p, φ, N_8^c) is created.

The contour tracing algorithm is as follows:

1. we define the maximal possible radius r'_{max} and the distance between the consecutive circles Δr ,
2. we calculate the number of circles o in accordance with (3),
3. we calculate the maximum radius r_{max}, such that $r_{max} = {}_{\Delta}r * o$.
4. for the first detected contour point *(i,j),* we calculate the coefficient N_8^c
   If $N_8^c = 1$ (ending point of the contour line), we start contour tracing procedure;
5. Let there be c*, (c = 1... C)* contours in the ear contour image. For each point on the contour c, we calculate the polar Coordinates (*p*, φ) as in (4) and the coefficient N_8^c ,
6. the record-table *T'* with the elements is *(i, j, p, φ,*N_8^c) created.
7. on the basis of the table *T'* we determine:
   - l_p - number of intersections points of the contour *c* with the concentric circle of radius r_l ,
   - N_E - number of points in the contour *c* for which $N_8^c = 1$,
   - N_B – number of points in the contour for which $N_8^c > 2$,
   The points for which $N_8^c = 1$

and are $N_8^c > 2$ presented in Fig. 5 (left).

The parameter l_p characterizes the length of each contour. The more intersection points with the consecutive concentric circles, the longer the contour. The contour with the marked points of intersection with the concentric circles representing consecutive radii r_l is presented in Fig. 5 (right).

8. The feature vector Fc is created.

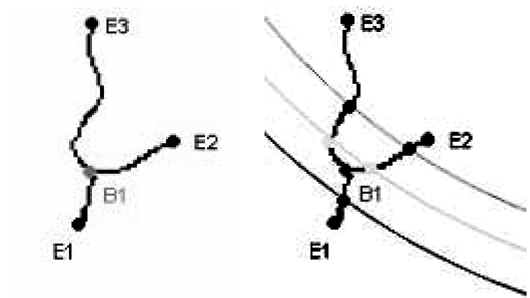

Fig.5. Symbolic presentation of the points extracted by tracing contour method. Ending points *E* and bifurcations *B* are marked in the contour, as well as the intersection points with the consecutive radii r_l (right).

For C contour in the image we obtain:

$$F = \left\{ \begin{array}{l} \left[\begin{array}{l} (l_l, N_E, N_B)\,((i_1, j_1, \rho_1)\ldots(i_s, j_s, \rho_s)\ldots \\ (i_u, j_u, \rho_u))_{r_l=1}\ldots((i_1, j_1, \rho_1)\ldots(i_s, j_s, \rho_s)\ldots \\ (i_u, j_u, \rho_u))_{r_l=o}((i_1, j_1)_{N_E=1}\ldots(i_1, j_1)_{N_E}) \\ (((i_1, j_1)_{N_B=1}\ldots(i_1, j_1)_{N_B}) \end{array} \right]_{c=1} \\ \left[\begin{array}{l} (l_l, N_E, N_B)\,((i_1, j_1, \rho_1)\ldots(i_s, j_s, \rho_s)\ldots \\ (i_u, j_u, \rho_u))_{r_l=1}\ldots((i_1, j_1, \rho_1)\ldots(i_s, j_s, \rho_s)\ldots \\ (i_u, j_u, \rho_u))_{r_l=o}((i_1, j_1)_{N_E=1}\ldots(i_1, j_1)_{N_E}) \\ (((i_1, j_1)_{N_B=1}\ldots(i_1, j_1)_{N_B}) \end{array} \right]_{c=C} \end{array} \right\}$$

(11)

The equation (11) describes the method of creating the feature vector corresponding to contour topology. Consecutively the number of endings, bifurcations and intersection points with the concentric circles are stored in the feature vector. Moreover, the coordinates of all the extracted characteristic points are stored.

The feature vector for each contour consists of the following parts:

1. 3 numbers *(* $l_l, N_E, N_B)_c$ corresponding to the number of intersection points, ending points and bifurcation points in each contour,
2. Subvector in which the coordinates of the intersection points are stored,
3. Subvector in which the coordinates of the ending points are stored,
4. Subvector in which the coordinates of the bifurcation points are stored.

The first part of the final feature vector has always the same length, while the next parts of the vectors for contours c depend on the number of the extracted characteristic points. Such division of the feature vector allows faster classification.

D. Angle – Based Contour Representation method ABM

Each extracted contour is treated as an independent open curve. Each contour is represented by two sets of angles [5]:

$$\varphi = \varphi_w ;1 \le w \le \varepsilon ;\varphi = \phi_w ;1 < w \le \varepsilon \quad \textbf{(12)}$$

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 centre 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 these extracted points is following:

$$j = b_1 * i + b_0$$

Where:

$$b_1 = \frac{j_k - j_p}{i_k - i_p} \quad b_0 = \frac{j_p \times l_k - j_k \times l_p}{i_k - i_p}$$

The distance between the ending points is computed:

$$d_{kp} = \sqrt{(i_k - i_p)^2 + (j_k - j_p)^2} \quad \textbf{(13)}$$

4. The centre point i_{ar}, j_{ar} of the line between $(i_p, j_p)$and (i_k, j_k) is computed in the following way. Let:

$$\tan \gamma = \frac{j_k - j_p}{i_k - i_p} \text{ and } \Delta j = \frac{d_{kp}}{2} \cos \gamma \quad \textbf{(14)}$$

Then $j_{sr} = j_k + \Delta j$

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).

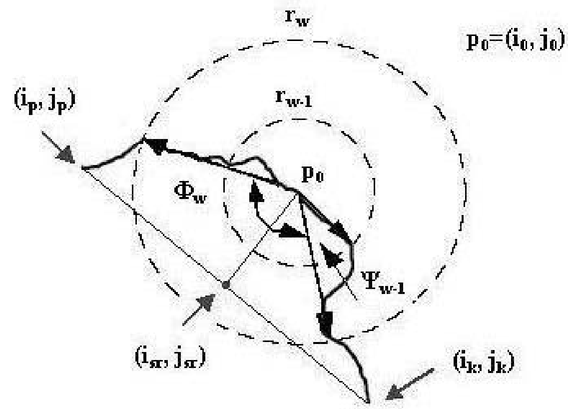

Figure 6. Visualization of the ABM method for a chosen ear contour and 2 radii (concentric circles) with a centre in p_0

The length of the maximal radius is determined by:

$$r_m = \sqrt{(i_k - i_0)^2 + (j_k - j_0)^2} \quad \textbf{(15)}$$

For each contour we consider ε concentric circles with the radii::

$$r_w = w \times \frac{r_m}{\varepsilon}(w = 1..., \varepsilon) \quad \textbf{(16)}$$

For each contour the point p_0 becomes the centre of the local polar coordinate system. In such system, for each contour point the record-table T created by analogy with the algorithm presented in Section B. In the table for $r_w = p$ the angle θ values are determined.
For each radius r_w we compute the angles:

$$\Phi_w = (\theta_{\max} - \theta_{\min})_w \quad \textbf{(17)}$$

$$\Phi_{w-1} = ((\theta_{\max})w - ((\theta_{\min})_{w-1}) \quad \textbf{(18)}$$

Having assumed that there are C contours in the ear contour image, and that each contour is analyzed by ' concentric circles, the feature vector is given by:

$$w = \{(\Phi_w, \psi_{w-1})_1, ..., (\Phi_w, \psi_{w-1})_c, ..., (\Phi_{w-1})_c\}$$

(19)

E. Geometrical Parameters Method – GPM

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

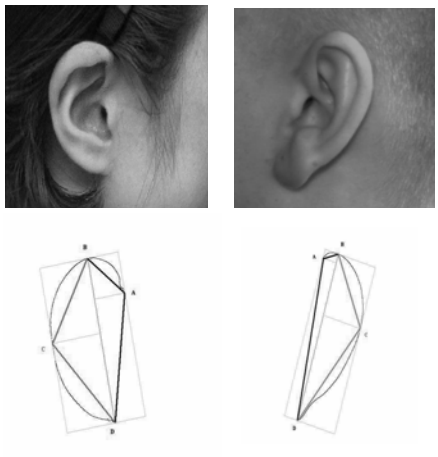

Figure 7. Triangle ratio method for sample ear images

In our case we use the properties of the triangle sidelines created in the following way:

1. Extraction of the longest contour L_{emax} within the ear image, contour length is calculated according to (20):

$$L_c = \sum_{q=1}^{Q-1} \sqrt{\left(x_{q+1} - x_q\right)^2 + \left(y_{q+1} - y_q\right)^2} \qquad \textbf{(20)}$$

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.

2. Calculation of the maximal chord according to (21):

$$Chord_{\max} = \{\sqrt{\left(i_c - i_b\right)^2 + (j_c - j_b)^2}\} \qquad \textbf{(21)}$$

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

3. having computed the coordinates of the maximal chord and its length, for the current points of the contour we
Calculate:

$$A_b = i_c j_b - i_b j_c + i_b j_{b\max} - i_{b\max} j_b + i_{b\max} j_c - i_c j_{b\max} \qquad \textbf{(22)}$$

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

$$rb = \frac{A_b}{Chord_{\max}} \qquad \textbf{(23)}$$

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 $j_b \geq j_{b\ max}$ determine the point C in the ear contour.

5. Two triangles are created: the triangle ABD and BCD,

6. The presented conditions (inequalities) are true for left images, for right ears inequalities are reverse,

7. 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.

8. 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 90º that is $b = h_m + h_d$.

9. 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.

10. we calculate the values of parameter $w1$ such as $w1 = ab + ad$ and, by analogy, $w2$ such as $w2 = bc + cd$.

11. we calculate the length ratio $w = w1 / w2$.

12. we calculate the triangles ratio according to(25).

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 90º. The parameter db is the length ratio calculated
as:

$$db = \frac{Chord_{\max}}{b} \qquad \textbf{(24)}$$

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

$$t_r = \frac{h_m w_1}{h_d w_2} \qquad \textbf{(25)}$$

The results of the presented method for 2 test images are shown in Figure 7.

Another proposed ear contours feature is the shape ratio. The shape ratio denoted as . is computed according to :(26)

$$kk = \frac{L_c}{d_{kp}} \qquad \textbf{(26)}$$

Where

- L_c is the contour length given by (20),

- d_{kp} is the length of the line connecting the ending points of each contour given by (13).

Shape ratio allows contours classification into 2 classes:
1. Linear contours for which $kk = 1$
2. Circular contours for which $kk >> 1$
   The shape ratio value is always $kk > 1$

The example of the circular contour is the contour number 8 extracted in the ear image in Fig. 2 (left). The examples of the linear contour is the contour number 6 extracted in the ear image in Fig. 2 (right).
Furthermore the ratio *cc* is proposed. It is computed as the number of intersections between 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. 2 (right).
The feature vector containing the parameters computed by the proposed method GPM is given by:

$$FV = \{(L_c, d_{kp}, kk, d, b, db, cc)_c\} \qquad (27)$$

3. CONCLUSION:
4.

In the article we presented 5 novel geometrical methods of ear contour image processing and feature extraction. Our work was motivated by ear biometrics human identification applications. Therefore we tested the efficiency of our methods on our own ear image database and we performed recognition tests.

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