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Posture Invariant Personal Identification System Using Convex Hulls: Ear Biometrics

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Authors' contributions

This work was carried out in collaboration between the two authors. Author MAJ came up with the novel idea, designed the computational experiments, guided the second author, and wrote the manuscript. Author GKP acquired the requisite number of images by leading the photography sessions outdoor, developed the personal identification system and ran computational experiments needed to evaluate and validate the system. Both the authors read and approved the final manuscript.

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ABSTRACT

Aims: In this work we have set forth two aims, i. to find a unique methodology to capture the shape of human ears using convex hulls and ii. to develop a rotation invariant personal identification system

Study Design: Application of convex hulls to capture the shape of the human ear in a precise manner.

Place and Duration of Study: Research Center, Department of Master of Computer Applications, Siddaganga Institute of Technology, Tumakuru, India, between June 2014 and July 2018.

Methodology: The work focused in this part is about using convex hulls for capturing the ear shape to utmost accuracy in two different orientations: i. orientation with respect to plane of the ear which accounted for rotation and ii. Orientation with respect to perpendicular axis through the ear plane which accounted for tilting. In order to meet the objective of developing a rotation invariant personal identification system. Thirteen parameters namely area, aspect ratio, bari centric

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coordinate, convexity, concavity, eccentricity, circular equi-diameter, Euler number, faret's diameter, form factor, orientation, perimeter and solidity were considered.
Results: The system was checked by conducting identification experiments. The recognition rate of 100%, 95%, 85% and 77% was noticed for 00, 22.50, 450, 67.50 orientations respectively when Euclidean distance matching criteria was implemented. Apart from this, similarity measures were also considered for matching test image with template image. In this connection Cosine, Jaccard and Dice similarity measures were used. Cosine similarity measure showed relatively higher recognition rates of 84%, 82%, 75.6% and 74.6% for 00, 22.50, 450, and 67.50 orientations respectively. Similarly Jaccard similarity measure performed with 78%, 75.25%, 74.25% and 72.8% for the four orientations respectively. Dice similarity measure exhibited 75%, 73%, 68% and 72% for the four orientations respectively. The overlapping similarity measure showed a drastic behavior by arriving at only two groups and with reduced recognition rates of 72%, 69%, 67% and 64% respectively.
Conclusion: It is concluded that the outcome of the research would be of immense help to the research community in the realm of ear biometrics. In addition, the contribution of head posture invariant person recognition system will definitely inspire the research community as well as the developers of biometric systems to explore the area of ear biometric related personal identification system.

Keywords: Ear biometrics; posture invariant; convex hulls; biometric features; Euclidian distance; similarity metrics; personal identification system.

1. INTRODUCTION

It is becoming increasingly clear among biometric research fraternity that ear as a biometric articulation in human beings, provide exclusive and unique advantages when compared with other kinds. Justifiably, the human ear with so many intricate features is deemed to be a rich source biometric for personal identification. The distinct advantages of ear biometrics are in order [1,2]. Ears of a person are visible from a distance, thus it becomes easy to capture the images.

- Ears are bestowed with a distinct articulation, stable and stiff structure which will not be subjected to appreciable change as the person's age goes by.
- The ear configuration remains unchanged even for the lowest degree when the person undergoes emotion or when he/she changes facial expression
- The background for every ear capture is highly predictable because ear is attached in almost middle side of the head firmly.
- There are no issues related to hygiene as ear need not be touched during image acquisition. The hygiene issue is prevalent with other contact dependent biometrics.
- There is no element of anxiety in ear biometric measurements in comparison with iris and retina measurements.
- The fanned out area of the ear which is amenable to measurement of different features is large when compared to area available in case of iris, retina and finger print.
- In a specific comparison with face biometrics, that strictly demands the face to be photographed with a distinct backdrop, no such restrictions are posed as far as the ear biometric is concerned.
- The features pertaining to facial biometrics are susceptible to changes because facial geometry changes when person dons an expression or cosmetics and presence of facial hair. Further, it is difficult to exclude such redundant features while acquisition because of other constraints (like lightning and shadowing).
- Through there is an established consistency as far as features of iris is considered it is nearly impossible to acquire the image of iris with a reasonable resolution from a distance.

Over the years ear biometrics has seen astounding progress and definitely it is not in its infancy. It is still mired in innovation stage. This aspect is show cased with many reported findings an three dimensional potential of ear biometrics [3]. In forensic circles, the ear has received a high place of sanctity simply because the appearance of an ear is truly individual. Added to this, there deep three dimensional structures with dips and humps, convolutes etc. are simply inimitable. This special aspect of human ear has ensured that they receive priority and a place of sanctity in situations where a high degree of foolproof protection against imposters is demanded. A huge literature survey on ear biometrics is reported [4]. Construction of convex hull is traditionally a geometric problem which can be solved using computers. By definition, a convex hull is a polygon which can hold all the points of a given set optimally. Computational development of a convex hull is basically a combinational problem in general and optimization problem in specific. Here, convexity is used to signify the shape of a polygon. Convexity is a property of a polygon by virtue of which a line connecting any two peripherals points will always pass within the plane of the polygon. This that means a convex polygon holds convex set like a capsule. With this definition, a rectangle, a pentagon, a hexagon etc. without any hollowness, dent or extended vertices could serve as convex hulls. The boundary of such convex is often referred as convex curve. This property of convexity is amenable to the analysis of shape of an object or entity it holds. Shape of an entity is used as a significant trait in many areas of scientific and technological analysis such as object classification and identification [5], biology [6], geomorphology [7] shape similarity measure, object indexing [8] and powder particle characterization [9], artificial intelligence, image processing [10] and pattern recognition [11]. Extending further, the applications of convex hull is found in allied areas like path finding, computer vision, game theory, and static code analysis, rotating calipers, and digital terrain model generations [12]. Some recent applications include, mobile application that can run android based ear biometric [13], use of ear biometric features for classification of humans [14], In this paper we explain the methodology adopted to capture the ear geometry with utmost accuracy through convex hulls. The rest of the paper is organized as follows, an elaboration on methodology used in this work in section II, the development of person identification system is detailed in section III, results and discussions are presented in section IV, and the paper concludes in section V.

2. METHODOLOGY

In this paper, a unique methodology proposed in this research work for recognition of shape of the ear is discussed. Convex hulls are used to capture the shape of the ear in an optimal way with utmost precision. Another hallmark of this part of the research is an attempt done to develop rotation or orientation invariant personal identification system. In doing so the features of the convex hull that are not sensitive to rotation or orientation changes of the ear are extracted and used in the development of the system. Two possible orientations considered in this work are that of a person who would pose his/her ear before the camera. They are:

- Orientation changes in the plane of the ear
- Orientation changes of the ear with respect to the perpendicular axis through the plane of the ear

In order to meet the purpose listed above, ear images were acquired exclusively by conducting ear image capture sessions. During capturing session the subjects were made to orient their ears at different angles both in the plane of the ear and perpendicular to the plane of ear. The details of convex hulls, methodology used, image acquisition, the feature extraction, the development of the system and its evaluation and validation are presented in succeeding paragraphs.

2.1 Development of Convex Hull

Construction of convex hull is traditionally a geometric problem which can be solved using computers. By definition, a convex hull is a polygon which can hold all the points of a given set optimally. Computational development of a convex hull is basically a combinational problem in general and optimization problem in specific. A detailed description of different methods is available in ref [15]. In this work the most widely used gift wrapping algorithm is used. The algorithm is shown in Fig. 1.

2.2 Acquisition of Images

Since it was set forth to develop orientation invariant personal identification system, images were acquired in a complete different setup. Arrangements were made for the capture of images in the following two types of orientations the ear.

- Orientation of ear in its own plane by imparting rotation by making the subject to bend his/her head in three orientations
- Orientation of ear with respect to vertical axis through the ear plane. This is achieved by holding the camera at different orientations.

The procedure adopted for the acquisition of the images for both the cases mentioned above is explained in the following paragraphs.

2.2.1 Orientations in the plane of the ear

The different orientations considered here will address situations when the person stands before the camera with his head/neck not in upright position but in a position with a bent head. For this purpose, Ear images of around 300 subjects of age group ranging between 21 – 55 years were captured outdoor with almost same illumination condition for all the captures. The subjects happened to be the students of the department and also the faculty members. The individuals were made to pose their ears in direct view of camera. For this a letter of consent was obtained from each of them. In the first instance, the subject was asked to hold his neck in upright position, followed by forward bending of neck to the maximum possible extent and backward bending of neck of the maximum extent. For all the 3 orientations of the neck the camera was held in such a way that the complete ear portion is available for all the 3 orientations of the ear. In order to maintain uniformity across all the images the distances of camera and illumination condition were same for all. In all, 800 images were captured and stored in the database. A segment of ear images gallery in 3 different orientations is provided in Fig. 2.

2.2.2 Orientations about the axis perpendicular to the plane of the ear

As it is nearly impossible to orient head of the person to different measurable inclinations, the camera itself was held in different accurately measured orientations. To achieve this, the person holding the camera was made to stand at different points on the radials lines drawn on the ground. Five radial lines were drawn over the ground along five directions which were precisely measured. The orientations being 0°, 22.5°, 45°, and 67.5°. These lines were drawn over the ground using Total Station, an angle setting survey instrument.

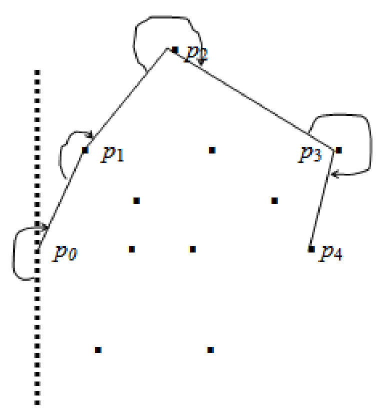
Total station is extensively used to measures angles on horizontal plane, on vertical plane, and sloping distances. The total station used in this work is shown in Fig. 3. The longitudinal profiling and cross profiling of the terrain is done using total station by civil engineers. This instrument has a built in microprocessor, a high power telescope with cross hairs, electronic data collectors and a small storage system [16]. The microprocessor provided in the equipment is capable of processing the data and to compute levels. In essence, the instrument is used for

- Finding elevation of objects
- Finding distance between two objects
- Computing horizontal distance between equipment and the object
- Locating objects in a three dimensional space
- Establishing alignment in different directions (angles)

It is the last utility among the enlisted capabilities of total station which is being used for drawing the lines in different orientation from a fixed point as shown in Fig. 4.

```
Given a set of points,
Starting with the bottom-most point and a
vertical line...
While the convex hull isn't closed off
   Rotate the line anchored
   At the point
   clockwise until  it hits
   another point
   Add the segment between
   the current anchor and
   the new point to the hull
   Make the new point the
   Anchor.
 end while
```

1(a)



1(b)

Fig. 1. Gift wrapping algorithm, a) Pseudo Code, b) Graphical illustration

Fig. 2. Region of Interest in captured images

2a) Direct view of the camera, 2b) Forward bending of the head, 2c) Backward bending of the head.

After drawing the lines along five orientations mentioned above, two points were decided along the lines. The subject was asked to stand at a point which is intersection of all the radial lines. For each subject, four images were captured for four different orientations of the Camera. During the capturing session, each subject was asked to stand at the central location looking at direction marked as 90° observing at a pole which was kept along the line at a distance to avoid distraction of the subject during image capturing session. The person with the camera was asked to stand along the line marked 0°, to obtain the image of the ear in direct view of the camera. Next the person with the camera will locate himself along the line marked as 22.5° to capture the ear image. In the similar manner the person with the camera moved along 45° and 67.5° lines. For the sake of uniformity across all the images, the distance between the camera and the region of interest and the illumination condition were maintained to be almost same. This was possible as the image capturing session happened in a single day. The subjects consisted of 200 voluntary young adults aged between 21-24 years majority of them being students. Before capturing of a photograph a written consent was obtained from each participant. In all, a total of 400 images were captured. A segment of database showing the region of interest captured in different orientations is shown in Fig. 5.

2.3 Feature Extraction

Before extracting the features the region of interest is cropped and the clear edge of the right ear was obtained using canny edge detection algorithm.

For the extraction of features first the convex hull is superposed over edge of the ear the convex hull was obtained using quick hull algorithm. Thirteen features were extracted from each of the convex hull encasing the ear edge. The features are explained [17,18,19] in the following paragraphs

a) **Area:** The area of the convex hull which optimally encapsulates the region of

Fig. 3. Total station Equipment

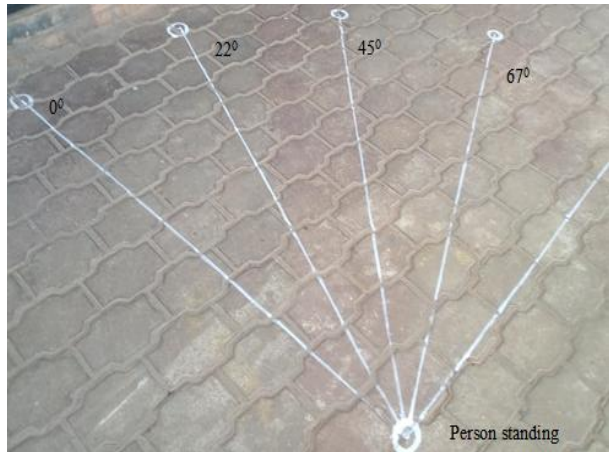
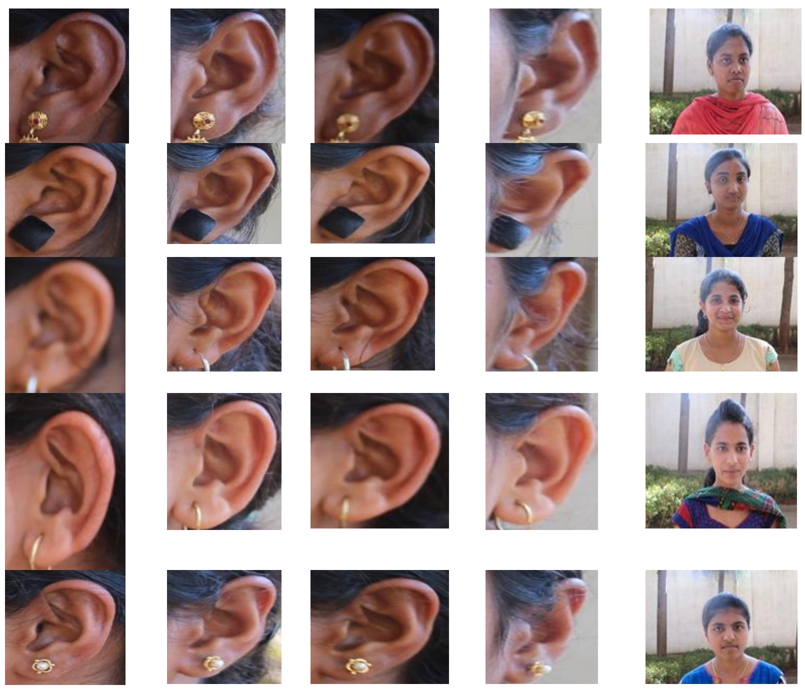


Fig. 4. Marking angles using total station



0° 22.5° 45° 67.5° 90°

Fig. 5. Ear images captured in different angles of head rotation

interest is deemed as the projected two dimensional areas. It is sum of the areas of each individual pixel. These pixels being are accommodated within the boundaries of the convex hull and hence boundary of ear. The total area is taken as number of pixels accommodated.

b) **Aspect ratio:** It is the ration of maximum length by minimum length i.e. major axis by minor axis of the hull.

c) **Bari Centric Coordinate (BCC):** BCC is a unique feature over convex polygon. BCC represents a common point within the convex polygon where all the common vertices of the elementary triangles that constitute the polygon would meet. Fig. 3 shows the location of BCC for a convex polygon of seven sides. BCC simply represents a point as a common. A BCC in a convex polygon is regarded as a close set with vertices $v_1, v_2, \ldots, v_n$ where $n>3$. Baric enteric coordinates must satisfy for all v belonging to convex hull (Ω) the following three equations.

$$\emptyset_i(v) \geq 0 \tag{1}$$

$$\sum_{i=1}^{n} \emptyset_i (v) = 1 \tag{2}$$

$$\sum_{i=1}^{n} \emptyset_i (v). v_i = v \tag{3}$$

(Here $\emptyset_i$ is asset of barycentric coordinates)

BCC will not be subjected to change even if orientation of the polygon changed. These coordinates can be determined using Cartesian To Barycentric () and barycentric To Cartesian() in mat-lab. BCC for a convex polygon is unique and does not change even if the plane rotated or translated. The notations are shown in Fig. 6.

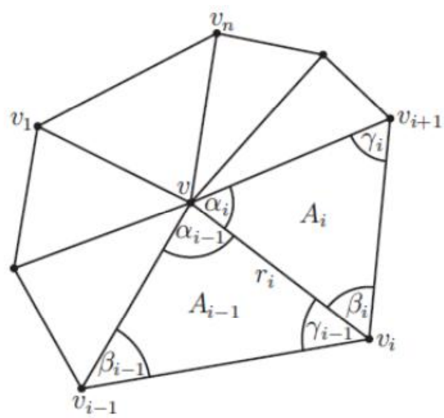


Fig. 6. Notations for convex polygons

d) **Convexity:** Convexity is represented ratio of convex hull perimeter (P_C) to actual perimeter (P). It is dimension less and is given by equation 4

$$C_x = \frac{P_c}{P} \tag{4}$$

e) **Concavity (CC):** It is the difference between convex hull area and the area of the actual region of interest encapsulated by the convex hull. It is given by the equation 5.

$$C_a = Area_{\ convexhull} - Area \tag{5}$$

f) **Eccentricity:** Denotes the property of an eclipse that has same second moment as that of convex hull. It is defined as the ratio of the distance between the foci and the major axis length of equivalent ellipse. The value of the eccentricity lies between zero and one. Extreme values of zero and one being degenerative cases.

g) **Circular Equi-diameter:** It is the scalar quantity that is equivalent to the diameter of a circle of area equal to that of convex hull. It is given by the equation 6.

$$d = \sqrt{\frac{4*Area_{convex\ hull}}{3.142}} \tag{6}$$

h) **Euler Number:** It is a measure of relation between the numbers of continues area of component parts of convex hull and the number of holes present. It is given by equation 7, here S_C is continuous parts and N_C is the number of holes.

$$Eul = S_c - N_c \tag{7}$$

i) **Faret's Diameter:** It is the maximum distance or farthest between any two parallel lines that are tangents at two extreme points on the peripherals

j) **Form Factor:** It represents the roundness of ear it is given by equation 8.

$$FF = \frac{4*3.142*Area}{(Perimeter)^2} \tag{8}$$

k) **Orientation (Branch Angle):** It is the angle between the major axis and the x-axis measured in radians.

l) **Perimeter:** It is two dimensional eight connectivity based neighborhood of the closed ear boundary.

m) **Solidity:** It is the ration of the area of the region of interest to the area of its convex hull, given by equation 9.

$$SL = \frac{Area\ of\ region\ of\ inerest}{Area\ of\ convex\ hull} \tag{9}$$

A typical convex hull encasing the region of interest is shown in Fig. 7.

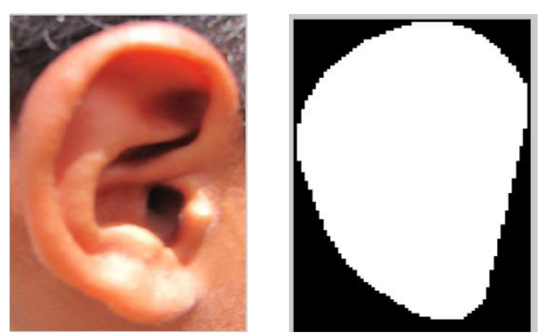


Fig. 7. Region of interest using convex hull

The flow chart showing the process of feature extraction is provided in Fig. 8.

3. PROPOSED SYSTEM DEVELOPMENT

Two identification systems were developed catering to different orientations of the ear

- Disorientation with respect to plane of the ear
- Disorientations with respect to vertical axis through the ear

3.1 Disorientation in the Plane of the Ear

This kind of disorientation covers situations when the person poses his/her ear with a bent head either in forward or in backward direction. It is typically rotation of the plane of the ear clockwise when the head forward and anticlockwise when the head is bent backward direction.

For the development of the system, three hundred images were collected and stored in the database. All the thirteen features were considered. However, huge variability was found in six features namely, are area, bari centric coordinates, aspect ratio, perimeter, eccentricity and form factor. Other features did not show such variability irrespective of orientation changes.The reason for selection of these six features is attributed to very low variability in the feature values in all three orientations considered. A sample segment of the database pertaining to the orientations discussed above is presented in Table 1.

The Euclidean distance was used as a matching criterion. Matching experiments were conducted using 200 randomly selected images drawn from the database. These experiments were done to find out the threshold criteria. For the testing of the system, 100 randomly selected images were considered. The system showed excellent recognition accuracy of 98%. The details are shown in Fig. 9.

3.1.1 Evaluation of the system

Evaluation of the system is crucial and is done in a similar manner satisfying international standards. This evaluation takes care of data quality related metrics, usability metrics and security metrics. The detailed explanations of all the metrics [20] are done in reference [self]. Table 2 displays various system performance measures found during evaluation of identification system. It is seen from the table that various measures of the system performance are in tune with international standards [21].

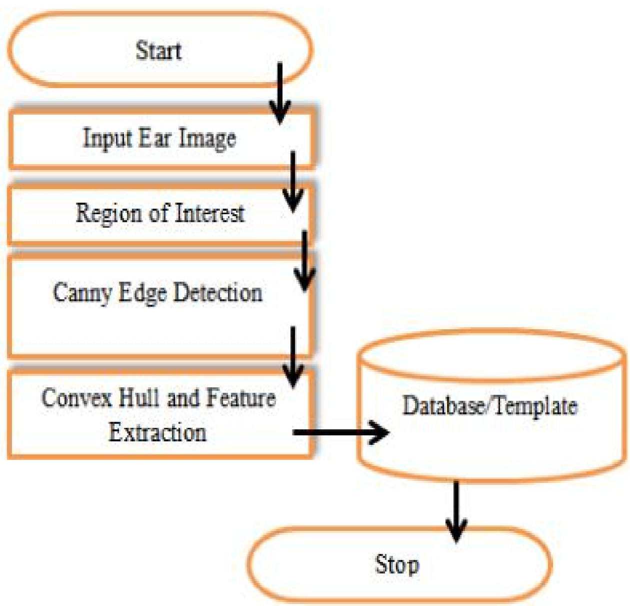


Fig. 8. Flow chart of feature extraction process

Evaluation of the personal identification system is very critical particularly in domains such as e-commerce, defense and criminal detection. There exist three kinds of evaluations [22,23].

- Based on data quality
- Usability and
- Security

The first kind of evaluation is all about quality of the raw data, quality criteria and other controls. Appropriate to this research work among the 300 samples, 40 samples were rejected because of their bad quality during the enrollment phase.

As per ISO 13407:1999 [24] usability is stated as an extent to which the product can be utilized by specified stakeholders satisfying requirements such as

- Effectiveness
- Efficiency
- Satisfactory functioning in specific use case.

The metrics considered under the usability criteria are:

a. Related To Fundamental Performance

In this category, the fundamental performance yardsticks [25] are the following;

- *Failure-to-enroll rate (FTE):* This is percentage of users for whom the identified system failed to capture the features when test image presented.
- *Failure-to-acquire rate (FTA):* It is the portion of verification attempts by the system in which the system failed to locate or to capture the template image in the database.
- *False-match-rate (FMR):* This is portion of mismatches.
- *False-non-match rate (FNMR):* It is the percentage of incorrect negative matches by the system.

Table 1. Sample features database with different rotations in the plane of the Ear

	Area	Eccentricity	Roundness	Bari- centric Coordinates		Form factor	Perimeter
Direct View	369	0.797519	0.095679	26	34	1.657566	0.095844
	588	0.852154	0.325893	15	6	1.910981	0.122807
	532	0.840555	0.102152	52	48	1.845953	0.109106
	350	0.877571	0.072759	20	35	2.085738	0.121528
	660	0.850385	0.094392	43	57	1.900561	0.106075
	612	0.897341	0.095692	25	44	2.265833	0.070264
	831	0.890024	0.209216	16	74	2.1934	0.083017
	664	0.929478	0.317526	25	53	2.710926	0.069434
	943	0.770215	0.307619	22	99	1.567929	0.067022
	897	0.755753	0.203056	93	5	1.52705	0.079184
Forward Bending	361	0.670519	0.024321	24	48	1.537566	0.083844
	580	0.725154	0.205893	13	28	1.790981	0.110807
	524	0.713555	0.017848	50	8	1.725953	0.097106
	342	0.750571	0.047241	18	5	1.965738	0.109528
	652	0.723385	0.025608	41	52	1.780561	0.094075
	604	0.770341	0.024308	23	106	2.145833	0.058264
	823	0.763024	0.089216	14	65	2.0734	0.071017
	656	0.802478	0.197526	23	74	2.590926	0.057434
	935	0.643215	0.187619	20	30	1.447929	0.055022
	889	0.628753	0.083056	91	29	1.40705	0.067184
Back ward Bending	359	0.697519	0.004321	25	35	1.557566	0.085844
	578	0.752154	0.225893	14	7	1.810981	0.112807
	522	0.740555	0.002152	51	49	1.745953	0.099106
	340	0.777571	0.027241	19	36	1.985738	0.111528
	650	0.750385	0.005608	42	58	1.800561	0.096075
	602	0.797341	0.004308	24	45	2.165833	0.060264
	821	0.790024	0.109216	15	75	2.0934	0.073017
	654	0.829478	0.217526	24	54	2.610926	0.059434
	933	0.670215	0.207619	21	100	1.467929	0.057022
	887	0.655753	0.103056	92	6	1.42705	0.069184

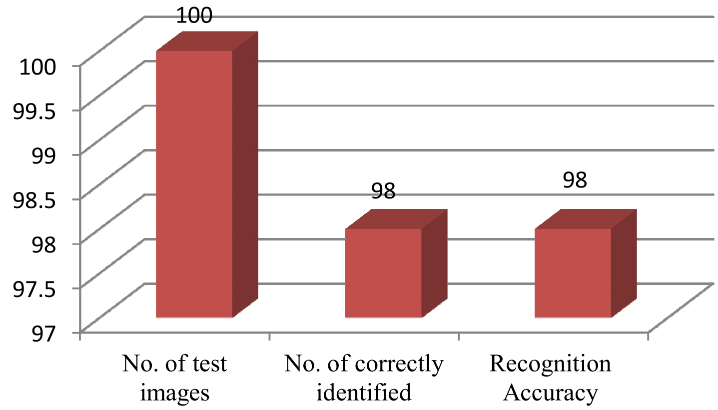


Fig. 9. Bar chart showing recognition accuracy

b. Verification System Performance

- There are two criterions to be satisfied under this metrics
- *False rejection rate (FRR):* Percentage of real users who are wrongly denied. FRR is given by the equation 10.

  FRR=FTA+FNMR*(1-FTA) (10)

- *False acceptance rate (FAR):* Percentage of imposters recognized incorrectly. FRA is given by the equation 11.

  FAR = FMR * (1 – FTA) (11)

c. Identification System Performance

- *Identification rate (IR):* Proportion of the transaction by the users enrolled in the system in which corrected identification is performed.

- *False-negative identification-error rate (FNIR):* It is the portion of transactions where user's authentic identity neither is nor echoed. FNIR is given by equation 12.

  FNIR = FTA + (1 – FTA)* FNMR (12)

- *False-positive identification-error rate (FPIR):* Proportions of identification of users who are not enrolled in the database of size N. FPIR is given by the equation 13.

$$FPIR = (1-FTA)*(1 – (1-FMR)^{N}) \quad (13)$$

The above mentioned metrics are useful in designing a robust system which is capable of withstanding potential security concerns.

The values of all the metrics discussed above were determined when personal identification system was administered for the available database. The results are presented in the Table 2. From this table it can be seen that the values of various metrics are highly acceptable and comply with international standards.

The entire processes starting from capturing of images until identification are depicted schematically by the flow chart shown in Fig. 10.

3.2 Disorientations with Inclination about Vertical Axis through Image

The database for this identification system ear consisted of around 400 ear images, 100 for each orientation i.e. 0°, 22.5°, 45°, 67.5° respectively. A segment of the database collected is presented in Table 3 and Table 4. The identification process performed by the matching of test ear image sample and templates ear image samples stored in the gallery. Since the images were taken at different angles the matching processes was done using Euclidean distance measure, and similarity measures (Cosine, Jaccard and Dice). For Euclidean measure the threshold value of differential

Table 2. Various system performance metrics and their values

FTE	FTA	FMR	FNMR	FRR	FAR	FNIR	FPIR
0.00	0.01	0.00	0.00	0.04	0.00	0.01	0.09

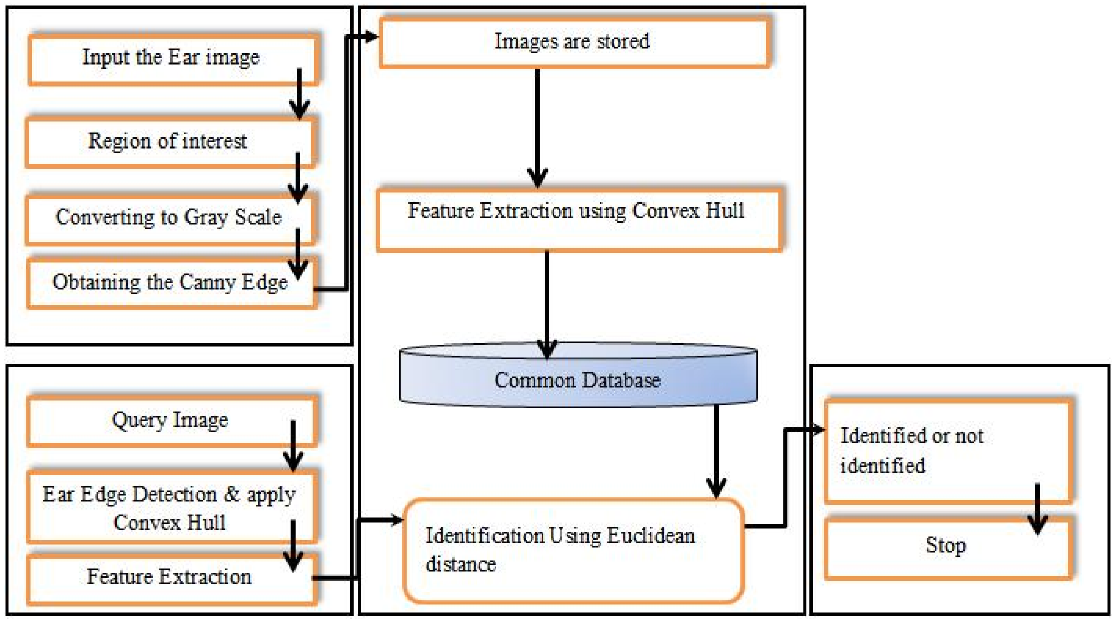


Fig. 10. Flow chart for identification/matching process

Euclidean distances between the test image and the template were found empirically by running identification experiments with 75% of the total collected images (300 numbers). The threshold value was found to be in the range of 1 x 10^{-4} to 1 x 10^{-6}. Similarly a threshold value with respect to each of the similarity criterion was also found empirically for the three measures (Cosine, Jaccard and Dice) considered. After this the identification experiments for 160(40 images per orientation) images that were randomly selected were performed. The flow chart of matching processes with reference to Euclidean distance criteria is shown in Fig. 10. General methodology adopted in matching the test images with the template images which is applicable to all the four measures (Euclidean, Cosine similarity, Jaccard similarity and Dice similarity) is presented Fig. 11. The system showed excellent recognition rate of 89% in terms over all recognition, when Euclidean distance criterion is considered. However, there were varied recognition rates noticed when identification test was carried out considering particular orientations i.e. identification experiments with ear images orientation of 0^0, 22.5°, 45°, and 67.5° respectively. An excellent recognition rate of 100% was noticed for 00 orientation, followed by 95% for 22.5° orientation, 85% for 45° orientations and a low recognition rate of 77% was noticed for 67.5° orientations. The results of the identification test are shown in Fig. 13.

Similar identification tests were carried out considering three similarity measures. For matching of the test and template images. Among them cosine similarity measure showed good results. The identification accuracy of 84%, 82%, 75.6% and 74.6% respectively for 00, 22.50, 450and 67.50 orientations of the image area of interest.

As far as Jaccard similarity measure is concerned, a recognition rates of 78%, 76.25%, 74.25 and 72.8% were recorded respectively for 00, 22.50, 450and 67.50 orientations. Lastly with Dice similarity measure showed discouraging results with 75%, 73%, 68% and 72% respectively for images captured at 00, 22.50, 450and 67.50 orientations. A comparative analysis of overall recognition rates when a test image is randomly presented to the system disregarding the orientation is presented. About 100 images selected randomly form the database were presented to the identification system. In this case also Euclidean distance based measure topped the recognition accuracy with 89%, followed by cosine similarity measure at 79%, Jaccard similarity was the next at 75%, finally the Dice similarity stood at a low overall recognition rate at 72% the details are presented in Fig. 14 a-d.

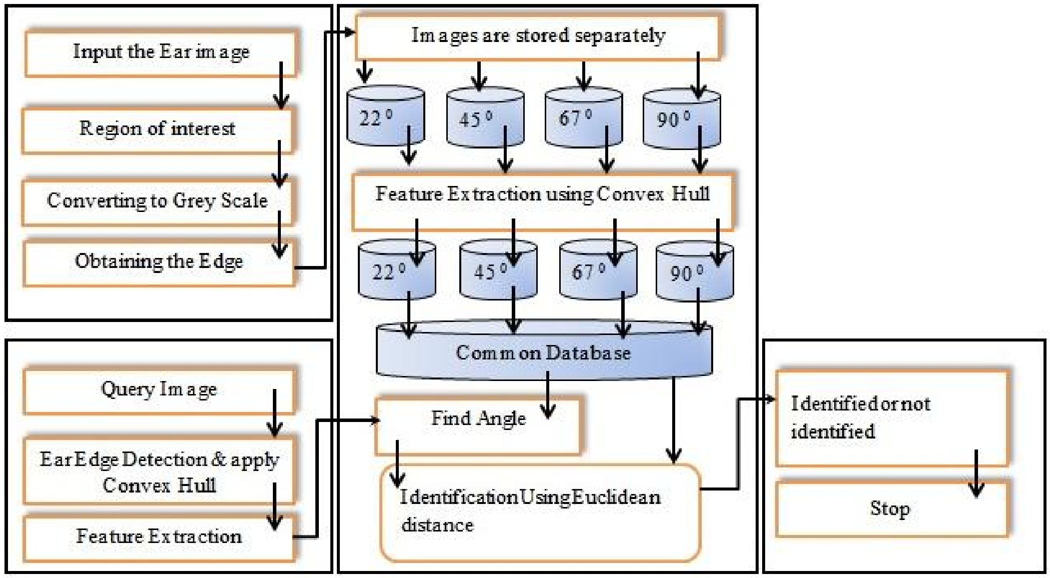


Fig. 11. Flow chart of the system (Euclidean distance criteria)

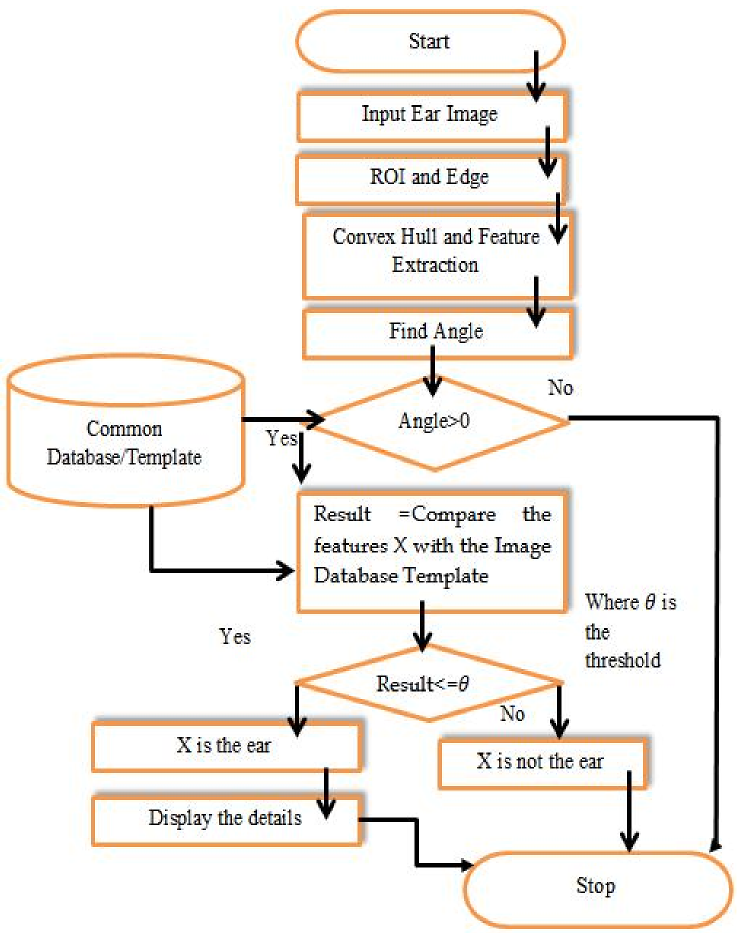


Fig. 12. The general flow diagram of personal identification system

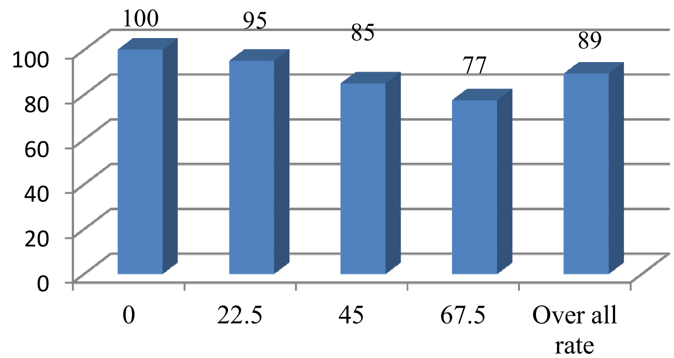
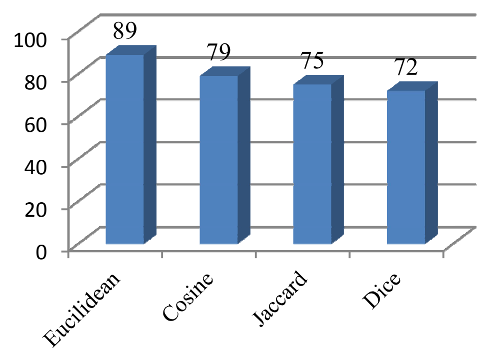
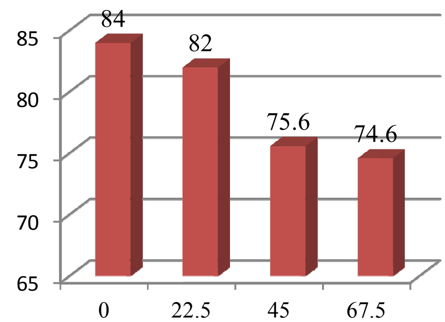


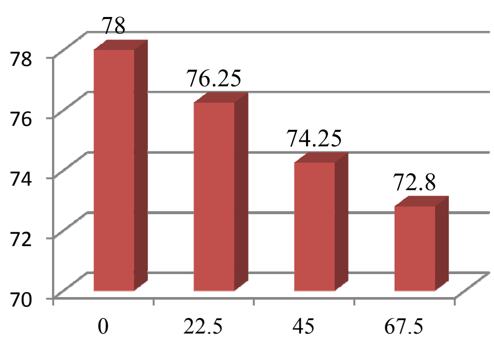
Fig. 13. Results of matching- the recognition rates



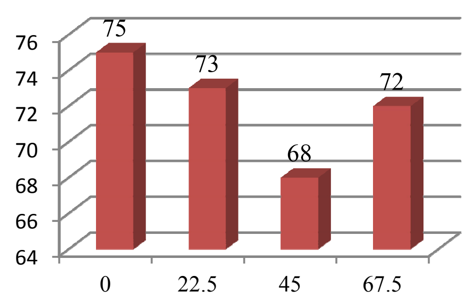
a. Overall performance rates



b. Results of Cosine similarity measure



c. Results of Jaccard similarity measure



d. Results of Dice similarity measure

Fig. 14. Performance of the system for different similarity measures

3.3 Identification Using Images with Arbitrary Orientations

As a matter of curiosity and also to test the generality of the system, identification experiments were carried out for test images captured at arbitrary orientations (other than the four orientations considered i.e. 22.5°, 45°, 67.5° and 90°). Around 80 ear images were captured during the acquisition session by making 20 subjects to occupy positions between 0°-22.5°, 22.5°-45°,45°-67.5° and 67.5°-90° respectively. These 20 subjects were also involved in initial acquisition session. Also these 80 images were not registered in the database. Therefore, these 80 ear images formed all together unknown test images for the system. The identification processes was performed by comparing the test image features with the template image features in the database with Euclidean distance criteria for matching with the lowest value of the threshold (1 x 10^{-6}) found earlier. Fig. 15 shows the results of overall performance of Euclidean distance measure and similarity measures. It can be seen from the Fig. that Euclidean distance measure showed relatively good performance with recognition rate of 81.25%, followed by cosine similarity measure at 78.75%, 75% by for Jaccard similarity measure and the low recognition rate of 73.75% with Dice similarity measure. The performance evaluation of identification system was done using the metrics such as FRR, FAR etc. Table 5 shows the listing of this metrics. It is seen from the table that all of them showed insignificant value. Thus proving the efficiency of the system.

Table 3. Features Database with different angles with Perpendicular to the plane of ear

a	b	c		d	e	f	g	h	i	j	k	l	m
22.5^0													
1186.881	1.873776	402	246	2331.822	84.20809	0.845685	52.79319	49	393	1157.544	70.91448	59.116	0.01588
2404.76	1.685934	51	181	964.3793	67.62567	0.805097	65.20235	53	437	357.9224	65.54906	131.3	0.02637
1923.808	1.273969	59	367	1078.511	77.43768	0.619561	48.01913	31	371	219.838	66.94143	123.384	0.013609
2038.796	2.19471	55	431	1242.821	58.66603	0.890164	37.4751	14	443	213.3392	56.6454	97.747	0.00908
2339.766	1.996597	256	202	599.0141	66.05707	0.865533	42.86356	26	382	82.55467	61.61007	179.727	0.013403
1521.848	2.63826	461	275	644.0717	98.06904	0.925381	34.83385	21	371	86.23465	67.45267	142.908	0.010354
1215.878	1.398148	34	453	691.0011	88.57502	0.698887	43.36559	21	387	117.4924	64.39197	152.418	0.014024
1009.899	1.898743	67	395	900.5615	81.83439	0.850073	49.12015	42	441	152.8381	59.50017	151.37	0.013901
1894.811	2.507051	361	364	2533.099	65.2779	0.917005	41.4593	37	424	1690.574	53.21222	38.415	0.013873
2124.788	1.482212	78	156	12975.34	56.8042	0.738122	53.93841	54	409	37681.17	73.72042	10.586	0.016635
45^0													
1186.763	2.246766	330	427	702.6716	84.19967	0.895489	39.79837	30	372	90.07577	53.12042	159.756	0.011082
2404.519	1.643194	459	360	715.138	67.61891	0.7935	37.81333	6	437	94.52815	25.44161	148.17	0.010598
1923.615	1.768084	409	227	1917.836	77.42994	0.824691	35.57527	11	350	637.6416	43.80984	53.673	0.009656
2038.592	1.535755	48	266	1977.067	58.66016	0.758953	49.92998	68	443	824.7579	63.77011	66.236	0.014952
2339.532	2.399441	72	439	189.4058	66.05046	0.909015	39.33174	12	333	9.596078	53.4897	483.718	0.013261
1521.696	1.242792	408	417	693.4139	98.05923	0.593763	49.49457	25	443	69.52557	86.60142	226.142	0.01227
1215.757	1.504136	30	260	606.6281	88.56616	0.746992	46.74269	19	358	68.76206	72.34799	214.751	0.013172
1009.798	2.691285	47	439	437.9643	81.82621	0.928405	39.87827	24	359	35.10295	56.60158	256.425	0.011121
1894.621	2.237158	35	424	1682.672	65.27138	0.894536	38.28183	18	443	1190.004	40.4603	42.278	0.016179
2124.575	2.367399	52	446	493.5185	56.79852	0.906407	39.12076	12	368	40.60256	52.41116	233.898	0.010413

Table 4. Features Database with different angles with Perpendicular to the plane of ear

a	b	c		d	e	f	g	h	i	j	k	l	m
67.5^0													
1185.338	2.007457	49	430	448.0094	84.09861	0.867095	48.17796	19	363	41.31339	63.80835	285.561	0.01425
2401.633	1.594514	60	212	1370.689	67.53775	0.778898	82.51068	96	443	551.0438	55.87576	133.91	0.029131
1921.306	1.332187	315	226	1650.596	77.337	0.660705	37.88061	12	443	312.31	17.18487	81.662	0.008361
2036.145	1.347838	192	168	1275.293	58.58976	0.670479	43.57063	20	354	248.0078	68.82709	105.404	0.011092
2336.724	1.229331	47	250	978.4844	65.97119	0.581634	61.50443	57	441	170.3189	82.39836	179.544	0.016911
1519.869	1.40665	40	391	518.5829	97.94153	0.703284	51.91771	30	365	63.61067	69.03348	247.997	0.016461
1214.298	1.225659	284	204	376.9943	88.45986	0.57821	35.89594	19	370	15.34899	2.199712	349.061	0.00769
1008.586	1.551635	53	234	4326.817	81.72799	0.76462	52.11353	32	443	2649.406	72.05824	38.572	0.012781
1892.347	2.808431	67	389	899.8643	65.19303	0.934459	44.79537	25	426	187.7731	48.90094	124.541	0.014063
2122.025	1.153892	46	414	1585.05	56.73035	0.498948	50.28572	36	432	300.132	86.72923	110.582	0.011331
90^0													
1187	2.518002	285	461	146.2122	84.21651	0.917758	38.8759	23	382	4.692714	40.58095	683.698	0.011874
2405	1.41669	135	20	2813.728	67.63243	0.708341	55.33662	26	443	1329.968	40.42127	57.808	0.014786
1924	1.200653	51	195	1775.264	77.44543	0.553454	49.49457	103	443	504.6975	23.15196	83.934	0.012912
2039	1.437228	47	385	1498.847	58.6719	0.718251	50.95229	27	350	591.4789	70.14687	79.816	0.017044
2340	1.456135	73	448	1095.599	66.06368	0.726894	54.5837	23	443	217.202	61.34308	141.1	0.015137
1522	1.243799	164	207	1691.8	98.07884	0.594645	44.02125	44	443	361.2724	62.61676	88.235	0.010196
1216	1.503238	87	404	517.5963	88.58388	0.746638	39.34793	11	359	51.88494	61.03493	208.112	0.011289
1010	2.509826	159	194	556.1791	81.84257	0.917197	35.86045	13	366	84.49895	63.46245	148.623	0.012219
1895	1.769267	66	424	975.9934	65.28443	0.82495	49.12015	31	403	217.9552	45.39913	126.757	0.015318
2125	1.847969	120	433	881.9477	56.80988	0.840936	52.01571	29	351	209.595	53.59416	136.88	0.017603

a-Area, b-Aspect ratio, c-Bari Centric Coordinate, d- Convexity, e- Concavity, f-Eccentricity, g-Circular Equi-diameter, h-Euler Number, i- Faret's Diameter, j-Form Factor, k-Orientation, l- Perimeter, m- Solidity.

3.4 The System at a Glance

An interface was developed for recognition system. However, for the sake the completeness the system behavior with Euclidean distance measure is only showcased. The snap shot in Fig. 16 depicts the loading of test image, the computation and display of the features, searching through the database and finally display of the matching template image on the screen along with the person. Similarly Fig. 17 shows a correctly identified of person by the system when test image corresponding to 45° orientation is presented. Fig. 16 pertains to ear image corresponding to orientation of 22.5°. Fig. 18 corresponds to ear image with an orientation of 0° i.e. direct vision of camera.

As an aside, Fig. 18 depicts the situation when a new image which is not registered in the database is presented to the system. As usual, the system extracts the features but has failed to identify the person because of non-availability of a matching template image in the database.

Table 5. Evaluation of the system when tested with Ears in arbitrary orientations

FTE	FTA	FMR	FNMR	FRR	FAR	FNIR	FPIR
0.0	0.01	0.00	0.00	0.76	0.0	0.01	0.09

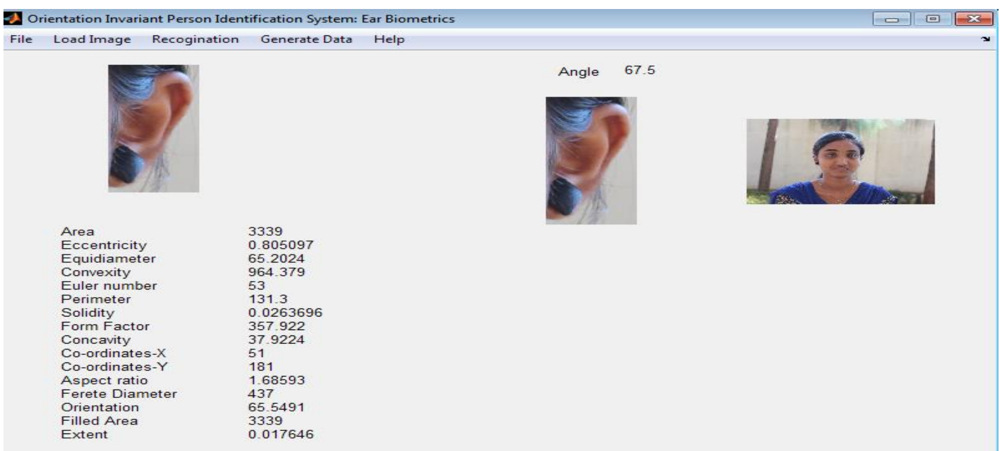


Fig. 15. Person identification when head tilt at 67.5°

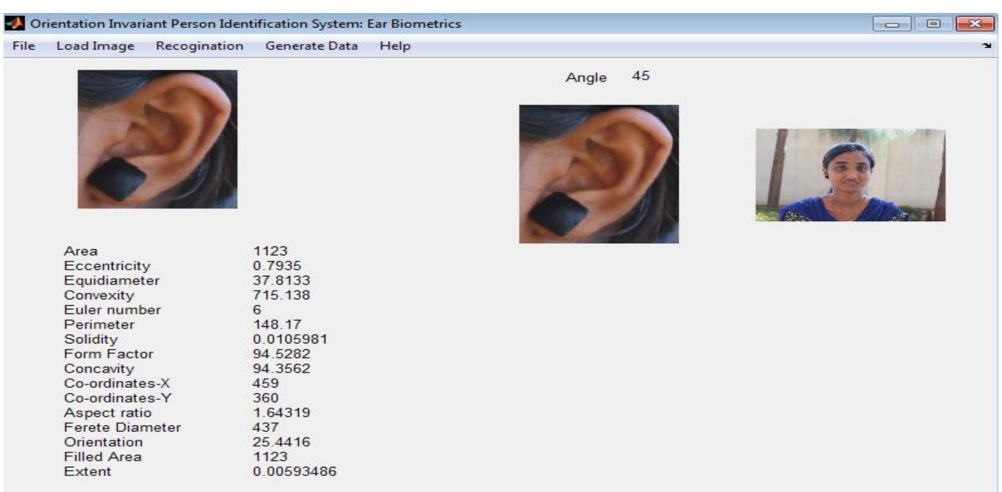


Fig. 16. Identification of the same person when head tilt at 45°

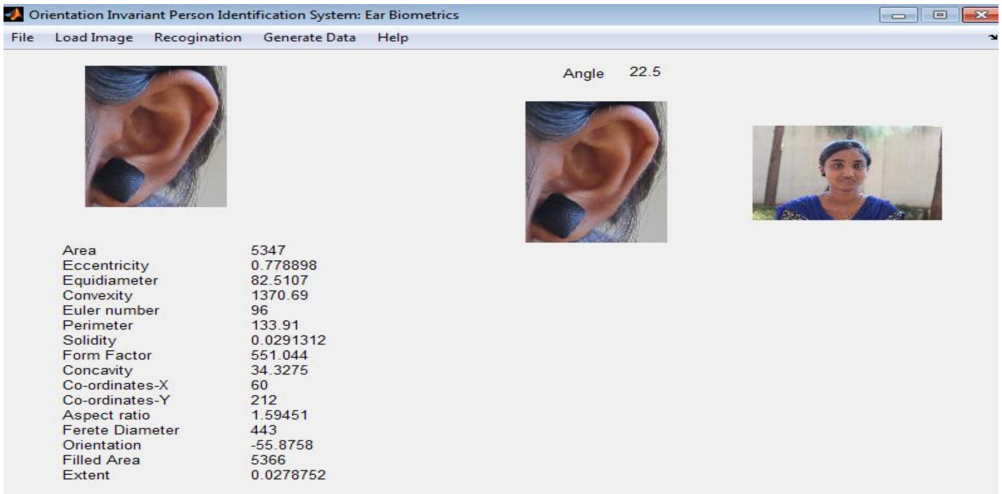


Fig. 17. Identification of the same person when head tilt at 22.5°

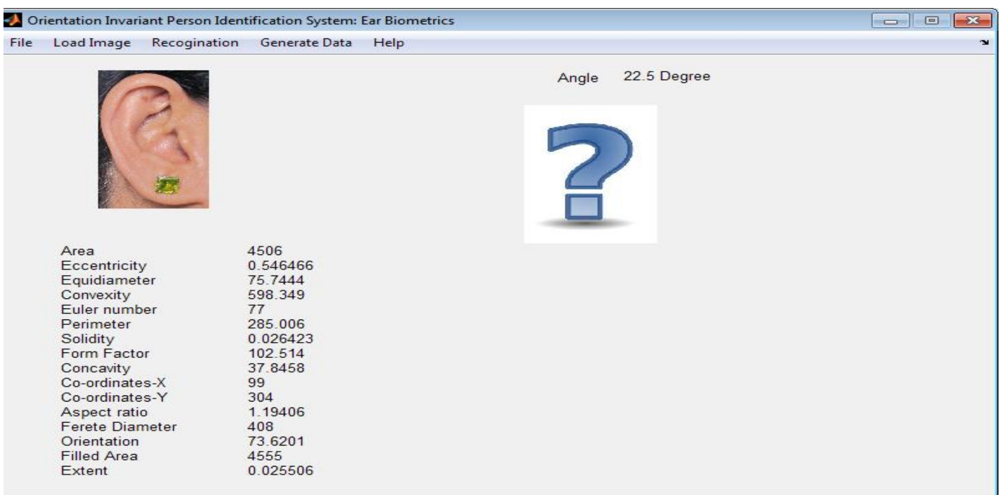


Fig. 18. System response when non-registered image is presented

4. RESULTS AND DISCUSSION

Based on the results obtained in this part of the study following conclusion could be drawn.

- The convex hulls provided excellent optimized convex polygons for capturing ear shape accurately for all the images taken in different orientations. For the orientations which corresponds to the rotation of the ear. Six properties of convex hull namely area, baric enteric coordinates, eccentricity, aspect ratio, perimeter and form factor were designated as features. These properties showed absolutely no change for three kind of rotations of the head i.e. upright head, head bent forward and head bent in back ward direction. Around 300 images were registered in the database for designing the system.
- The performance evaluation of the system showed very insignificant values of performance measures such FTE, FTA, FMR, FNMR, FRR, FAR FNIR and FPIR.
- The disorientations when a person stands before the camera with his/her head tilted or rotated in horizontal plane is also considered. As it is difficult to account for angular rotation of the head, tilting or orienting the camera itself in four inclinations i.e. 00, 22.50, 450 and 67.50 and capturing the images was found to be workable. This added to the innovativeness of the research.

- Thirteen parameters of the convex hull (hence the ear) namely area, aspect ratio, bari centric coordinate, convexity, concavity, eccentricity, circular equi diameter, Euler number, faret's diameter, form factor, orientation, perimeter and solidity were considered to be features.
- The system was developed by conducting matching exercises using Euclidean distance matching criteria. The results were highly encouraging with 100%, 95%, 85% and 77% recognition accuracy respectively for 00, 22.50, 450 and 67.50 inclinations.
- Apart from Euclidean distance criteria, the four similarity measure namely cosine, Jaccard, Dice and overlapping were also used separately during matching experiments. Cosine similarity measure showed higher recognition rate of 84%, 82%, 75.6% and 74.6% for 00, 22.50, 450 and 67.50 orientations. While Jaccard similarity performed with 78%, 75.25%, 74.25% and 72.8% respectively for four orientations. However, Dice similarity measure showed relatively low recognition accuracy of 75%, 73%, 68% and 72% for the four orientations respectively. However overlapping similarity measure did not perform well with further reduced recognition rates of 72%, 69%, 67% and 64% respectively for the four orientations considered.
- Person identification systems were developed using Euclidean distance criteria and cosine similarity matching criteria only. This is owing to their excellent recognition rate in all the four orientations of the ears. The system showed negligible values of such FTE, FTA, FMR, FNMR, FRR, FAR FNIR etc showcasing its robustness.
- To check the generality of the identification system the images captured in arbitrary orientations in four inclinations ranges viz. 00-22.50, 22.50-450,450-67.50 and 67.50-900 were tested. About 80 images were captured and these images were not registered in the database. Therefore, they were unknown to the identification system.
- The matching of these test images were done using Euclidean distance criteria and three similarities criteria. Interestingly, a high recognition rate of 81.2% was recorded when Euclidean distance was used. Cosine similarity measure showed 78.75% recognition accuracy, followed by Jaccard similarity measure showing 75% recognition accuracy. However, Dice similarity measure showed a low recognition accuracy of 73%.

5. CONCLUSIONS

In a nutshell, it can be said that this research work conclusively proved supremacy of geometrical shape based ear biometric features related to convex hull properties which can distinguish uniqueness of ear shapes among persons. And these shape based features also provided a testimony to excellent and precise recognition of persons with insignificant number of mismatches. It is anticipated that the outcome of the research would be of immense help to the research community in the realm of ear biometrics. In addition, the contribution of rotation invariant person recognition system will definitely inspire the research community as well as the developers of biometric systems to explore the area of ear biometric related personal identification system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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