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...
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 showcased 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].

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 radial 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

Fig. 1. Gift wrapping algorithm, a) Pseudo Code, b) Graphical illustration
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
interest is deemed as the projected two dimensional areas. It is sum of the areas of each individual pixel. These pixels being 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 ratio 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 \( \Omega \) the following three equations.
\(\phi_i(u) \geq 0\) \hspace{1cm} (1)

\[\sum_{i=1}^{n} \phi_i(u) = 1\] \hspace{1cm} (2)

\[\sum_{i=1}^{n} \phi_i(v), v_i = v\] \hspace{1cm} (3)

(Here \(\phi_i\) 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.

\[\sum_{i=1}^{n} \phi_i(v), v_i = v\]

**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

\[C_x = \frac{P_c}{P}\] \hspace{1cm} (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.

\[C_a = Area_{convex hull} - Area\] \hspace{1cm} (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.

\[d = \sqrt{\frac{4 \times Area_{convex hull}}{3.142}}\] \hspace{1cm} (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.

\[Eul = S_c - N_c\] \hspace{1cm} (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.

\[FF = \frac{4 \times 3.142 \times Area}{(Perimeter)^2}\] \hspace{1cm} (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 ratio of the area of the region of interest to the area of its convex hull, given by equation 9.

\[SL = \frac{Area \text{ of region of interest}}{Area \text{ of convex hull}}\] \hspace{1cm} (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, area, barycentric 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].

![Flow chart of feature extraction process](image)
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.

| 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   | 0.178484                 | 50          | 8         | 1.725953 | 0.097106 |
|                       | 342          | 0.750571   | 0.047241                 | 18          | 5         | 1.965738 | 0.109528 |
|                       | 652          | 0.723385   | 0.256080                 | 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   | 0.021522                 | 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 |
c. Identification System Performance

- Identification rate (IR): Proportion of the transaction by the users enrolled in the system in which correct 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.

\[
FNIR = FTA + (1-FTA)^* FNMR
\]  

- 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.

\[
FPIR = (1-FTA)^*(1 - (1-FMR)^N)
\]

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

| FTE  | FTA  | FMR | FNMR | FRR  | FAR  | FNIR | FPIR |
|------|------|-----|------|------|------|------|------|
| 0.00 | 0.01 | 0.00| 0.00 | 0.04 | 0.00 | 0.01 | 0.09 |
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 $1 \times 10^{-4}$ to $1 \times 10^{-6}$. 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 $0^\circ$, $22.5^\circ$, $45^\circ$, and $67.5^\circ$ respectively. An excellent recognition rate of 100% was noticed for $0^\circ$ orientation, followed by 95% for $22.5^\circ$ orientation, 85% for $45^\circ$ orientations and a low recognition rate of 77% was noticed for $67.5^\circ$ 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 $0^\circ$, $22.5^\circ$, $45^\circ$ and $67.5^\circ$ orientations. Lastly with Dice similarity measure showed discouraging results with 75%, 73%, 68% and 72% respectively for images captured at $0^\circ$, $22.5^\circ$, $45^\circ$ and $67.5^\circ$ 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 from 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
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 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 these 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1186.831 | 1.873776 | 402 | 246 | 2333.822 | 84.20698 | 0.843582 | 52.789319 | 59 | 383 | 1107.544 | 70.91448 | 30.116 | 0.01338 |
| 2404.766 | 1.689324 | 51 | 181 | 364.37639 | 67.62567 | 0.805997 | 65.20225 | 53 | 437 | 357.9224 | 63.54906 | 31.313 | 0.02637 |
| 1923.808 | 1.273693 | 59 | 367 | 1078.531 | 77.43728 | 0.619561 | 48.01913 | 51 | 371 | 219.838 | 66.94143 | 123.584 | 0.01609 |
| 2038.796 | 2.194721 | 55 | 431 | 1242.821 | 58.66603 | 0.890164 | 37.47751 | 14 | 445 | 231.3392 | 58.64943 | 97.747 | 0.00908 |
| 2339.766 | 1.986957 | 226 | 202 | 599.0141 | 60.60606 | 0.805537 | 42.86565 | 26 | 382 | 82.54462 | 65.06702 | 329.792 | 0.01430 |
| 1521.848 | 2.632862 | 461 | 275 | 644.0171 | 93.69094 | 0.922381 | 34.83835 | 21 | 371 | 62.23465 | 67.45267 | 142.908 | 0.01054 |
| 1347.126 | 1.599146 | 43 | 435 | 491.0011 | 88.57502 | 0.480887 | 43.34519 | 21 | 387 | 117.4024 | 64.39107 | 112.418 | 0.01402 |
| 1009.899 | 1.899741 | 67 | 395 | 900.815 | 81.84349 | 0.850073 | 49.12037 | 24 | 441 | 152.8381 | 59.90007 | 151.371 | 0.01390 |
| 1894.811 | 2.507051 | 361 | 364 | 2335.069 | 65.27789 | 0.917005 | 41.45937 | 37 | 424 | 1690.574 | 53.21722 | 38.415 | 0.01387 |

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1186.763 | 2.246766 | 330 | 427 | 702.6716 | 84.19967 | 0.805480 | 39.79357 | 30 | 372 | 90.75775 | 53.12042 | 159.756 | 0.01102 |
| 2404.519 | 1.641914 | 453 | 360 | 715.138 | 67.61881 | 0.79335 | 37.81333 | 56 | 437 | 94.28135 | 25.44616 | 148.17 | 0.01059 |
| 2033.651 | 1.768084 | 409 | 227 | 1917.836 | 77.42994 | 0.824691 | 35.57527 | 11 | 350 | 631.6416 | 43.80984 | 53.673 | 0.00956 |
| 2033.592 | 1.355755 | 48 | 266 | 1977.067 | 58.60016 | 0.789953 | 49.99998 | 68 | 443 | 82.47579 | 63.77011 | 66.236 | 0.01492 |
| 2339.252 | 2.399414 | 72 | 438 | 1390.402 | 60.06304 | 0.890913 | 39.33174 | 12 | 333 | 9.59607 | 38.4897 | 458.718 | 0.01261 |
| 1521.699 | 2.124792 | 408 | 417 | 693.4139 | 98.50929 | 0.593769 | 49.44957 | 25 | 449 | 69.32557 | 66.01642 | 226.142 | 0.01227 |
| 1215.757 | 1.904316 | 39 | 260 | 606.6238 | 88.56616 | 0.749922 | 46.74469 | 19 | 358 | 68.76266 | 72.34799 | 214.731 | 0.01317 |
| 1009.978 | 2.691281 | 47 | 438 | 437.9643 | 81.82621 | 0.929045 | 39.87827 | 24 | 359 | 35.10295 | 65.01598 | 256.425 | 0.01121 |
| 1894.821 | 2.237158 | 35 | 324 | 1682.672 | 67.25173 | 0.895168 | 38.28183 | 18 | 443 | 190.004 | 40.16033 | 42.278 | 0.01619 |
| 2124.775 | 2.567395 | 52 | 446 | 495.5182 | 56.78026 | 0.738029 | 10.39707 | 12 | 348 | 40.0262 | 52.41116 | 213.898 | 0.01015 |

22.5°

45°
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 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 | FNMR | FRR | FAR | FNIR | FPIR |
|-----|-----|------|-----|-----|------|------|
| 0.0 | 0.01| 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°
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, baricentric coordinate, convexity, concavity, eccentricity, circular equi diameter, Euler number, facet'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 0°, 22.5°, 45° and 67.5° 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 0°, 22.5°, 45° and 67.5° 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. 0°-22.5°, 22.5°-45°, 45°-67.5° and 67.5°-90° 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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