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Mini Review

Role of External Ear in Establishing Personal Identity - A Short Review

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Abstract

Since centuries external ear and its peculiarities had been attracting the attention of Scientists from diverse fields of Science. The possibility of using the external ear as a tool for establishing the unique identity of individuals was first recognized by Bertillon who included the same in the system he developed in 1893. Since then several studies on its range of peculiarities in morphology have emerged especially to correlate it with the field of personal identification. With the emergence of 'Information age' even the field of criminology has broadened its horizon by including more and more morphological features (face, hand, finger, iris etc.) for establishing identity. This paper traces this historical journey of the maturation study from the first step taken by Bertillon, to a foolproof personal identification trait that it is today.

Keywords: External ear; Personal identification; Ear biometrics; Soft biometrics

Introduction

With the dawning of the 'Information Age' in the last century, several electronic gadgets have been invented to secure the society from the evil forces (e.g. Closed circuit television, Motion detection cameras, Infrared camera etc.) and the same were placed in most 'perceived high risk areas'. For the same reasons and to establish unique personal identification in a more foolproof manner, morphological features other than face, like iris (eye), hand, finger scans etc. are being increasingly used across the world today. Furthering such foolproof identification, in recent years, external ear has emerged as a potential tool for forensic investigations and establishment of personal identification.

Ear: a tool for personal identification

As early as in eighteenth century the complex shape of ear had attracted the attention of early Physiologists Lavater [1]. On the basis of the various ear features he tried to classify the behavioural nature of human (Figure 1). The earliest reference to individuality of external ear was made by Bertillon [2] who mentioned in his book that it is almost impossible to meet with two ears which are identical in all their parts. Though Bertillon did not undertake any research work on the use of ear as personal identification tool, he had made the above observation from his experience gathered from working on anthroposcopy and anthropometry of criminals. He had formulated a system based on anthropometry to prevent repeat offenders from concealing their identity. But with time certain loopholes came to light in Bertillon age system and ultimately it was replaced with finger print.

Since last century studies on various aspects of external ear have gained momentum. In the book *'L'identification des recidivists'* the author Locard [3] had written that '*This organ, that is a part of the face which in present day is the least looked at, can be considered as one of the most important for police science because it contains the most characteristic feature parts. The ear has a double character, on the one side qua sizes and forms it is unchangeable from birth till death, and on the other appears to be so varied that it is almost impossible to find two identical ears.'* The above statement was made from his observation on ear and no supporting data was provided to substantiate his observation.

A set of 500 ears was studied by a Prague doctor, Imhofer [4]. The characteristic forms of the ear were described by him and in his sample he could clearly distinguish between ears based on only four features. Investigating on the same line Hammer and Nuebert [5] worked on the features of the 100 ears and found no two ears corresponding to each other in all features.

An important study worth mentioning was undertaken by Fields et al. [6] in 1960. Finding finger and palm prints ineffective in mixing up of newborns in hospital, they conducted a pilot study on 206 babies to investigate the possibility of using external ear to distinguish babies from one another. Ear of every baby was found to be different from the other and the general shape unchanging throughout the hospital stay. Though changes in size and shape were visually observed, nothing was mentioned about the method of comparison and no empirical data as such had been reported.

The correlation between personal identification and body marks was studied in detail by Hunger and Leopold [7]. In one of the chapter the role of ear features was discussed in detail and lifelong stability of ear was hypothesised by them. Similarly while delivering a lecture in Germany Trube-Becker [8] commented that there are no absolutely identical ears, but only similar ears. Even two ears of one and the same individual are not completely identical. This was also claimed for identical twins. Unfortunately no supporting data was given by him too.

Anthropological data on external ear from 500 males and females was collected by Oepen [9]. Relative frequencies of various ear features, sexual and bilateral differences were studied by her. On a similar line in a recent publication in 2013 Murgod et al. [10] working

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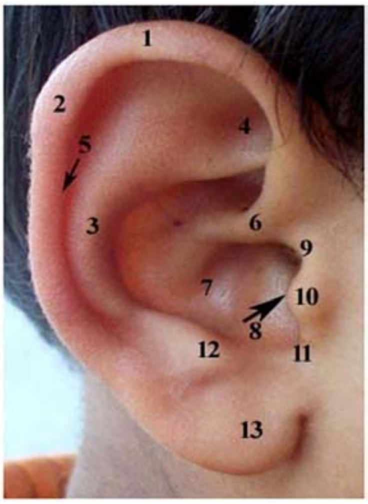

Figure 1: Features of external ear **1.** Helix **2.** Darwin's tubercle **3.** Antihelix **4.** Triangular fossa **5.** Scapha **6.** Crux of helix **7.** Concha **8.** External auditory meatus **9.** Incisura anterior auris **10.** Tragus **11.** Incisura intertragica **12.** Antitragus **13.** Lobule.

on Indian sample (150 males and 150 females) measured the various parameters of external ear and found prominent bilateral asymmetry and moderate sex difference.

A prominent contribution in the study of ear's role in personal identification has been made by Iannarelli [11]. With experience of analyzing more than 10,000 ears over a period of 40 years, all ears were found to be distinguishable from each other. His book '*Ear Identification*' is a pioneer work in this domain. Racial variation, closeness of ear structure in siblings, parent and child, twins, triplets were investigated by him. The sample size being large would have put to rest the controversy raging over ear uniqueness if only his claim was supported by empirical data on uniqueness. A new science 'Earology' that involves the study of anatomical structure, overall design, and comparison and general classification of the external ear was also defined by him. Following fingerprint classification external ear of an individual was classified into Primary classification by sex and race. While in secondary classification twelve measurements of anatomical parts of the ear were taken into consideration. With the data of primary classification the measurements were represented in a formula.

Discussing the problem of proving uniqueness of ear Hoogstrate et al. [12] had suggested two ways to do so. One was acceptance of the statement on its face value that nature creates things and shapes with large between individual variations so that every ear can be individualised. The other was to collect large sample and check whether each ear can be distinguished from the other and if none was left undistinguished then it may be taken as proof of its uniqueness. The possibility of identification by ear from surveillance camera film was also investigated by them. Use of better camera surveillance equipment with proper installation and handling were found to increase the chances of identifying an offender. The claim that personal identification can be established from the ear print left by perpetrator at the scene of crime was made by Lugt [13-15], the pioneer of ear print evidence. The claim was based on several studies he had been carrying on since 1987. The measures of ear and the morphology of various ear features were also studied by him [14] on a sample of 500 male images. In the year 2001 Forensic Ear Identification Project (FEARID) was launched in Europe by Meijerman et al. [16] that aimed at individualization of ear prints. Various aspects had been extensively researched including studying inter and intra-individual variability in print, changes in ear print on application of different magnitude of force, individualisation of prints etc.

A detailed study to investigate the extent of post maturation growth in external ears among adult males was undertaken in India. The belief of Computer Scientists engaged in developing programmes/algorithm for automatic recognition that external ear remains unchanged throughout life prompted the study. The finding regarding post maturation growth is useful to the Law Enforcement authorities who use software to authenticate individuals on the basis of match between presented image and the one which is stored in their database. The rapid changes taking place in the ear structure after the age of 60 years would necessitate the Law Enforcement agencies to update their data from time to time [17].

Few studies in this direction were also reported from Europe. A longitudinal study to investigate the changes in the magnitude of various body dimensions after a gap of ten years was undertaken by Gualdi-Russo [18]. Subjects in four age groups starting from 31 years to more than 60 years were measured for parameters including ear length and width. Ear length in both sexes showed significant increase in length in all age groups while ear width remained more or less stable in dimension over the period.

A similar study conducted a year later using a new method electromagnetic three-dimensional digitizers was adopted by Ferrario et al. [19] Three age groups, adolescent, young adults and mid aged male and female Italian subjects were included in the study. The ear length was found to increase in size in both sexes as one progressed from lower to higher age group. In contrast the ear width remained more or less stable in female while 2mm increment was observed among male subjects. Another study on Italian subjects using the same method was reported in 2009 [20] covering a wide span of age, 4 to 73 years. The post maturitation growth of both ear length and width continued in both sexes without break. However the ear length increase was found to be faster than its width. The adolescent growth pattern was much faster than during aging.

Four hundred and four males belonging to three European countries Germany, Italy and Lithunia ranging in age between 20 to 30 years were included in a study conducted by Gibelli et al. [21] Fourteen facial measurements including ear length and width were measured directly on the subjects. Similar to the earlier studies the ear length was found to register an increase while width remained stable. A similar study on the above populations containing 900 male subjects [22] conducted morphological and metrical assessment of facial features. Frequency of various types of features was calculated to identify the rarest of them which would help to build the biological profile thus helping in personal identification.

A preliminary study to test the uniqueness of ear pattern was conducted on 350 males and same number of female subjects in Central India. The twelve direct measurements taken on the ears were projected in a twelve dimensional feature space. The Euclidean distances were measured between subjects to test uniqueness.

Few cases which could not be distinguished by the 12 dimensional comparisons were subjected to direct superimposition to distinguish between them. None of the ears were found to be identical [23].

A study in Eastern India on a limited sample (varying from 79 to 114) was conducted by Chattopadhyay and Bhatia [24]. Measurements were taken directly on ear and also on images. Ear length-breadth index with observations on the shape of ear, its position with respect to head, ear lobe type were noted. While conducting a study on a large sample (2661 subjects) in Central India the author found that shape of ear features, eg., shapes of ear, lobule, tragus, upper helix and anti helical border around the concha are most variable even bilaterally in the same individual [25]. These features can be used as traits for 'identification' at a low scale. While comparing images of ear for identification in forensic cases, before proceeding for direct superimposition, one can visually compare the above ear shape characteristics to locate any variation. For example, if the lobule is triangular in the known subject and rectangular in 'questioned' subject, there may not be a requirement to proceed for further investigation on the 'questioned' subject (Figure 2). Moreover, these characteristics are related to different features of the ear, hence even if partial image is available as a 'questioned' ear the feature characteristics seen in the 'questioned' image can be compared to the known ear sample [26].

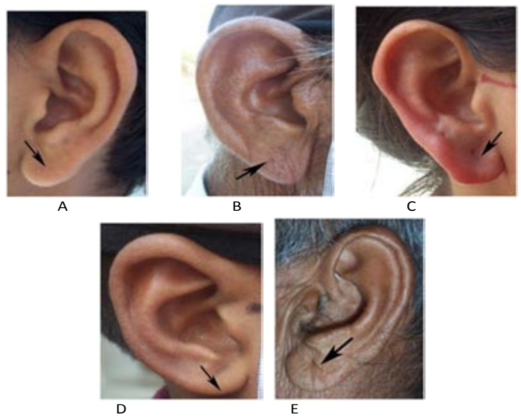

Figure 2: Shapes of Lobule. **A**. Tongue **B**. Triangular **C**. Rectangular **D**. Arched **E**. Round.

The identity of Veerappan, the notorious sandalwood smuggler in India who was killed by the Special Task Force in 2004 was at first established through the morphology of ear. While comparing the anatomical structure of Veerappan's external ear in ante-mortem and post mortem photographs the Forensic Scientist confirmed his identity on the basis of combination of various features. A large and squarish lobule with a flat tragus which is contiguous with the curved portion of the helix made Veerappan's ear 'unique', thus helping in his identification [27].

Individuality of external ear is also claimed by Verma et al. [28] in a study conducted in Northern India on 100 male subjects. Their opinion is based on varied results of nine anthropometric parameters measured on each ear.

The task of establishing identity of unknown cases become quite difficult for the investigating officer especially in cases of mass disaster, burn, drowning etc. where the face is severely disfigured. If the ears are left unharmed, in such cases the identity can be established using metric and morphological features of ear of the victim. Post mortem images of victim's ear can be compared with ante mortem photographs supplied by his family. Disaster Victim Identification team of Federal Police of Belgium has been working in this direction since 2003 using digital form of Iannarelli's scale [29].

Ear biometrics

Biometrics is an automatic method of identifying or verifying the identity of an individual based on the morphological and behavioural characteristics. An ideal biometric should be universal, unique, permanent and collectable [30,31]. Most of the studies are so far conducted by Computer Scientists. Few landmark studies in Ear Biometrics are discussed here.

The advantages of ear over facial images for the identification purpose were cited by Perpinan [32]. The variation in shape and size of ear features, reduced spatial resolution, more uniform distribution of colour and no effect of expression change on ear makes it a richer biometric tool than face. In his MS thesis he used Compression neural network of outer ear images for human recognition.

Three methods for ear identification were proposed by Lammi [33], by comparing ear images, obtaining ear print on glass and taking thermogram pictures. Various application scenarios of ear utilising its passive nature was also discussed by him, e.g. its use in Automated teller machine, at various security levels etc.

Graph matching based algorithm was introduced by Burge and Burger [34] for ear identification. A neighbourhood graph was built from Voronoi diagrams of the curves of ear. Thermogram imagery was proposed to circumvent the problem of ear images partially occluded by hair. Hair being the coolest as compared to other parts of ear could be segmented out from the image.

A method based on transformation of force field was proposed by Hurley et al. [35]. An image converted into force field consisted of peaks and ridges likened to energy wells and channels respectively. A source of force field was formed from Gaussian attractors representing the image. Location of potential energy wells and channels were based on the directional property of the force field. Matching was done on the basis of these wells and channels.

One of the most popular methods adopted in biometric studies is the Principal component analysis. A test was conducted by Victor et al. [36] to check the performance of ear in the recognition process. Changing various conditions, lighting, expression, time lapse between image acquisitions etc. the recognition property of the ear was tested. Though the results of experiments for face based recognition gave better performance than ear but their study proved the suitability of ear as a prospective tool for identification. Following the same method in a similar experiment Chang et al. [37] found similar performance of both ear and face in the recognition test. The performance significantly improved when both features face and ear were used together.

Another novel method, geometrical process of image extraction was adopted by Choras [38]. The contour containing the most distinctive information characterizing human ear images was selected. The geometrical features of contours were found to be more suitable for identification than colour or texture information which may not vary much between different ear images. Adopting a similar technique Shailaja [39] and Shailaja and Gupta [40] used two stage geometric approaches for ear recognition. The technique which was found to be scale and rotation invariant was based on finding the outer shape of ear using the canny edge detection algorithm. Detection of the maximum line in the image determined the accuracy of the method. As the images always may not be ideal an alternative suggested by the authors was to test the query and test images with different max-lines in different angles.

A comparison of two different techniques was undertaken by Moreno et al. [41]. The first was based on simple detection and analysis of facial features. The second used compression network classifier method. Variation in facial orientation and expression was studied on a data set of 168 images. Though 93% recognition accuracy was achieved it was concluded that combination of classifiers did not improve the identification rate in the study.

Haar wavelet transformation technique was used by Sana et al. [42] to decompose an image and derive coefficient matrices from it. Hamming distance approach was implemented to match test with trained images. The study using two data bases, 600 individual from North India and 350 individuals from Central India achieved 98% and 97% recognition accuracy respectively.

A method of detecting ear irrespective of its varying background was proposed by Ansari and Gupta [43]. Canny edge detector was used to extract edges from the whole image. Two ends of outer helix of external ear were extracted and joined to form a complete ear. The method used relative values of angles without extraction of template from the image. A claim was made of of localizing ears rotated in any direction in speedy and robust manner. 93% localisation accuracy was achieved on a sample of 700 images.

Soft biometrics

Soft biometric traits are those characteristics which provide some information about an individual but that information is not distinct enough to establish the identity of the person. Examples are ethnicity, skin colour, stature, tattoos, voice accent etc. [44]. The identity information contained in primary biometric traits like fingerprint, face, iris, and voice are complemented by soft biometric information. Methods of how soft biometric traits like gender, ethnicity, height etc. can be automatically extracted have been suggested by Jain et al. [45,46]. It was concluded from their study that use of additional soft biometric significantly improves the recognition performance of the fingerprint biometric system.

Taking a cue from the above research the author [25,26] proposed the attributes of external ear as soft biometric traits. The computation time of the system can be greatly reduced if ears are categorised into separate groups on the basis of sets of characteristics/features. This way, the software/programme would take much lesser time to compare the characteristics of the 'questioned' ear than comparing a 'questioned' ear with an uncategorised database of characteristics. From an anthropologist's point of view it was suggested that only those characteristics will be useful for categorisation which show high variability between individuals and are least affected by genetic relation. Though somatoscopic characteristics are not unique to any individual, the information about the variant characteristics if stored in the system with primary biometric data may improve the speed and search efficiency of the application software. For example, during the authentication of an individual with round ear lobule, the system will automatically restrict the search area to the subjects with this profile enrolled in the database (ignoring individuals with triangular, tongue, rectangular, or arched shaped lobule) thereby reducing the search area.

Limitations of the study

It is an established fact that various parts of external ear do exhibit changes with progression of age. This is due to reduced resilience and elasticity of skin, decreasing tensile strength of connective tissue and gravitation pull. The elongation of lobule contributes maximum to the overall increase of ear length, especially after 60 years of age [17]. Wearing heavy ear jewellery not only speeds up the elongation process of lobule but also hides part of ear anatomy.

Epilogue

The ear as an identification tool is slowly emerging from its infancy and it has shown encouraging progress so far - which is improving with time. But one primary aspect of external ear has remained largely unexplored till date. Though the question of its 'Uniqueness' had been raised repeatedly through the years little attention was paid to the issue. As such an inquiry following rigorous scientific scrutiny has not been undertaken but is necessary for admissibility as forensic evidence in the court of law. The court rulings [47,48] has motivated Scientists to undertake study to prove individuality of some of the age old accepted 'evidential traits' like fingerprint [49], documents [47] etc. Working on the same line it was felt necessary to undertake a similar exercise on external ear too. Two studies to test individuality of external ear were undertaken by the author [23,25] on samples of Central and Northern India. Such studies need to be repeated in more populations to prove the 'uniqueness' of external ear so that it can be admitted as evidence in the Court of Law.

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