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Could earprint identification be computerised? An illustrated proof of concept paper

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Abstract To date, the ear remains an under-utilised part of the human body for use in forensic practice. Although the ear has been used since the nineteenth century as part of the process of human identification, in this particular function its use, to date, remains low and in the case of earprints, controversial. A limited number of publications exist related to methods used for the purpose of ear image identification and the growing field of ear biometrics but to date, a computerised system for earprint identification does not exist. This paper illustrates the concept of a computerised earprint identification system. To assist those considering similar developments we share the concept problems and possible solutions we have identified and encountered to date, and highlight the advantages for such a system over traditional manual methods used for earprint identification.

Keywords Ear · Earprint · Computer · Biometric · Centroids

Introduction

The ear is an under-utilised resource in forensic investigations. It can be used to assist in identifying how someone died by the examination of the pathology present in the external, middle and internal parts [1]. It can also be of assistance in estimating when they died by use of temperatures recorded from the external auditory canal [2]. Finally, by the analysis of ear images or prints, be they from the living or dead, or through anthropological or radiological examination of skeletal components of the ear, one can use the morphological features of the anatomical structures of the ear to assist in the identification of an individual [3–7]. Even otoacoustic emissions have been considered as a means of identifying individuals (http://www.dolphin.soton.ac.uk/Feb2003/clickingear.html).

The ear has been used for human identification since the late 19th century when Alphonse Bertillon devised a manual system of identifying individuals using 11 anthropometric body measurements; the ear was one of the components of this system (http://www.forensic-evidence.com/site/ID/ID_bertillion.html). With the advent of fingerprinting in the early twentieth century, the use of the ear dwindled into almost insignificance until interest in the use of ear was rekindled by the work of Iannarelli who is recognised in developing the first photograph-based biometric system for ear image analysis [8]. This manual method has been recently revisited by several authors researching machine vision biometric systems for ear identification [9, 10] (http://www.it.lut.fi/kurssit/03-04/010970000/seminars/Lammi.pdf).

The use of earprints for criminal identification is a relatively modern concept which has received increased interest in the last ten years. It is reported that earprints may be found at up to 15% of crime scenes, the prints being left behind as a result of the criminal pressing their ear onto a window or door in order to detect if someone was inside the property (http://www.cordis.lu/growth/calls/top-4.18.htm). Known as "earology," earprints may be detected and lifted in a similar manner to that of fingerprints but to date there is no agreed published peer-reviewed manual or computerised method for earprint analysis. To date earprints are compared by manual method on a one-to-one basis with a suspect's print, thus introducing operator-selectivity and bias. Although they have been claimed to be as unique as a fingerprint, this remains unproved to date.

Competing interests GN Rutty and Ali Abbas declare that they have no competing financial interests. D Crossling is the owner of Patent WO 97/28513 (D Crossing. Imprint Identification System) and a member of the development team for the Treadmark Analytical System

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Unfortunately, the use of earprint-based evidence in court has been plagued with controversy and criticism as illustrated in a recent case where DNA retrieved from the site of an earprint did not match that of the person originally identified as leaving the print (http://www.forensic-evidence.com/site/ID/DNAdisputesEarlID.html).

Although Champod et al. [4] have presented their initial results in relation to an automated feature extraction algorithm in an attempt to produce a structured database of earprints, we present, to our knowledge (based on the failure to identify any other peer-reviewed publication on the same subject or a commercially available system), the first illustrated concept paper considering whether earprint identification could be computerised based on the undergraduate thesis of Abbas [11–14]. We illustrate the concept of image acquisition, preprocessing, alignment and normalization, recognition and verification as applied to computerised earprint identification. This paper does not attempt to present a functional computerised system for earprint identification and thus does not contain system performance data used for testing methodology developed in the biometric world; rather it restrains itself to the illustration of the concept (http://www.cesg.gov.uk/site/ast/index.cfm?menuSelected=4&displayPage=4). It identifies problems encountered in the assessment of the research model system which may assist others who may be presently working on similar systems in other areas of the world and discusses possible ways forward for future research and development in the field.

Illustration of concept

The following sections illustrate the components of the concept system, i.e. image acquisition, preprocessing, alignment and normalization, recognition and verification as well as highlighting problems that were identified during the investigation of the concept (http://www.it.lut.fi/kurssit/03-04/010970000/seminars/Lammi.pdf).

Literature review

We started with a review of electronic, international library-based medical (including forensic) literature databases and Internet search using Google.com for previously peer-reviewed published methods of identification of individuals from their ear images and prints to identify any published method that we could consider to apply to a computerised earprint system. In the case of ear images this identified a small number of both manual methods and machine vision systems (http://www.it.lut.fi/kurssit/03-04/010970000/seminars/Lammi.pdf) [8–10, 15–17]. Although earprints have been used as evidence in court we could identify no peer-reviewed standardised published method for earprint identification. This was confirmed by enquiry with the local police fingerprint bureaux. Since the completion of the work presented in this paper the FearID group have now published the results of their exploratory study on earprints which contains reference to two unpublished methods of earprint examination using computer software [5]. In addition to this, we undertook a review of published congenital and acquired abnormalities, anatomical variations, surgical procedures, genetics and anthropological publications related to the ear which we considered essential to establish a base line for ear variation for ethnic groups, gender and age of individuals which in turn can affect the characteristics of the earprint.

Volunteers for study

Having undertaken this review, local medical ethical committee permission was granted to seek volunteers from the university, hospital and community populations of Leicester, United Kingdom to have both of their ears printed for this concept study. Only adults were recruited.

For an earprint to function as a biometric it should have *universal* characteristics that all individuals possess, yet the characteristic should be *unique*, i.e. no two individuals share the same characteristic which, in the case of earprints, is theorised but unproven. The characteristic should also be *permanent*. Although the ear reaches 94% of its adult width by the age of one year and is virtually fully formed by age 13 in females and 14 in males, it continues to increase in size throughout life due to the affect of gravity and alteration in intracellular tissue and loss of elastin. Thus it is not *permanent*. This mainly affects the lobe and can result in an increase in ear length of 11 mm in males and 13 mm in females by the age of 80 years [18, 19]. To date there are no published prospective longitudinal studies considering the affect on earprints of ear lengthening through adult life. Such studies are required to consider the affect that this growth will have on the recognition stage of a computerised earprint system.

A total of 400 adults volunteered for the study of which 236 were females and 164 were males. The volunteers represented a cross section of the local population with 299 white, 8 black, 58 Asian and 30 mixed ethnic backgrounds. The prints of both ears from each volunteer were taken resulting in 800 images within the database, i.e. 400 right earprints and 400 left earprints.

Image acquisition

The biometric image must be *collectable* which in the case of a suspect earprint is an *invasive* process, requiring the assistance of the individual.

Both ears of each volunteer were printed by one researcher (A.A.) in an attempt to standardise print acquisition. A thin sheet of plastic designed for capturing prints (cobex) (K9 Crime Scene Investigation Ltd, Northampton, UK) was marked with a unique number, placed in the palm of the investigators hand and pressed onto the volunteer's right ear. Uniform pressure was applied in a single upward motion that began by pressing the piece of cobex onto the lobe and ended with printing the helix of the ear. This method of print acquisition was selected following consultation with the local police force that uses this method for the acquisition of earprints from suspects of crime. A single print was taken from each ear using single pressure. The same process was repeated for the left ear. Each cobex sheet was then dusted in the laboratory with aluminium fingerprinting powder to reveal a print. This was fixed using lifting tape, in order to prevent the print from being damaged or altered.

Only one print was taken from each ear with sufficient force to ensure that, in 92% of all images, a complete print was achieved. Although it was considered that at least three prints should have been taken from both ears of all volunteers, i.e. at three different pressures as previously reported by some investigators, this study is not designed to assess the affect of pressure upon an earprint but purely the concept of whether earprint analysis could be computerised. Hence, to try and keep the model as consistent as possible, only a single print was taken by the same researcher in each case.

Preprocessing, alignment and normalisation

As for fingerprints, earprints have to be scanned into the system. To date, earprints do not have a scale on the cobex to assist *preprocessing* and *normalisation*. Thus to achieve this stage all prints should be scanned within a defined target window at the same resolution. To achieve *alignment*, i.e. all images are scanned in the same axis, the scanner could use a marked grid similar to that of the polar axis described by Maat [20]. However, the software used for our study did not require the consideration of alignment (see below). For the concept model each print was scanned (Colour Scanner Epson Perfection 1240U, Epson UK) at a resolution of 9,600×9,600 dpi with no modification of the original print size and saved as a TIFF file.

For commercial development scanning must be undertaken in a controlled environment using a specified scanner to eliminate artefacts from shadowing and lighting variations. This was not tested for in this concept paper, although we illustrate the ability to scan an earprint into the system. The images were scanned at maximum resolution and saved in uncompressed file format. It remains untested whether this was necessary and a standardised resolution and file format would have to be developed.

Computer software

To enable earprint analysis to be computerised one requires a software package that will store the images in a searchable database and contain an automated programme to allow *recognition* and *verification*.

To date the most significant developments in computerised ear identification are within the field of machine vision ear biometrics which apply to ear images, not prints. Within this field a number of different methods have been explored including principle component analysis (PCA), force field transformations and the use of Voronoi diagram of its curve segments [9, 10, 16, 17] (http://www.it.lut.fi/kurssit/03-04/010970000/seminars/Lammi.pdf). It is proposed that these applications could be investigated for automated earprint analysis. Thermograms have been explored to try and overcome the problems of occlusion of the ear by hair although this is not an option for earprints (http://www.it.lut.fi/kurssit/03-04/010970000/seminars/Lammi.pdf). At the time this work was undertaken, the only published work related to computerised earprint analysis was that of Champod et al. [4]. Subsequent to the completion of the work the FearID group have published their exploratory study results within which there is reference to an unpublished computer system which calculates "centroids" for earprint analysis and an illustration of digitised computer superimposition [5]. The use of centroids, as explained below, may assist in the automation of earprint recognition.

For this concept project we decided to apply a computerised photo comparison system with a manual point (*tag*) location system. As no commercial software is available to date for the purpose of earprint analysis, we used a version of the software package "Treadmark" (Version 1.0, K9 Crime Scene Investigation Ltd, UK). The Treadmark analytical system is designed for shoe mark comparison [21]. *Tags* are allocated to the random damage characteristics generated on the shoe outsole by use in hostile environments, for example damage caused by walking over broken glass at a point of entry to a crime scene. This method of mapping the random damage characteristics is totally independent of the presence of a tread pattern or moulded pattern components on the shoe outsole. The (tags) can be applied to visible damage characteristics on a scanned photograph of the suspect mark. The scanner is calibrated to ensure dimensional accuracy of scanned image. Each *tag* has an *XY* coordinate where 00 is the top left corner of the VDU screen. To remove the problem of *alignment* the software measures the most direct line between each *tag XY* co-ordinate and all other *tags* allocated to the image. This method generates a matrix of dimensionally stable polygons, which will always be the same no matter how the image is aligned on the screen. The image and measurement data from each triangle generated within the matrix is stored in a relational database, which is used to search against comparison images.

Recognition

For any machine vision system to work it must have a database of *known* individuals to search the *suspect* mark against. Thus the next stage was to create a database of *known* from the 800 ear images. Once scanned, each image was imported into the software for allocation of tags to be used in the *recognition* and *verification* stages. The system allowed us to allocate a unique code to each image, enter demographic details (gender, age, ethnic origin, body height), specify whether it was a right or left earprint and enter free text if required. All of these can be used as search parameters. The Treadmark system then allowed us to allocate up to 20 tags to an image. However, there are no published methods for earprints to assist us in the choice for the anatomical sites of where to allocate the tags. Thus we progressed through a series of stages of development to standardised anatomical tag allocation:

Stage 1 We took the first 10 volunteer prints (20 prints—10 left, 10 right) and randomly applied tags to each image, both by anatomical site and order of application of each tag to the image. We stored all 20 images with allocated tags into a new database—these became the *known* prints. To test the principal of *recognition* we used a simple model. One of the same 20 images was randomly selected and imported into the software as a new *suspect* print. It was again randomly allocated tags and then this image was searched against the *known* database. During this phase we also tried to apply tags to the same anatomical points on the prints without the use of a localising system, i.e. a means to locate the same anatomical site on each print. The test runs were then repeated as before.

The system failed to match the *suspect* image to its corresponding database image by both methods. By repeating this stage we verified other authors observations that, for this particular method, the anatomical positioning of the tags and the order that the tags were allocated (software dependent) renders the recognition stage inaccurate as all measurements are relative to the origin which if not exactly localised will result in all subsequent measurements been incorrect [8, 9]. Thus if similar systems are developed they must overcome anatomical tag localizing problems.

Stage 2 We considered using the system of Iannarelli to localise the points on the image. However, this cannot be done. The original method of Iannarelli centres the grid on a point "where the start of the inner helix rim overlaps the upper choncha flesh line, just below the slight depression or hollow called the triangular fossa...", a point which cannot be seen or located on an earprint [9].

Stage 3 As the original version of the software (Version 1.0) had no internal application to assist us we decided to

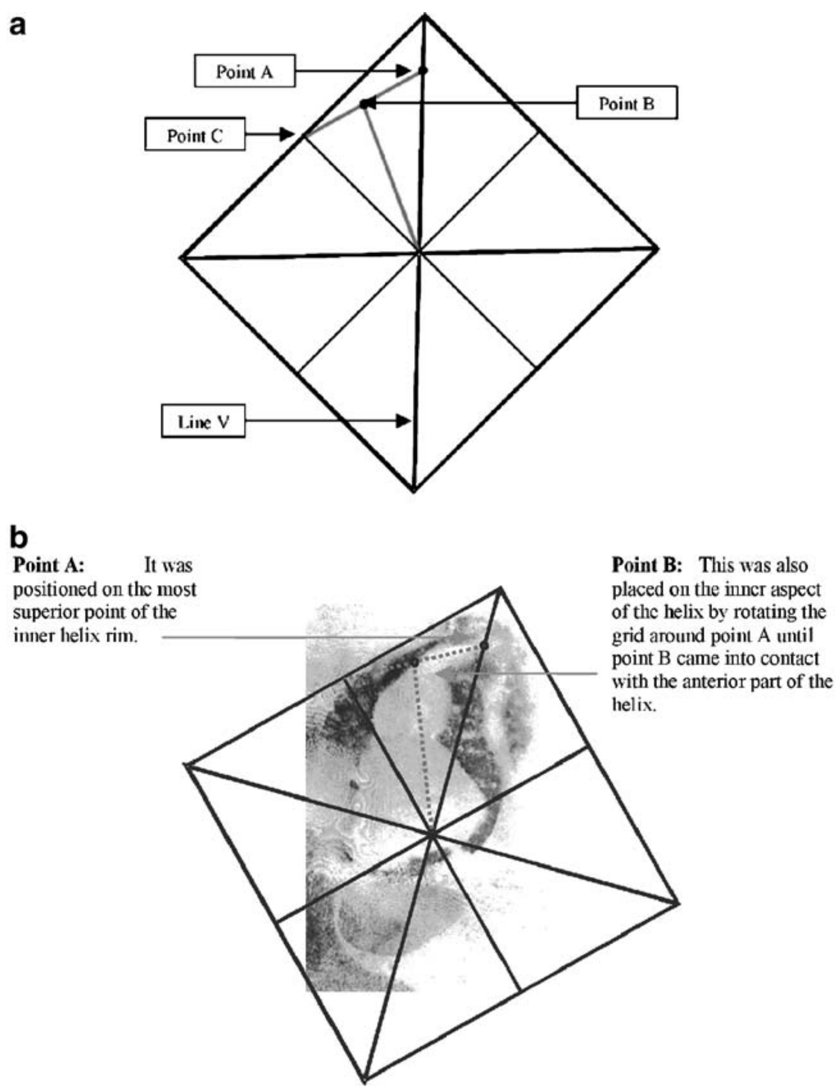


Fig. 1 **a** The grid used for the investigation of the concept. **b** The grid applied to an earprint

develop a grid system using two anatomical landmarks to standardise the localisation of the tags. First we identified the parts of the earprint that were most likely to be present in each print and from this identify two landmarks. After analysing all 800 prints we identified that the anterior and superior aspects of the helix were almost always present (92% of images). We then took a rectangular grid and rotated it so that one of the diagonal lines became the new vertical line (line V) (Fig. 1a). A line was then drawn to connect point A and point C and a second line drawn from the centre of the grid to intersect the middle of line AC (point B). Points A and B were then used to localise the grid onto each earprint (Fig. 1b).

The final grid measured 7.6×7.6 cm (3×3 in.), was drawn on paper, photocopied onto acetate and the acetate applied directly to the computer monitor screen. Each image was analysed by the same operator (A.A.) who, as a component of the development and use of a biometric system, underwent a period of *training* with the use and positioning of the grid [22]. Initially the landmarks of the outer edge of

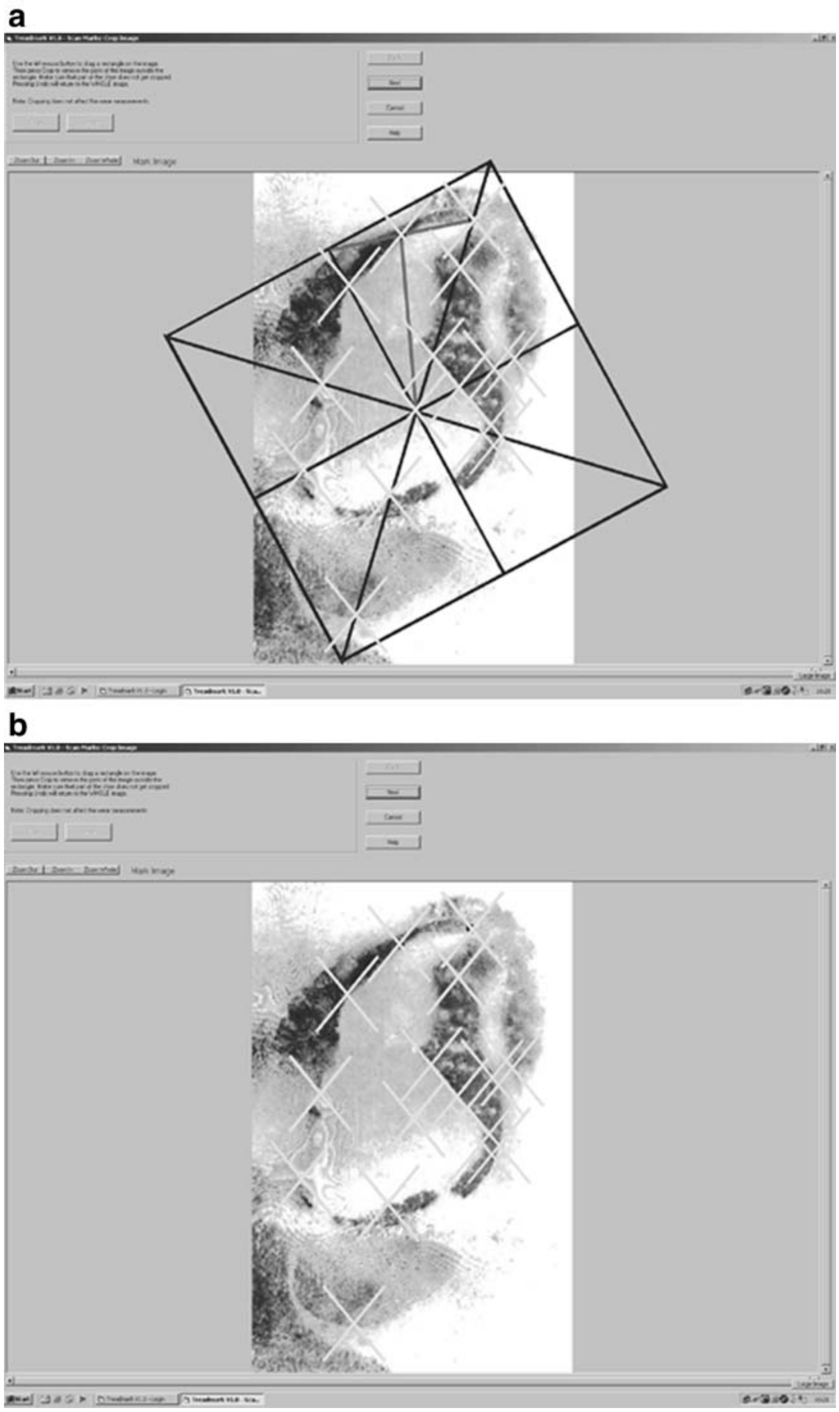


Fig. 2 **a** Using the grid, tags are allocated to the anatomical sites where the grid lines intersected the print. **b** The final *known* image with allocated tags is stored in the database

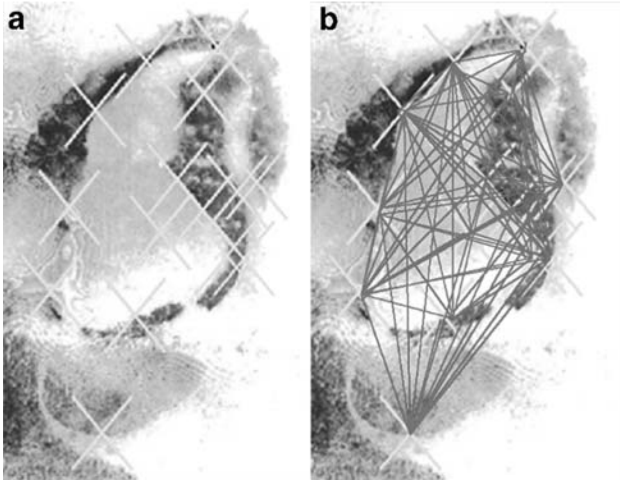


Fig. 3 **a** An example earprint with allocated tags. **b** A dimensionally stable polygon matrix is produced by the computer by linking and measuring the distance between each tag relative to each other

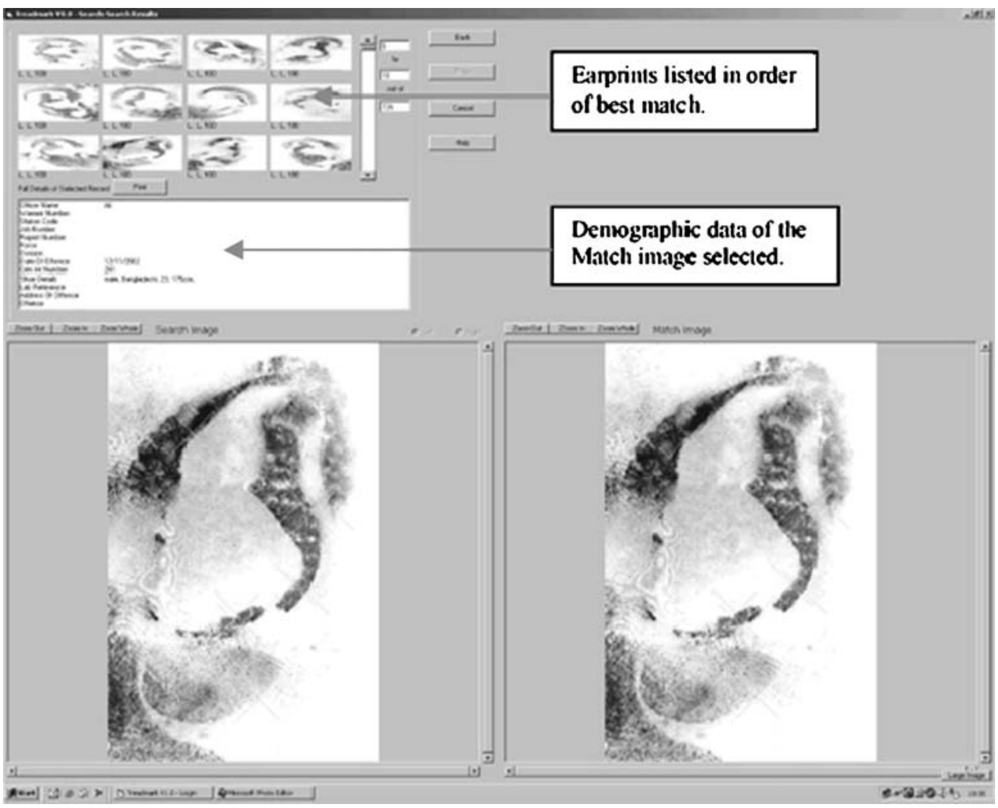
the helix were used to localise the grid, but it was found that this part of the print was often unclear. This was because it may be covered by the individual's hair or the upper portion of the helix was thicker than in real life due to the skin of the side of the head above the ear being printed or due to the affect of pressure on the upper helix during printing. Through experimentation the landmarks on the inner rim of the helix where finally used to localise the grid as it was less prone to printing variation distortion.

Tags were allocated to each print at the sites of intersection of the grid lines with the anatomical structures of the earprint before the image was stored as a *known* into the database (Fig. 2). The software then calculated the polygon matrix based on these points (Fig. 3). A problem that was encountered was that with some prints more than 20 points were required to mark all the points of intersection. It was therefore decided to limit the number of points allocated to the helix to a maximum of four on the inner aspect of the helix and four on the outer aspect of the antihelix. This applied to both whole and partial prints.

Stage 4 Once the *known* database had been created, *recognition* test searches were undertaken. For whole prints, random *suspect* images were imported, tags allocated (as stage 3) and then the image searched against the *known* database (as stage 1). This was done by image alone and by using combinations of demographic details, for example a search for a right ear print of a white male aged 20–25 with a height of 160–165 cm.

A commercial system must be able to use both whole and partial prints. In the case of the latter we found the part of the ear most likely not to print was the lobe, either due to unequal pressure during the process of printing or due to the presence of jewellery lifting that part of the ear of the printable surface. To investigate the concept of whether a partial *suspect* print could be searched against a whole *known* print, whole test *suspect* prints had tags allocated to the upper helix only, i.e. no lobe tags and searches run against the whole *known* database.

Fig. 4 The completed search. The *upper left window* displays the matched thumbnail by increments of 1% probability match. The *suspect* print (*bottom left*) is verified as a match with the *known* print (*bottom right*). The demographic details of the *known* and hence the *suspect* are shown in the *middle left window* (Treadmark version 1.0)



Verification

The system must be able to display any *matches* (where the computer considers that the *suspect* and *known* images could be the same), calculate the probability of the match, allow the operator to compare the matched *suspect* and *known* prints, store or print the match, and for court purpose, be capable of recording and printing a chain of custody (*audit trail*) for the entire process, from image entry to match printing.

In the case of this concept study a simple *verification* protocol was utilised. It did not involve, as stated previously, performance data testing but rather the simplified question of whether or not the system and method employed could match the *suspect* print to the *known* within the database. The particular version of the software used (Treadmark Version 1.0) ran each search and then displayed the result as a series of thumbnail images, each image ranked from 0 to 100% probability match (in 1% increments). Multiple *known* images where found to be assigned the same percentage match, for example on one search 96 *known* images were assigned a 100% match to the *suspect* print. Despite this obvious drawback the *known* match was always identified in the 100% category. By reviewing the thumbnails of the suggested matches the operator was able to identify the matched thumbnail, expand the image in a comparison window to *verify* the match and then print of the final paired images (Fig. 4).

During the time taken to investigate this concept the Treadmark software was modified for shoe mark analysis through user trials. These developments, although specific for shoe mark analysis, illustrate features that could be utilized in computer earprint systems. The software now allows for *suspect* and *known* image superimposition, zoom, brightness, contrast and sharpness controls as well as comparison of all plotted characteristics, polygons, matching characteristics, matching polygons and source/demographic information.

Discussion

For the first time to our knowledge this paper illustrates the concept of computerisation of earprint identification. The development of such a system for earprint identification has many advantages over traditional manual methods. Earprints could be printed at a scene of crime, ultimately scanned at the scene and then sent for immediate analysis anywhere in the world either at a central identification server or shared between multiple agencies. Thus the time between collection of the print and analysis becomes that of the time that it takes for the image to be collected, electronically sent, received and processed by the operator. As databases of earprints become electronic, it allows for standardised data storage, faster retrieval and analysis. As large numbers of prints belonging to known individuals are stored within databases, the potential for operator bias is removed as a suspect print is searched against all stored prints rather than the present system of comparing a scene print to a single suspect. Finally, the manner in which the analysis is undertaken becomes automated and standardised.

We have illustrated the principles that must be employed for the development of such a system, i.e. image acquisition, preprocessing, alignment and normalisation, recognition and verification. We acknowledge that the concept system illustrated has not been subjected to the rigours of performance data testing required for commercial development and that some of the stages presented use simplistic concept testing methodology which where subject to operator induced inaccuracies. The concept system has also not investigated alterations of print morphology caused for example by the ear moving on the printable surface, pressure differences, age related changes, blurred or overlapping prints. All of these require investigation during the development of such a system. However, despite these admissions, the concept illustrated, which is the point of this paper, was shown to work. Any system developed must meet requirements for *performance* and *accuracy.* Although these remain untested the system has reduced the time taken to normally manually search a database of 800 earprints to finding a match between a *suspect* and *known* image to a matter of a few minutes.

As part of the illustration of the concept we have highlighted areas that are required to be researched and overcome in the development of a suitable system. First, for this particular system, the issues of alignment have been overcome by use of the dimensionally stable polygon matrix. The second common problem relates to the affect of pressure distortion on the print and thus the localisation of the tags, if a tag-based system is opted for rather than for example other ear image-related biometric systems which to date have not been investigated in relation to earprints. The effect of pressure could be overcome by the use of centroids, which have been investigated for other irregular pressure-dependent print marks, for example barefoot impressions [23–25]. To index the irregular or diffuse shapes within an impression mark one can determine the theoretical centre of each of the shapes—the centroid or optical centre. This can be done by auto tracing the contrast boundary of the shape and determining the number of pixels contained within that area. A Boolean equation is then applied under the following conditions:

- Draw an ellipse with an aspect ratio of L1 to W1 containing the same number of pixels as the irregular area, which has been auto traced.
- Centralise the drawn ellipse with the major axis aligned with the longest dimension of the irregular area. The major and minor axes of an ellipse intersect at right angles and this point will form the theoretical centre of origin of the irregular area.

This procedure, which can be automated, is undertaken for each component shape to generate a series of centroids

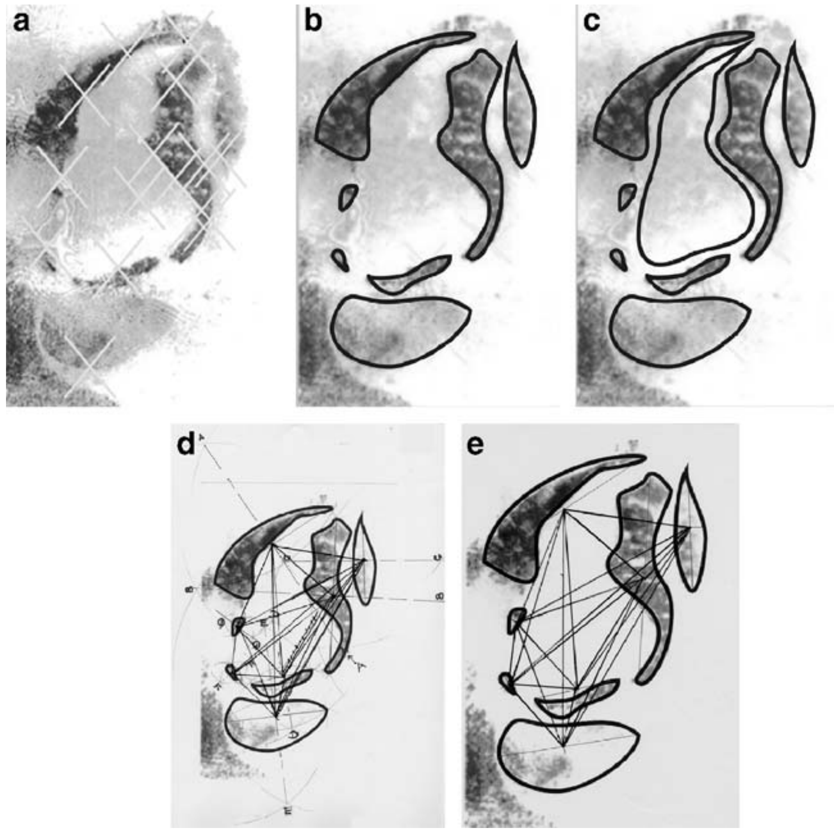


Fig. 5 A theoretical example of how the use of centroids could assist in the localisation of tags to the print using the concept model. **a** An example earprint. **b** The irregular distinct areas of the print are auto traced. **c** The central none-printed component of the print can also be auto traced to produce a reference tag. **d** The centroids of each auto traced area are identified and the polygon matrix is applied using the centroid generated reference tags. **e** The simplified alternative to centroids with the polygon matrix applied to the reference tags generated by this method

which can be considered equivalent to using manual tags. The software will then draw the polygon matrix using these centroids to provide a numerical description of the print (Fig. 5). This data can then be used to compare the special relationships between theoretical centres of origins for different images. A simplified alternative to the use of centroids could also be considered. In this method a line is drawn between opposing points on the longest dimension of each irregular contact area. This line is bisected, producing a reference point. The procedure is repeated for each contact area within the earprint. The resulting reference points are then linked generating a series of measurable polygons, which can then be databased. This would describe in numerical form the total contact area of the ear impression and, assuming that the contact areas increase uniformly with increase in pressure, could overcome the effect of pressure.

The last common problem to be addressed is that of growth of the ear during life. To achieve this further research is required. It is necessary to take a number of earprint impressions from a cohort of individuals from each gender and different ethnic diversity over a set time period. From these impressions the centroids of the contact areas can be determined on each occasion and when sufficient data is accumulated it can be applied to a scatter graph in order to determine the statistical mean value (growth/time). This can then be applied as a compensation factor to developed computer software.

Conclusions

This concept paper illustrates the potential for the development of a computerised earprint identification system. It does not attempt to answer every unknown in the development of such a system or to provide a fully functional commercial system but rather, for the first time to our knowledge, illustrate a proof of concept paper and the problems that were experienced in the investigation of such a system. It illustrates a number of new methods of earprint analysis which could be considered and developed as a way forward for standardising manual earprint identification and outlines areas of development to overcome problems with the system used for the investigation of the concept in relation to alignment, tag localisation, pressure distortion and aging affects on the ear.

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