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Skull Identification in Forensic Science- A Literature Review

C. Kamali[1*], D. Murugan[2]

[1, 2]Dept. of Computer Science and Engineering, Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli-627012, Tamailnadu, India

Corresponding Author: kamalichidambaram@rediffmail.com

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Abstract— Human identification is one of the most noticeable disciplines in forensic medicine. To the area of Forensic Anthropology, identification task is performed by reviewing the skeletal remains. Over the past few decades, anthropologists have paid their attention on improving those techniques that allow a more precise identification. Hence, Forensic Identification has become a very active research area & Skull identification has been emerging as a vital field in this discipline. Skull Identification is drawing wide attention and been applied in huge number of forensic domains, ranging from the identification of victims of the Indian Ocean tsunami, Uttarakhand disaster to the recognition of terrorists. At present skull identification research points mainly on two categories. One is craniofacial superimposition and other is craniofacial reconstruction. In Craniofacial superimposition a photograph of a missing person is compared with a skull found to determine its identity. On the other hand, craniofacial reconstruction is concerned about getting a visual outlook of an individual where only skull and bone are remaining. These research topics are reviewed in this article.

Keywords-Craniofacial Superimposition, Skull Outlay, 3 D Modeling, Craniofacial Reconstruction

I. INTRODUCTION

Biometrics allows a person to be authenticated based on a set of recognizable and verifiable information, which are unique and specific to them. *Biometric* authentication is defined as the process of comparing data for the person's characteristics to that person's *biometric* "template" in order to determine resemblance. Fingerprints, retinas, irises etc forms the special attributes or data for the biometric authentication.

Skull based Human Recognition heads into an advanced research topic in Biometric. For the convenience of users, a skull recognition system is suitable rather than a traditional personal password or an ID card [1]. Skull identification for a victim has been researched for over a century. Unlike other biological features such as DNA, fingerprinting etc., skull data for a living person still cannot be acquired in a convenient and non-intrusive way. Thus, skull identification cannot be realized in the same way as used by other biological feature identification technology, i.e., matching an unknown skull with a large set of skull database [2].

With the development of digitization technologies such as CT, MRI, 3D scanners etc., data acquisition becomes easier and human identification by skulls has been an interdisciplinary research focus of informatics, anthropology, forensic sciences, and so on. In this research area, for the identity recognition or identification with the help of computers, one of the methods is to choose some symbol features based on the 2-D skull image; the second is to reconstruct 3-D or 2-D face image from the skull utilizing certain methods and technology

Current skull identification research focuses mainly on two categories one is craniofacial superimposition [3], [4], and the other is craniofacial reconstruction [5], [6].

A. CRANIOFACIAL SUPERIMPOSITION

Craniofacial superimposition (CFS) is a forensic technique to identify a missing person from a skull and ante-mortem images [7]. It involves checking whether a skull might belong to the person shown in a photo, which is carried out by superimposing the skull on the image reproducing the pose of the face. The anatomical and morphological correspondence between a skull and a face is studied in the CFS technique. It involves an overlaying process with a variable number of facial images with the skull.

This technique has great potential since nowadays the majority of the people have photographs where their faces are clearly visible. In addition, the skull is a bone that hardly degrades under the effect of fire, humidity, temperature changes, etc. [7]. This process is guided by a number of anthropometrical landmarks located in both the skull and the photograph of the missing person. The selected landmarks are located in the areas where the thickness is low for soft tissue. The goal is to facilitate their location when the anthropologist must deal with changes in age, BMI, and facial expressions. The typically used skull landmarks are shown in Figure1 and commonly used face landmarks are shown in Figure 2.

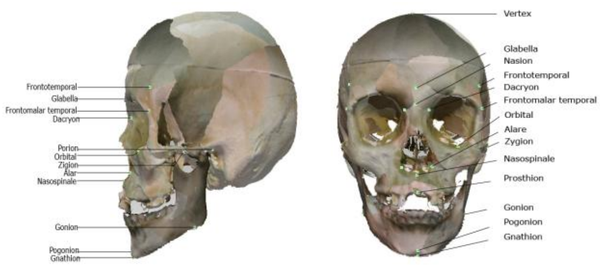

Figure 1. From left to right, principal craniometric landmarks: lateral and frontal views [1]

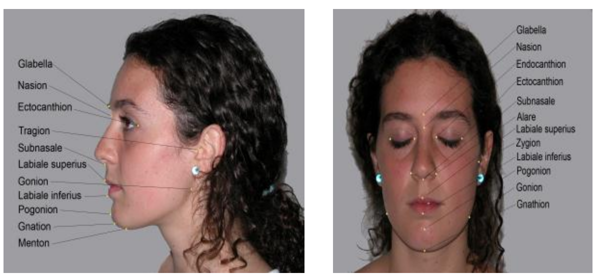

Figure2. From left to right, principal facial landmarks: lateral and frontal views [1]

Craniofacial superimposition development has passed through three technological phases: photographic, video and computer-assisted. The photographic technique was started in the 1930s, the video technique was developed in the 1970s and the computer assisted technique was introduced in the 1980s [4, 7, 8, 9].

The whole CFS process can be divided into three consecutive stages [10]: 1) The acquisition and processing of the resources, i.e., skull and ante-mortem (AM) facial images, and somatometric landmarks location on both; 2) skull-face overlay (SFO), that deals with accomplishing the best availablei superimposition of the skull and a single AM photograph of a missing person. This procedure is repeatedly executed for each photograph, thus obtaining different overlays; and 3) decision making, which aims to determine the degree of support for a match based on the SFOs achieved in the previous step. The final decision is managed by different gauge based on the anatomical relationship between the face and the skull. These criteria can vary depending on the region and the pose [11].

Face Enhancement and Skull modelling

The first CFS stage involves achieving a digital model of the skull and enhancing the face image. The subject of the identification process, i.e. the skull, is a 3D object. Hence, the use of a skull 3D model instead of a skull 2D image should be preferred because it is definitively a more accurate representation that avoids the usual distortions of 2D cameras.

The face image is typically a photograph which was acquired under some conditions that are fixed and usually unknown at the moment of the forensic analysis. The quality of a digital image can be enhanced. If the photograph is not in digital format, it can be scanned and transformed into a 2D digital image. Then, it can be enriched using digital image filters and/or processing algorithms. However, the skull is an available physical object and its model needs to be obtained to competent an automatic procedure.

Regarding the model of the skull, recent techniques for CFS need an accurate 3D model. In the biomedical field computed tomography scanning images are the beginning data to reconstruct the skull. Laser range scanners are used nowadays in many forensic labs to acquire the 3 D view of the skull. Laser range scanners are based on the optical principle of triangulation and acquire a dense set of three-dimensional point data in a very rapid, non-contact way. Every 3D view of the skull obtained by the laser range scanner must be preprocessed. This task involves the cleaning (to remove those artifacts that were acquired by the scanner as part of the scene but which do not correspond to the skull), smoothing (removal of some artificial vertices that could have been wrongly included by the scanner on the borders of the surface be- cause of a perspective distortion)., and filling (to avoid small holes to appear in those parts of the skull that are not correctly scanned because they are too dark for the scanner capabilities or because they are located in shadow regions)of the view.

Skull-face overlay

The skull-face overlay consists of searching for the best overlay of either the 2 D images of the skull and face or the 3 D model of the skull and the 2 D image of the face achieved during the first stage. This is usually done by bringing to match some corresponding anthropometrical landmarks on the skull and the face.

The success of the superimposition technique requires placing the skull in the same pose of the face as seen in the given photograph. The orientation process is a very challenging and time-consuming part of the CFS technique. Most of the existing CFS methods are guided by a number of landmarks of the skull and the face. Once these landmarks are accessible, the skull- face overlay procedure is depends on searching for the skull orientation leading to the best matching of the set of landmarks.

Decision making

Depends on the skull-face overlay achieved, the identification decision is made by either judging the matching between the corresponding landmarks in the skull and in the face, or by analysing the respective profiles. The straightforward approach would involve measuring the distances between every pair of landmarks in the face and in the skull. In this case, errors are prone to be accumulated during the process of calibrating the size of the images. Instead, studies based on proportions among landmarks are preferred. Geometric figures like triangles or squares are good choices. It is also mandatory to consider as many landmarks as possible and different proportions among them.

The superimposition is usually performed manually by forensic anthropologists and needs special utilities and professional qualifications. Thus, the procedure of the identification is time-consuming and easily influenced by the subjectivity of the practitioners. Recently, a few automatic skull-face overlay (SFO) methods have been proposed. For example, Ballerini et al [12] used a genetic algorithm to find the optimal transformation to match the landmarks on the 3D skull model and the face photo. Ibanez et al [13] used fuzzy logic to solve the uncertainty involved in the location of the cephalometric landmarks. Automatic methods need no tedious manual operation and can be easily reproduced. However, nevertheless of whether the method is automatic or non-automatic, it is toilsome to fit a 2D image (the face photo) onto a 3D object (the skull). The reason is that the skull and face are two objects of different natures [p7-16], which cause some inherent uncertainty in the matching. Moreover, accurate localization of craniofacial landmarks has been a longstanding problem in the field, and the uncertainty introduced by landmark localization also affects the matching.

B. CRANIOFACIAL RECONSTRUCTION

Craniofacial reconstruction focuses to estimate an individual’s face appearance from its skull using the relationship between soft tissues and the underlying bone structure. It can provide a clue and trigger recognition by the victim’s relatives, so that further identification evidence can be collected on a restricted list of candidates. The word "craniofacial" is a union of "cranium," which is the medical word for the upper portion of the skull, and facial.

The traditional facial reconstruction methods are based on manual procedures, producing 2D portraits or 3D sculptures. These methods basically consist of three common steps: (1) equip (a replica of) the raw skull with a sparse set of anatomical landmarks; (2) apply an average soft tissue thickness to each skull landmark in order to estimate a corresponding landmark on the face; (3) draw up or sculpt a face fitting the estimated landmarks [14]. Most practitioners add a face muscle model in order to enrich the anatomical accuracy of the reconstruction

The results obtained from forensic art are often quite plausible, as the medical artists may take anatomical, historical, archaeological or other types of expertise into account, giving the observer a feeling of coherence. However, the final result of a manual reconstruction depends on the subjectivity of the artist. Additionally, one single reconstruction requires several days of work of a well experienced forensic artist, making impracticable the realization of multiple instances and feature variations.

During the last few years, a large amount of work has been devoted to the conception of objective fully automated methods. In the common pipeline of modern facial reconstruction software, first, an expert examines the unknown skull in order to determine anthropological parameters like age, gender and ethnicity. Then, a virtual replica of the dry skull is produced and represented according to the modelling parameters. A craniofacial template encoding face, skull and soft tissue information are derived from a head database. Then, an admissible geometric transformation drives the adaptation of the craniofacial template onto the unknown skull, according to the “proximity” between the skulls. As a result, the template face is deformed onto the predicted face associated with the unknown skull, linking together information coming from both the database and the examination of the unknown skull. Finally, a skin texture and hairiness are added to the reconstructed face [15].

The dominant methods in CFR (Craniofacial reconstruction) construct facial surface from the soft tissue thickness measured at a set of skull landmarks. The quantity and position of the landmarks are very essential for craniofacial reconstruction. The soft tissue thickness measured on skull is the base for craniofacial reconstruction. To get complete tissue thickness, the head samples are usually measured by different equipments such as Computerized Tomography (CT), Magnetic Resonance Imaging (MRI) and ultrasound scanner.

Most computer-aid craniofacial reconstruction methods fit a selected face related template to the target skull according to the average thickness of soft tissue at the skull landmarks [16-20]. Others deform a reference skull to match the remaining part of skull according to the features of skull such as anthropologic points [21], lines [22], and other features [23]. Applying an extrapolation of the skull deformation to the face template, the reconstructed face will be attained. The selection of the template or reference is vital for a precise craniofacial reconstruction. In general, a generic or a specific craniofacial template with matching shape attributes is chosen. But it is difficult to get suitable reference for every dry skull because of the diversity of skull and face modality. In addition, as the complex deformation between the reference and the target skull, the warping methods must intensively be studied to get the most accurate reconstruction result.

So many deformation methods are proposed to model the non-rigid shape deformation of skull and face, such as radial basis functions (RBF) [24], [25], a thin plate spline (TPS)-based deformation [26], [27] for its smoothness.

The craniofacial reconstruction is to figure out the face of skull which is unknown by the knowledge of skull and face dependency, which is concretely represented as the distribution of the tissue thickness on skull surface. Most current methods make use of the soft tissue thickness of a set of skull landmarks for craniofacial reconstruction, but it is considered not an ideal approach to model the relationship between face and skull.

In order to reflect the complete tissue thickness distribution and get rid of the disadvantages of the sparse representations, the methods which measure tissue depth at all points have been proposed. In these methods, the face and skull are typically represented in dense form. For examples, Tu et al. [28] constructed a face space for craniofacial reconstruction from the dense skull and face surfaces extracted from head CT images. Vandermeulen et al. [29] also used dense representations (implicit surfaces) for both skin and skull in craniofacial reconstruction. Pei et al. [30] presented a dense tissue depth image representation for craniofacial reconstruction, namely tissue-map. The dense tissue depth methods make use of more information of the relationship between face and skull; it generally has better craniofacial reconstruction results.

II. DISCUSSUION

When the information pertaining to a missing person is scarce or when the condition of the remains is poor, skeletal information can provide the last resort for identification. CFS is among the most relevant techniques available in this scenario. The creation of a superimposition is fundamental for the CFS process, thus the need for a reliable, fast and accurate methodology for SFO. Using computer aids provides a solution to this need. The application of inaccurate techniques could lead to significant biases, compromising the identification process carrying serious consequences. The issues in 3D skull modeling, skull outlay and decision making should be properly encountered while designing and proposing new methods.

The absence of a common repository of solved CFS cases has limited the development of automatic methods that could solve some of the most tedious CFS tasks in a fast, accurate, reproducible and objective way. To date, few automatic CFS tasks are used in practical applications despite the high number of cases examined and the large amount of time that the forensic expert invests in performing the examination.

Facial restoration is one of forensic and an archaeological device used by experts to aid the proof of identity procedure of the unidentified human remains. The last goal of a facial reconstruction is to create the best similarity to the original facial position of the unidentifiable remains and to stimulate community concentration that may finally lead to the recognition and proof of identity the person. It has not always been possible to get a positive successful result due to the existing limitations. When efforts are made to fully explore the true nature of the relationships between the soft facial tissues and the underlying skull, reliable accuracy rates of reconstruction techniques can be obtained. Throughout years, studies and estimates have been carried out to increase the consistency of the methods like face pool identification, similarity evaluations or anthropometrical calculation. Since the human face is a very detailed structure involving of a number of variables such as the eyes, ears, nose, and lips; skin color, hairstyles, occurrence of facial hair in males; surface patterns such as tattoos, scars, moles; ornaments such as rings and glasses, etc, the renovation methods, whether be it manual or computer-based, can never accomplish an exact demonstration. It should also be taken care that the success of a renovation method does not depend only on the skill of the experts and the accuracy of the reconstruction but certain other numerous factors determine whether a reconstruction is deemed successful or not.

III. CONCLUSION

The techniques behind cranial superimposition and reconstruction continue to be more apt, gradually changing from non-automatic method to automatic one, as the years go by. With the advancement in technology, new and more reliable methods are being studied. Nevertheless, it is clear that both methods at present do come with some inaccuracies due to which the techniques are yet to be standardized. To increase the degree of accuracy and reliability will be the main challenge in the coming future in this research field. Even though counting on the limitations and the apparent fact that positive identification could certainly not be allowed to rest on superimposition and reconstruction alone, there also exist many successful cases that validate the use of superimposition and reconstruction techniques individually as a last resort technique. Although it is a long shot, yet, it is worth taking when other attempts fail to identify the unknown remains. Hence more research works should be carried out on the lacking elements. In real applications, it is better to combine these techniques, i.e., craniofacial reconstruction and craniofacial superimposition

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Authors Profile

C.Kamali, Currently pursuing full time Ph.D in ComputerApplications at Manonmaniam Sundaranar University,Tirunelveli, Tamilnadu, India. She received her master's in Computer Applications from Sarah Tucker College, Tirunelveli, India. Her current field of interest is with Medical Image Processing. She is interested in Bigdata, Artificial Intelligence and Remote Sensing

Dr.D.Murugan, is a Professor and HOD at Department of Computer Science and Engineering, Manonmaniam Sundaranar University, Tirunelveli, Tamilnadu, India. He has 27 years of teaching experience and has 12 years research experience and published more than 50 papers. His areas of expertise are Face Recognization and Medical Image Processing. He He has also published 3 books which are indexed to Springer.

