Freeform Fabrication Assists Forensic Scientists in the Identification of Unknown Victims

Bahram Asiabanpour [1α]

Jerry Melbye [β]

Vicky Melbye [β]

Evan Jensen [α]

Joshua Shaw [α]

[α]: Ingram School of Engineering

[β]: Forensic Anthropology Center at Texas State (FACTS), Department of Anthropology

Texas State University - San Marcos, Texas 78666

Reviewed, accepted September 10, 2008

Abstract:

According to the International Homicide Investigators Association, there are currently over 40,000 unidentified bodies being held in coroner's and medical examiner's offices across the United States. Over half are estimated to be victims of homicide, and all are awaiting positive identification. One technique utilized by forensic anthropologists to establish the identity of unknown skeletal or decomposed individuals is the use of facial reproduction. In facial reproduction, soft tissue approximating muscle and skin is added to the skull in an attempt to reflect how the individual looked during life. Soft tissue depths at specific locations (i.e., certain craniofacial landmarks) are known and have been standardized according to an individual's sex, age, ancestry, and body type. For the most part, facial reproduction is still accomplished manually by adding layers of soft clay to represent tissue on the actual skull of the deceased individual. This method is quite time-consuming (often taking two or more weeks) and often not feasible because the skull may be damaged, or the use of clay overlying the actual skull may destroy evidence. To overcome these limitations, researchers have recently turned to Computed Tomography (CT scan) technology to generate CAD files of unidentified skulls, which are then modeled and recreated with rapid prototyping machines. One limitation of this method is that it is dependent on the initial CT scanning instrument, which is not portable and requires that the unidentified remains be removed from their original storage sites (typically morgue coolers or crime scenes) to the location where CT scanning instruments are available (often hospital or clinical settings). Because many of these unidentified remains are either skeletonized or are in various stages of decomposition, the transport of these bodies to locations with CT scanning machines is often not possible or permissible. In this paper, we first propose a new method to rapid prototype skulls via stereolithography (STL) files generated by hand-held portable laser scanners, as opposed to using CT scanning machines. These rapid prototypes can then be fabricated for facial reproduction, negating the use of the actual skull, and not requiring the body be removed from its original location. Also, results of the facial reproduction for an active case are presented. Secondly, we outline preliminary results of a new computerized facial reproduction and superimposition method, which accurately models tissue depth and is not dependent on the manual application of clay.

Keywords: Facial reproduction, Forensic anthropology, skull prototyping, Laser Scanning

1- An introduction to forensic anthropology

"Forensic anthropology is the application of the science of physical anthropology to the legal process. The identification of skeletal badly decomposed, or unidentified human remains is important for both legal and humanitarian reasons." [1] Many unidentified body remains are found by law enforcements in a daily basis. Unidentified bodies may be classified as

[1]Corresponding author, Email: ba13@txstate.edu

skeletonized, decomposed, mummified, burned, fresh, living, historic, and nonhuman. Along the US-Mexico border alone, more than 200 unidentified human remains are found annually. The families of these victims may wait for years to hear back about their love ones fate. "Forensic anthropologists apply standard scientific techniques developed in physical anthropology to identify human remains, and to assist in the detection of crime. In addition to assisting in locating and recovering suspicious remains, forensic anthropologists calculate the decedent's age, sex, ancestry, stature, pathology and unique features from the skeleton."[1] Also, forensic anthropologists lend their expertise in the "detection of crimes, and discover evidence of foul play and/or postmortem interval." [2] Forensic anthropology is very popular among American people and media. Several popular TV shows such as Bones and CSI have increased the visibility of the forensic anthropology. The drawback is that such semi-fiction programs have increased judges' expectation beyond the capacity of this science.

2- Facial reproduction

According to the latest report from the law enforcement agencies, currently more than 40,000 unidentified bodies exist in the US [3]. One of the areas that forensic anthropologists aid in the identification of unknown decedents is facial reproduction. In facial reproduction –also known as facial construction, 3D craniofacial reproduction, and facial approximation-, soft tissue is added to skull. Soft tissue depth (i.e., muscle and skin), known as anthropological landmarks, is determined based on the individual's race, gender, age, and body type (Figure 1). Currently this method is being done manually by use of adding soft clay as a tissue on the skull.

Facial reproduction is one method that is used when the victim has remained unidentified through the usual avenues to obtain a positive identification. In other words, while facial reproduction has never been accepted in a court of law, it is an investigative tool which can lead to a positive identification. Simply put, the skull is used to generate a facial likeness. This image is then advertised widely, along with information of age, race, sex, stature, and any other unique features found on the skeleton. Positive identification is dependent upon a match between antemortem and postmortem unique characteristics such as fingerprints. In the case of decomposed remains, dental x-rays are generally non-existent among these victims. A list of missing persons is then compared against DNA. For example, if a facial reproduction is widely advertised along with the biological profile (age at death, sex, race, stature) this often alerts people to suggest possible missing persons.

Figure 1. Anthropological or craniometrical landmarks on a skull (left) and a reconstructed facial (right) [4]

In current facial reproduction methods, **s**pecialists work directly on the skull, however, many times, facial reproduction cannot be carried out on a skull because it must be preserved as evidence. By making a prototype of the skull we are not interfering or damaging critical evidence, but are still able to reproduce the face of an unknown victim. Recently some research has been done to make the facial reproduction in the form of virtual model by use of computer art work (Figure 2) [5 -7].

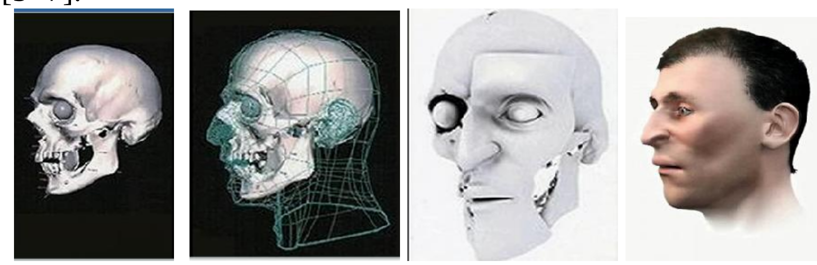

Figure 2. Computer facial reproduction [4]

Some experts do not accept computer models as valid reproductions [2]. Another approach that has recently been proposed is the use of rapid prototyped skull, instead of using the real skull, in the facial reproduction process. The CT image file is then sent to an intermediate program such as Mimics or 3ds Max. This program makes a virtual model of the skull which is then fabricated by a rapid prototype machine. Finally, a facial reproduction specialist builds a face on the prototype by using the clay method [8 and 9]. One limitation of this method is that it is dependent to the CT scan instrument. Because many of these unidentified remains are either skeletonized or are in various stages of decomposition, therefore, the transport of these bodies to locations with CT scanning machines is often not possible or permissible. Also, the CT scanning process is relatively expensive (about $500) and for under budgeted sheriff offices (i.e., US-Mexico border) this expense is not within their budget.

3- Facial reproduction on a skull directly prototyped from a laser scanned file

To overcome the limitations of the previous methods (such as build on the real skull, moving skull from its original site for CT, and also the need for intermediate facial reproduction programs which are not accessible to the public), a method is proposed that simplifies the system while maintaining the accuracy of original skull. The methodology of this approach is as follows:

Step 1: 3D scanning of skulls: The skull is scanned by a Polhemus 3D hand-held laser scanner called FastSCAN at the law enforcement agencies or medical examiners' offices. This equipment instantly acquires three dimensional surface images when the handheld laser scanning wand is swept over an object, in a manner similar to spray painting. FastSCAN works by projecting a fan of laser light on the object while the camera views the laser to record cross-sectional depth profiles. The object's image will immediately appear on the computer screen.

Step 2: Post scanning processes and rapid prototyping: The scanned file is exported from the Fastscan software in the stereolithography (STL) format, which is recognizable by the 3D rapid prototyping (RP) machine. The quality of the STL file may be improved or edited within the Fastscan program or intermediate CAD software before sending it to the RP machine. The Rapid prototyping machine used for this process is Zcorp 3D printer model Z450. After building a prototype, an exact replica of the skull, it was then reinforced by the *Z bond- 101* glue.

Step 3: <u>Facial reproduction:</u> Facial reproduction specialist create a clay face from the prototype of the skull by gluing tissue depth markers onto anatomical points of the cast, and clay is used to fill in the spaces between the markers, eyes, nose, lips and hair are added, thus ultimately creating human face. Facial reproduction is not positive identification of an unknown victim; rather, it is a method that can lead to positive identification.

Figure 3 illustrates different stages of the proposed method on an active case in San Antonio, TX area. The gap on top of the skull displays areas that suffered blunt force trauma.

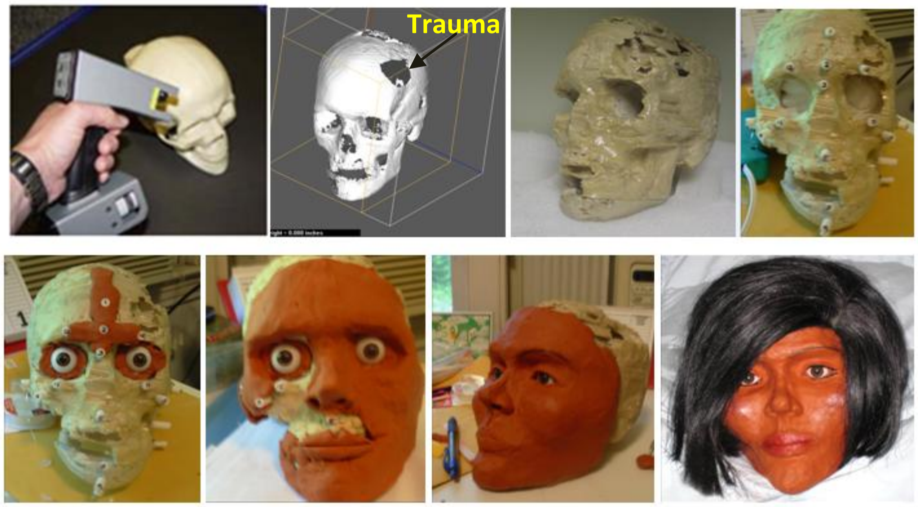

Figure 3. Laser scanning, CAD file improvement, rapid prototyping and different stages of the facial reproduction in an active case involving a White or Hispanic female 18-24 years old

4- Advantages and limitations

The advantages and uniqueness of this approach is that the 3D laser scanning can be done on-site and does not require an intermediate/confidential program for building a virtual model. After a positive identification is obtained, the prototyped skulls may be used as teaching tools in forensic anthropology labs across the United States. .

The drawback for this method is that some common laser scanning processes and rapid prototyping machines have limitations. For example, the quality of darker surfaces is not great and in the end we may see gaps in certain areas of the prototype. Because of the fixed position of the skull during the scanning process, some areas of skulls such as under lower jaw, neck, and inside of the mouth, are not reachable by the hand-held laser scanner gun. The software for the Zcorp 450 rapid prototyping machine, Zprint, does not give much flexibility to the user to define the thickness of the model to be prototyped. Therefore, the entire skull is built as a solid material, rendering it very heavy and costly to produce.

5- Supporting tools

To address some of the above limitations, some tooling additions and process modifications have been implemented. A new mechanism has been designed, manufactured, and tested. This mechanism holds the skull at minimum contact points and is capable of turning the skull and the laser scanner transmitter simultaneously in all six turning directions (+ and – around X, Y, and Z axes). The advantage of this tool is that it allows the operator to scan the entire surface from all sides. (Figure 4).

Figure 4. Skull holding/turning mechanism for the laser scanning process

To improve the quality of the scanned skull CAD file (e.g., filling the gaps between surfaces) and to build the prototype with the desirable thickness, Materialise 3matics software was used. This enabled us to save considerable amount of material and build a much lighter skull. This model later was built by use of Zcorp Z450 rapid prototyping machine (Figure 5).

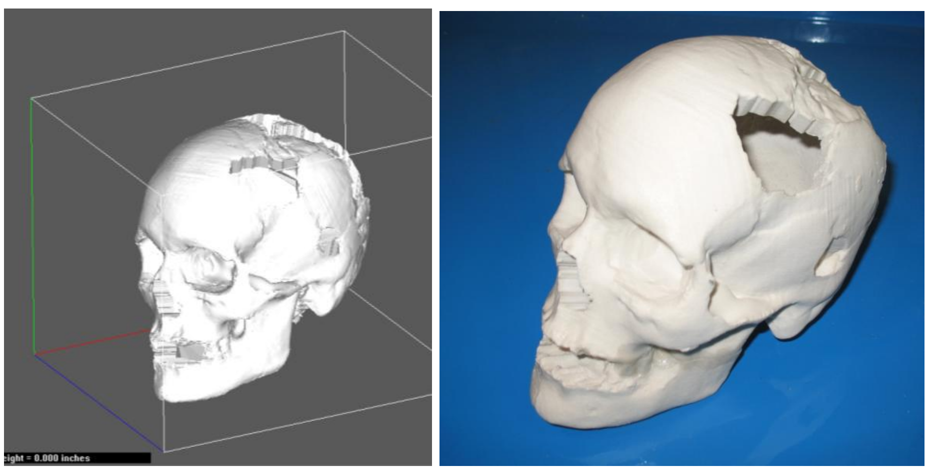

Figure 5. New skull prototype with half inch Zcorp 450 machine

The use of the interfacial programs such as 3Matics has facilitated the skull prototyping in better surface quality. However, the visual inspection of the final prototype hypothesizes that surface quality improvement process might have changed the skull geometry and orientation of the important landmark points. As an alternative method, a new project is under investigation by the authors and a team of talented high school students participating at Texas State University's Siemens honor summer mathematics camp. In this research, the research team is trying to give desirable internal thickness to the skull shell that was produced by the laser scanning process by creating a freeform geometry inside the skull. The result of this output will be a file in STL format acceptable for rapid prototyping. Since the external shell of the skull is untouched, the geometry of the external surface of the reproduced skull will be exactly similar to the original skull.

6- Validation

The newly opened Forensic Research Facility at Texas State University is the largest decomposition facility in the world, and one of three facilities in operation [10]. At this facility donated bodies will be laid out in the open area to decompose naturally. This facility provides very unique opportunity for validation of this research. The human body, facial features, and head can be laser scanned and measured precisely before being placed in the open to decompose. Once the skull has skeletonized, it can be laser scanned again. A prototype can be produced from the CAD for facial reproduction. The final reproduction can then be compared against a photo of the living individual and measured visually, manually, or through software work such as the three dimensional quantification facial shapes by Thomas [11, Chapter 4].

7- Photographic superimposition

Photographic superimposition is the process of overlaying two photographs, one of the unidentified skull, and one of a possible victim. This method is usually used when investigators believe that the remains may belong to the person in the photograph [12]. If there is a match, the person is considered to be a possible victim; however, if there is no match, the person is excluded.

A preliminary effort has been done to implement a more consistent photographic superimposition. Based on this research, by use of parametric CAD software a picture was imaged and matched with a designed (not scanned) face (Figure 6). This match was successfully built by the Zcorp 450 color 3D printer (Figure 7).

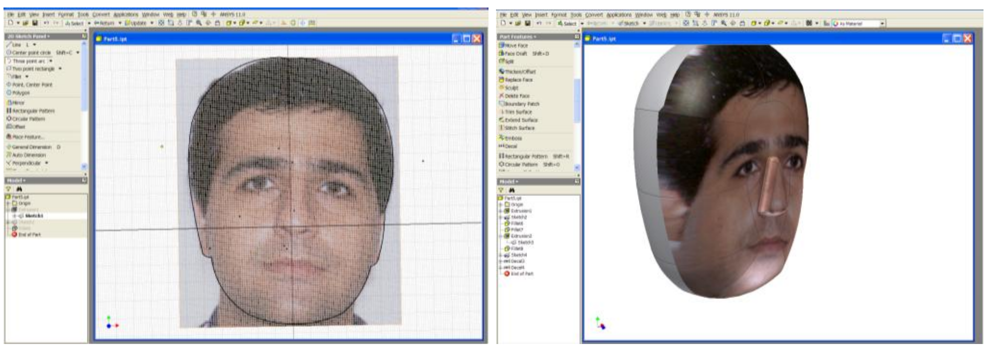

Figure 6. Photographic superimposition

Figure 7. A physical prototype of a model built by photographic superimposition

8- Computerized facial reproduction

Several research and developmental works have been reported on computerized facial reproduction systems. In a method by Tu et. al., a given skull is matched with a face that is saved in a database of CT scanned heads [13]. Also, law enforcement in the United Kingdom and the

FBI are using computer programs for facial reproduction called *3ds Max* c and *Reface* c respectively [8]. Clement and Marks in their 2005 book, "*Computer-Graphic Facial Reproduction*" have presented different facial reproduction approaches [11]. Subsol and Quatrehomme use Crest lines extracted from a CT scan file, registration of the feature lines, geometric normalization, and computing the 3D transformation [11, Chapter 5]. Also, Vargas and Sucar propose a method for predicting the most probable facial features by use of discrete landmarks, Bayesian networks, mathematical morphology, and computer graphics [11, Chapter 7]. Davy et.al. have introduced a facial reproduction method using the 3ds Max computer modeling software. They use anatomical reproduction and Non-Uniform Rational B-Splines (NURBS) Control Vertex (CV) curves based on the underlying muscles in modeling (Neave method) [11, Chapter 10].

Under a collaborative work between the School of Engineering and the Department of Anthropology at Texas State University, a new facial reproduction method is being developed. This method, similar to Davy et. al., is based on the underlying muscular or Neave method. Also, the facial reproduction will be fully automated in generating, orienting, adjusting landmarks, muscles, and skin based on information such sex, age, race, and body type of the victim with minimum artist and/or forensic anthropologist interaction.

The proposed method for the facial tissue regeneration program includes the following steps. First, all known tissue thickness data will be stored in a database with the ability to query based on the race, gender, age, and build of an individual. Then, a computer program will be used to create generic facial tissue geometry, which will also be added to the database. In the initial stages of development, the user will interact with the software to pick points best suited to match the landmarks for tissue data thickness. The points will then be processed to compute a normal vector for each point in order to provide the proper location and orientation for the tissue generation process (Figure 8). The generic tissue will then be attached to the points in their corresponding locations, and will be automatically oriented to fit the imported skull model. Then, through a set of graphical menus, tissue thickness data are modified by the desirable combination of race, sex, age, and build. As the user inputs the data, the tissue thickness data will be updated on the 3D model, and start to resemble the owner of the unidentified skull. The user will be able to pick from a set of predefined features such as ears, noses, hair, and eyes. An algorithm will then be run to wrap skin around the facial features, and apply race specific skin texture and eye color for a near photorealistic rendering of the subject. Once complete, the model can be prototyped in full color, or rotated in 3D space for help with identification.

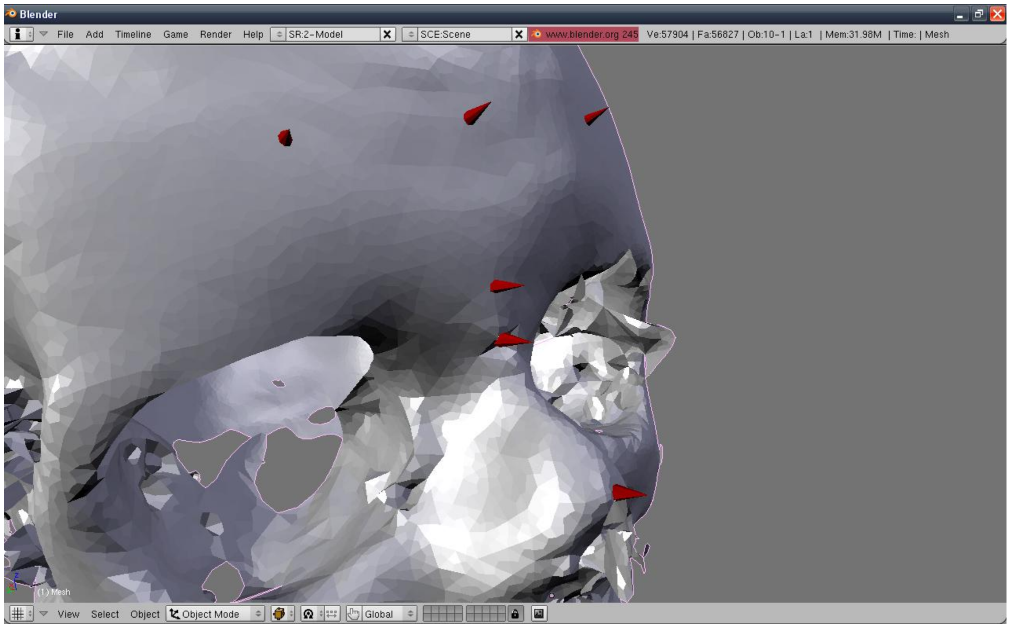

Figure 8. Vectors to specify anthropological landmarks' locations and orientations

9- Conclusions and discussion

According to Stephan and Henneberg, approximately1 in 16 reconstructed faces have led to the identification of a missing person or unknown victim [14]. The traditional method of manual facial reproduction is quite time-consuming and often destroys evidence (the skull). The use of CT scan technology to generate CAD files of unidentified skulls, which are then modeled and recreated with rapid prototyping machines, has improved the facial reproduction process. However, this method is dependent on the non-portable CT scanning instrument and necessity of removing the unidentified remains from their original storage sites to the CT scanning instrument, which is often not possible or permissible. In this paper, a new method to rapid prototype skulls via STL files generated by hand-held portable laser scanners is proposed. These rapid prototypes can then be fabricated for facial reproduction, eliminating to the need to move the unidentified remains from their original storage sites.

References:

1- American Board of Forensic Anthropology website, Retrieved on March 28, 2008 http://www.csuchico.edu/anth/ABFA/
2- Komar, D. and Buikstra, J., "Forensic Anthropology: contemporary theory and practice", Oxford University Press, New York, 2008.
3- 'Doe Network' works to give names to the dead http://www.cnn.com/2008/CRIME/03/25/doe.network.ap/index.html, retrieve on March 25, 2008.
4- Feature Story: Turning head, *UT Arlington magazine*, Fall 2007, http://www.uta.edu/publications/utamagazine/fall_2007/index.php?id=529

5- Henry M., "3D image animates victim", Toronto Star, Jan 30, 2008, http://www.thestar.com/News/GTA/article/298669.

6- Matter, P., "Face Value: Professor uses digital technology to aid police", University of Toronto News release, Feb 13, 2008, http://www.utm.utoronto.ca/361.0.html?&tx_mininews_pi1%5bshowUid%5d=2001&tx_mininews_pi1%5bbackPid%5d=51&cHash=bd704b19bd

7- Decker, S. and Hilbelink, D., *"Virtual Skull Anatomy: Three-Dimensional Computer Modeling and Measurement of Human Cranial Anatomy*", Proceeding of the American Academy of Forensic Scientists Annual meeting, Washington DC, 2008.

8- Decker, S. and Hilbelink, D., *"Who Is This Person? A Comparison Study of Current 3-Dimensional Facial Approximation Methods*", Proceeding of the American Academy of Forensic Scientists Annual meeting, Washington DC, 2008.

9- Crockett, R.S., and Zick R., "*Forensic Applications of solid freeform fabrication*", Solid freeform fabrication symposium, 2000.

10- Steinberg, R.U., "*Listening to Bones*", The Austin Chronicle, April 4, 2008.

11- Clement, J. and Marks, M., "Computer-Graphic Facial Reproduction", Elsevier Academic Press, 2005.

12- Ubelaker, D., "*A History of Smithsonian–FBI Collaboration in Forensic Anthropology, Especially in Regard to Facial Imagery*", Forensic Science Communications, Volume 2, Number 4, October 2000.

13- Tu, P., Book, R., Liu, X., Krahnstoever, N., Adrian, C., Williams, P., "*Automatic Face Recognition from Skeletal Remains*", Computer Vision and Pattern Recognition, IEEE 2007.

14- Stephan, C. and Henneberg, M., "*Building faces from dry skulls: Are they recognized above chance rate?*" Journal of Forensic Science 46(3).