FORENSIC APPLICATIONS OF SOLID FREEFORM FABRICATION

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Abstract

Solid Freeform Fabrication was recently used to identify the dismembered body of a woman found in rural Wisconsin. Skin from the face of the victim had been removed, making visual identification impossible. A model of the skull was constructed by Laminated Object Manufacturing (LOM), using data extracted from CT scans of the victim's head. Forensic anthropologists performed a facial reconstruction directly on the LOM model, which was then photographed and distributed. The computer model was further manipulated and served as supplemental data to investigators preparing the reconstruction. An identification from one of the distributed photographs led to the arrest of a suspect and a subsequent conviction. This is the first example that we are aware of where SFF has been used in an active criminal case, and the successful results show a promising future for SFF as a forensic tool.

Background

Solid Freeform Fabrication recently served an important role in a high-profile police investigation. The dismembered body of an unidentified woman was found in the Wisconsin River near Spring Green, Wisconsin in July, 1999. Skin from the face of the victim had been removed, thus making visual identification impossible. Although an autopsy revealed information about the victim's sex, age, race, and medical history, investigators could not find a match with any reported missing person in national databases. With no further leads, it was decided that a visual identification from a facial reconstruction was the most promising approach.

Forensic anthropologists routinely create facial reconstructions from discovered skulls, whereby clay is built up over multiple reference points on the skull surface. The height of these points corresponds to statistically determined tissue depth in various areas (Figure 1). In this particular case, however, the standard procedure for a facial reconstruction was not a desirable option for identifying the victim. Because the victim's remains were an actual head, not merely bone, the remaining flesh would have had to be removed to prepare the skull for reconstruction. This remaining soft tissue needed to be preserved as possible evidence, as it contained cut marks and other identifying clues to the murder.

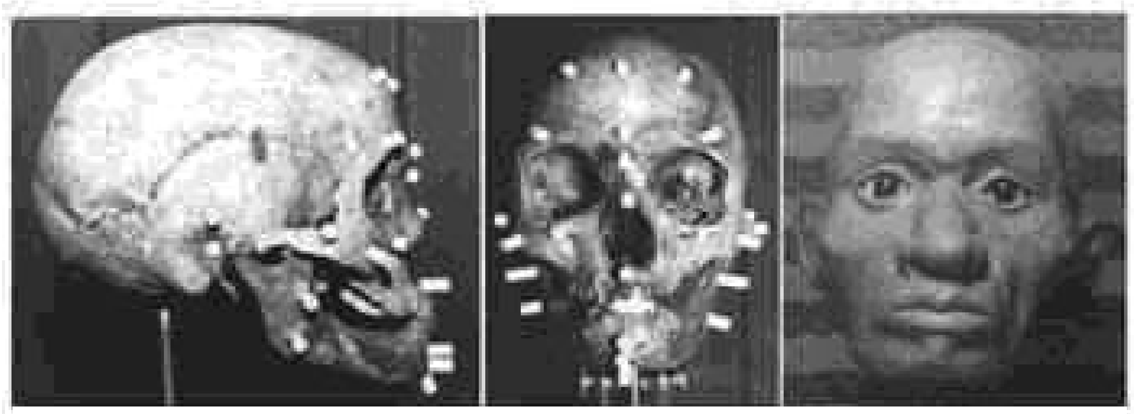

Figure 1. Typical forensic reconstruction. Pegs are rubber erasers, cut to lengths determined by statistical data.

Milwaukee School of Engineering received a call from Detective Joe Welsch of the Sauk County Sheriff's Department, indicating that he had been informed of the capabilities of Solid Freeform Fabrication and asking if we could help.

Model Preparation

The victim's head was CT imaged at the University of Wisconsin, and the resulting data file was transmitted to the Rapid Prototyping Center at MSOE. Mimics software from Materialise[1] was used to extract just the features of the skull (Figure 2). During this process, minor CAD manipulation of the data file was required. The top of the skull had been removed during the autopsy; although this cut was fairly clean in the resulting computer solid model, Mimics tools were used on the model to ensure that it was a separate piece. Similar processing was performed on the jaw. In addition, it was decided to fill the interior of the skull model with solid material, both to speed up the LOM build

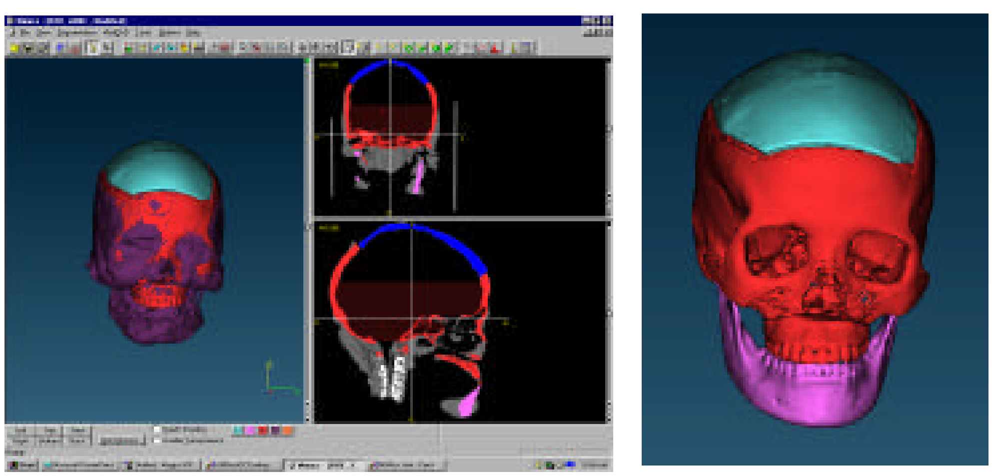

Figure 2. (left) Mimics software was used to manipulate the CT data and extract just the features of the victim's skull. (right) Completed computer model

[1] http://www.materialise.com

process and to give the resulting physical model a density and center of gravity similar to an actual skull. Finally, a CAD-designed attachment was merged with the model to enable the SFF object to be supported on a stand during the reconstruction. Anthropologists typically make use of the opening at the base of a skull where the spinal cord terminates. Because we were building a filled skull, however, we had to replicate this feature artificially. Later feedback from the anthropologist confirmed that adding designed components such as this to an otherwise organic structure could significantly simplify their process.

An .stl file was generated directly from Mimics, and a full-scale, accurate model of the skull was then build using Laminated Object Manufacturing (Figure 3). Although MSOE also has equipment for Stereolithography, Fused Deposition Modeling, and Selective Laser Sintering, LOM was preferred both because it was the fastest machine for this size and geometry (filled solid with a complex surface), and because the resulting physical model has a density and "warmth" similar to bone. This second fact was extremely important, as it enabled the acceptance of SFF technology by extremely conservative professions such as law enforcement and anthropology, as well as by a later jury. Total build time on the LOM was 30 hours. Within 3 days from scan data to physical object, the skull model was shipped to a forensic anthropologist from the Kentucky State Medical Examiner's Office.

Computer Model Data Manipulation

Although we did not plan it at the time, the .stl file used to create the skull model served an important continuing role as a source of supplemental data during the process of creating the facial reconstruction. First, at the request of the anthropologist, features of soft tissue still extant on the skull were manipulated on the computer directly from CT data; measurements and printouts of the skull both with and without this tissue were used to aid in the forensic reconstruction (Figure 4).

Additionally, measurements taken directly from the .stl file that created the skull were

Figure 3. (left) LOM model before decubing. (right) Finished model.

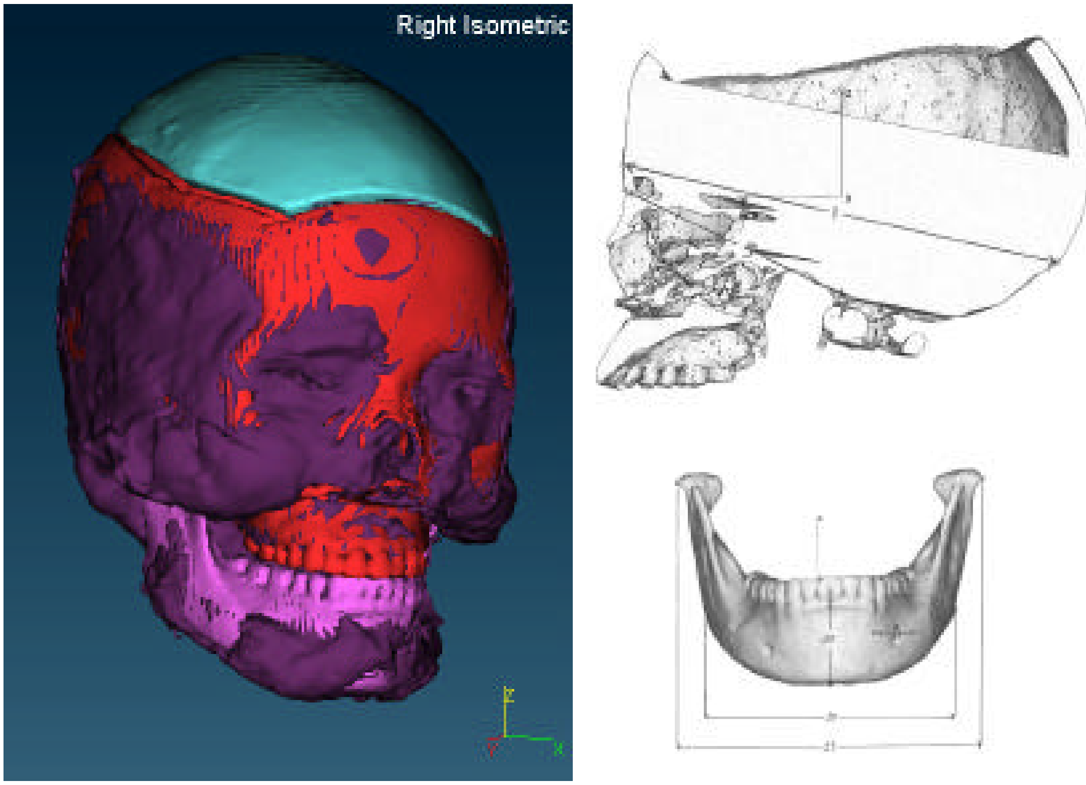

Figure 4. Computer model was further manipulated and used as supplemental data to aid the forensic anthropologist. (left) Imaging of the soft tissue. (right) Measurements used for confirmation of victim's race.

used to confirm the victim's race. At the completion of the facial reconstruction, many of the resulting features appeared to be Asian, whereas the earlier autopsy had determined the race to be black. Forensic reconstructions are a combination of science, art, and the intuition of the anthropologist, so this new information was taken very seriously. A typical method of determining race involves taking measurements of the skull at about 30 points using calipers; statistically, these measurements have a high correlation with race. Unfortunately, by the time the question of race was raised, the reconstruction was nearly complete. To take measurements on the physical model would require removing the clay; to take measurements on the actual head would require removing the remaining soft tissue, which was not an option. The solution was to take measurements directly off the .stl file, using point-point measurement tools in Magics RP (also from Materialise). These measurements confirmed the race of the victim, again avoiding any disturbance to the actual evidence.

Facial Reconstruction and Results

The completed reconstruction was photographed with a variety of hairstyles. Investigators selected four images and prepared flyers, which were posted around the area of the murder (Figure 5). Nearly three months later, someone identified one of the images. The woman was a student from Tanzania who had not been reported missing.

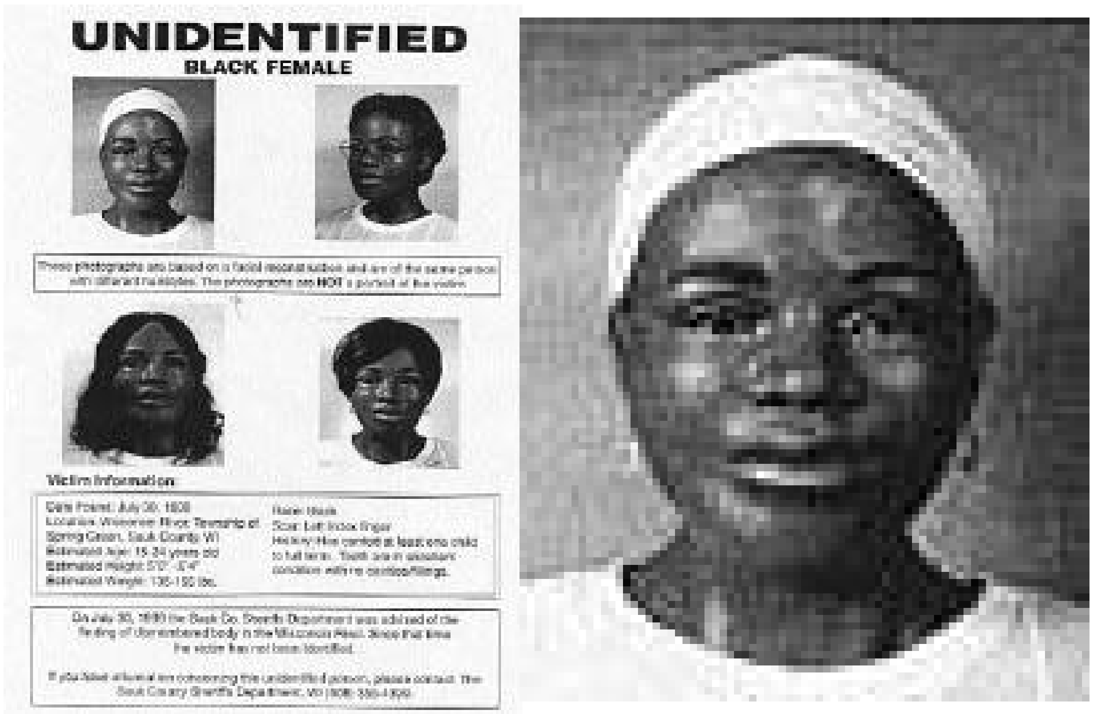

Figure 5. (left) Photographs of the completed reconstruction were distributed by the Sheriff's department. (right) An identification of the victim was made by the above photograph, which was described by the identifier as an exact match to the victim.

According to investigators, the image (shown enlarged in Figure 5) was nearly identical to the victim. Within a day, police had arrested her cousin and charged him with first degree homicide. He was subsequently convicted and is currently serving a life sentence. Without the identification of the victim, it is likely that this murder would have gone unsolved.

The Future of SFF as a Forensic Tool

This was a highly visible and successful technology demonstration, and it points to some promising continued use of SFF as a forensic tool. The FBI and the National Institute of Justice have both expressed interest in this technique as a near-term solution to automating the identification of victims. There are three primary areas where SFF could potentially reduce the time and cost, as well as increase the consistency, of facial reconstructions:

1) *Integration of CAD into the process to reduce the preparation time for reconstruction.*

   A simple example of this would be the tissue depth markers of Figure 1 placed during feature extraction and built directly into the model. The ultimate goal would be to deliver a skull model to the anthropologist that is nearly complete, with base tissue depth already part of the physical model.

2) *Ability to extract features of interest and manipulate data in physical form.*

It has been shown that features of the bone can be selectively extracted from a larger data set. Alternatively, SFF models of just the soft tissue can be constructed, as well as interior sections, etc. All of this data in *physical* form is important to anthropologists, who are used to working with physical objects.

3) *Ability to create multiple copies*

SFF can be used to create multiple copies of forensic evidence, for multiple reconstructions or multiple partial reconstructions.

This is the first example that we are aware of where SFF has been used in an active criminal case. All of the participants in this project were really stretching the limits of what can be done – not from a technology point of view, but from an emotional or mental point of view. New tools such as DNA sequencing in the 1980s and Solid Freeform Fabrication today can make a huge impact on the way crimes are solved. Acceptance of these innovations, however, is generally much slower. By using SFF in a successful case, an important step has been taken toward making this technique available to a larger community.

ACKNOWLEDGEMENTS

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