Computational Forensics:
Creating a Digital Environment for Facial Synthesis and Reconstruction

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Abstract

Facial Reconstruction involves the recreation of craniofacial structures and face geometries from an unidentified skull. Computer-aided techniques are at present preliminary, and cannot yet replace the anatomical judgment of the experienced practitioner. Thus, the current methods commonly employed in law enforcement cases involve the manual reconstruction of an individual by forensic experts. Despite their effectiveness, manual techniques prove time-consuming, expensive, and inflexible, relying on the expertise of the modeler for their success. Thus, the goal of this project is to utilize geometric modeling methods to streamline the manual technique into a 3-D digital environment.[1,2] The computer-aided method will directly address the limitations that manual methods face by providing consistent, objective, and flexible results that can be executed within a short amount of time.

Background

During forensic investigations, the reconstruction begins with the handling of the skull. After skull fragments have been re-assembled and the individual's ancestry and gender have been evaluated, the facial reconstruction proceeds with one of the two available methods:

American Method	Russian Method
Measures tissue thickness at anthropological landmarks. Clay/plasticine is then interpolated over the marker guidelines.[3]	***Determines the muscular structure*** of an individual and sculpts muscles, glands, and cartilage layer by layer.[3]

The **American Method** was our method of choice. Interestingly, **the method bears many similarities to surface fitting techniques commonly used in computer graphics,** increasing the possibility of a successful transfer of the manual approach to a digital one.

Facial Synthesis Algorithm

Let F be the facial surface to be deformed to F':

Suppose for each vertex $v_i \in F$, its target vertex is v_i'.
Thus, the displacement vector is given by: $d_i = v_i' - v_i$.

For the as-rigid-as-possible deformation, two criteria are necessary:

a) Displacement between any two adjacent vertices should be equal:

$$E_s = \sum \sum_{j \in N(i)} ||d_i - d_j||^2$$

b) The face markers v_f should deform to the markers v_f' on the skull:

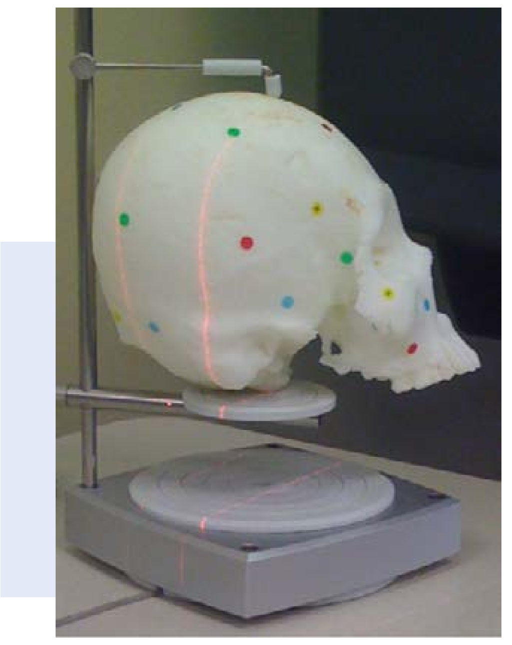
$$E_f = \sum ||d_i - (v_f - v_f')||^2$$

We want to **minimize** the quadratic energy function: $E = E_s + E_f$.
By setting the derivatives of E equal to 0, this yields a system of linear equations. Thus, we can solve for the unknowns, v_i.

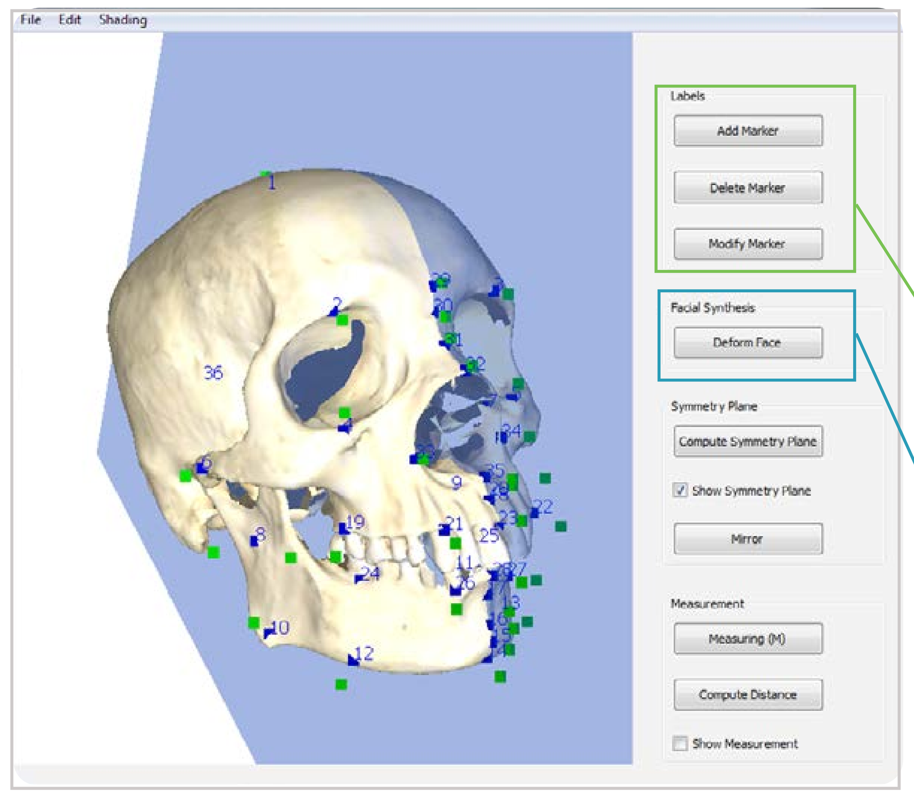
Finally, the new face can be obtained by solving: $v_i' = v_i + d_i$.

Method

In order to perform the reconstruction, 6 skulls, labeled by gender (male, female) and ethnicity (Caucasian, African American, Asian), were acquired from the LSU FACES laboratory and digitized using a 3-D scanner.
In the computer, each skull is visually represented as a 3-D, triangular mesh.



Skull Cast of B-86-A Being Scanned[4]



The Graphical User-Interface (GUI) displaying landmarks (blue) and their normals (green) that were computed using a symmetry plane

1. Digital Environment (GUI) Development:

The digital environment was created in **VisualStudio** using **C++** as the programming language. The **OpenGL** API was utilized for the rendering of objects and the **Qt** framework was used for the incorporation of user-interface elements. Functionality described in the following steps were later implemented into the system.

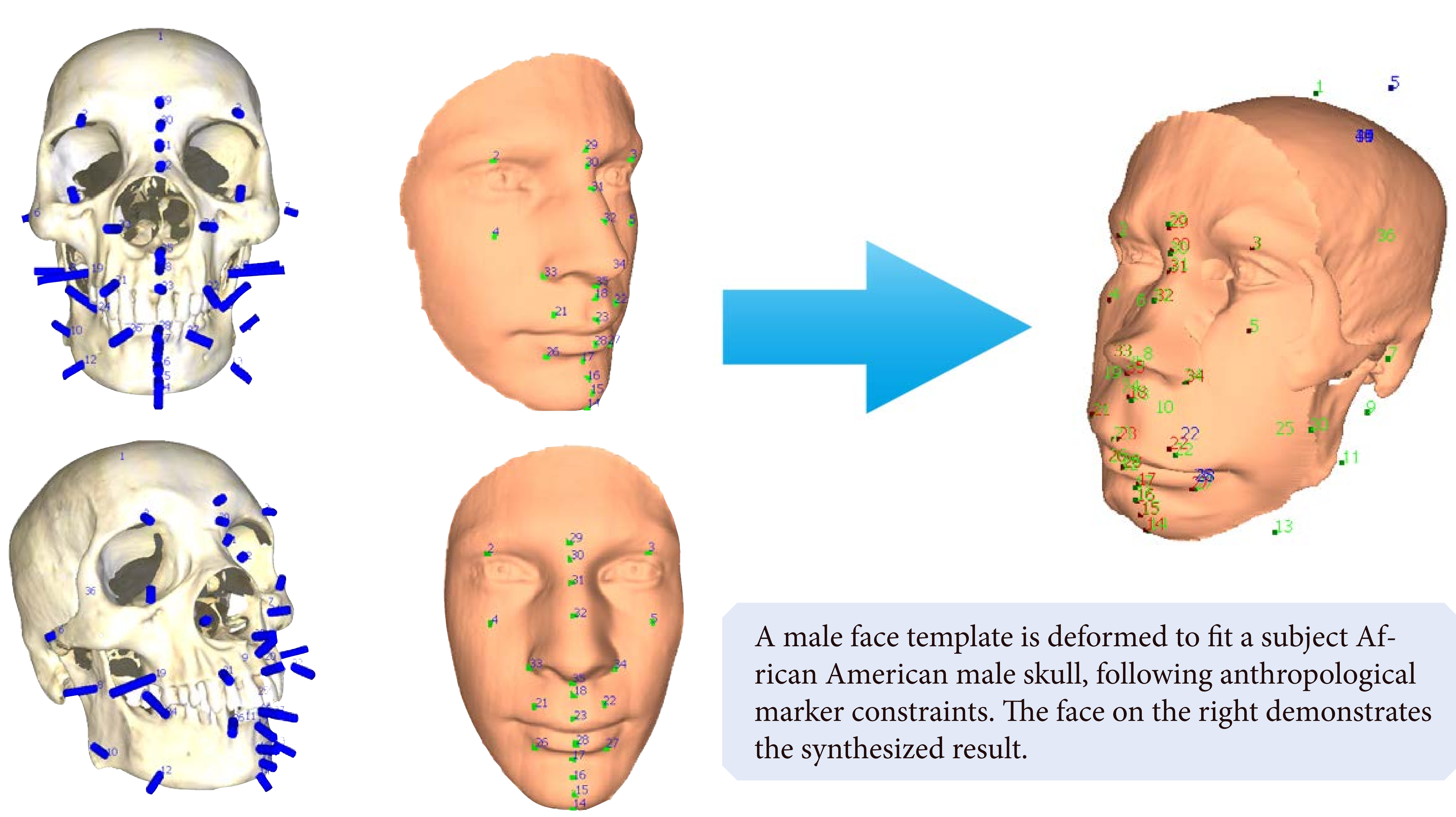
2. Skull Modeling:

For each skull, **digital landmarks** were computed at anthropometrically significant points. Cylinders for tissue depth were rendered orthogonal to the skull mesh.

3. Facial Synthesis:

Facial landmarks were also computed on a constrained face template. The **facial landmark coordinates were then deformed to the skull** using the as-rigid-as-possible facial synthesis algorithm.

Results



A male face template is deformed to fit a subject African American male skull, following anthropological marker constraints. The face on the right demonstrates the synthesized result.

The GUI effectively streamlines the manual American Method of reconstruction into an interactive, digital system, providing the necessary tools to perform reconstruction on any skull and face template combination. Rotation interaction also offers an increased possibility of recognition after reconstruction.

Improvements

Consistency/Objectivity: Given the same modeling assumptions/input data, computational results remain consistent. (Manual reconstructions are limited by measurement errors and artistic ability.)

Flexibility: Individual facial characteristics can be altered by re-positioning facial landmarks through the GUI. Morphing facial thickness can also be accomplished by modifying tissue depth data at any given time.

Conclusion

The computer-aided method directly addresses the challenges that manual methods face. However, certain limitations exist in using a constrained face template for certain soft-tissue features (lips, nose, and ears). Future improvements involve refining the reconstruction to account for the individual's age/ancestory and conducting resemblance studies on the facial synthesis results.

References/Acknowledgements

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