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Multi-Platform Skeletal Visualisation and Reproduction in Stereolithography

B. Magnanti*, A. Nicholls+ and R. Sayle+

*Department of Forensic Pathology, The University of Sheffield, Sheffield, South Yorkshire, United Kingdom
+ OpenEye Scientific Software, Santa Fe, New Mexico, United States

Abstract

Adapting well-known molecular visualisation packages to accommodate the display of skeletal human remains is discussed. Features of the system include rapid generation of surfaces, real-time manipulation, viewing of the wireframe and conversion of files from the GRASP file format to one suitable for stereolithography. Additional work has adapted the viewer as a Java applet and incorporated database capabilities. Future developments for the system are discussed.

Keywords:
Osteoarchaeology, forensic anthropology, surface visualisation, stereolithography.

1. Introduction

Archaeologists depend on the skeletal remains found at excavation sites to be used as research and teaching materials for osteology students. As each skeleton is a record of a human life from disease history to diet, they are irreplaceable. The process of bone diagenesis makes archaeological remains especially sensitive to handling. It is also important to note that when training future osteologists, examples of unusual pathologies may not be easy to come by. Therefore, a method of collecting surface data from specimens is needed, with the appropriate software to store, display and eventually reproduce copies of an object.

Ideally any system used in visual data collection from human remains should be as small and portable as possible. To this end, approaches from the field of molecular visualisation were applied to the problem. RasMol (Sayle and Milner-White) is well known and widely used, as it and its descendants, including the Web-launchable Chime, run on most operating systems. However RasMol depends on knowing the location of a sphere centre – i.e. the location of atomic nuclei - to generate a surface. In contrast, GRASP (Nicholls, Bharadwaj and Honig) only runs on Silicon Graphics workstations, but is a 'pure surface' visualisation program capable of displaying any surface, not just molecular ones.

Many research institutions now possess, or have access to, laser surface scanning apparatus. If a visualisation program existed that could accommodate the files produced from these setups, display them in a viewer that can be launched in any environment and convert them to a file type suitable for physical reproduction methods such as stereolithography or laser sintering, the potential applications in both the areas of archaeology education and forensic osteology would be many.

In the following sections we cover the development of the tools needed to accomplish such a task, the creation of example stereolithography models and a methodology for building models from morphometric data of bone so that surface scanning equipment will not always be necessary.

2. Existing Systems

Surface visualisation of bones - especially on the Web using VRML - has been addressed by several groups.

The Interactive Skeleton, a product of the TX Text Control Company, contains a detailed model built from CT scan data. A series of products using this imagery was developed, including Interactive Hand, Interactive Knee and Interactive Foot and Ankle. The specific function of these products is to display text, images, movies and three-dimensional representations of different bones.

An interactive Web site incorporating 3-D imagery and comparative anatomy of various Great Ape skeletons is located at http://www.eskeletons.org (Kappelman et al). The website launches a separate viewer window which allows discrete views in GIF format of several aspects of a single bone. There are also manipulable images in Virtual Reality Markup Language (VRML) format.

These and other similar projects are intended as teaching aids to a beginning osteology curriculum or similar course. The needs of postgraduate and professional osteologists, however, demand a level of interactivity beyond exmaining models on websites, problems that would be addressed by the approach we will discuss here.

3. Aspects of the Viewer

The surface viewer was based on algorithms used in both RasMol and GRASP. In order to demonstarate what a successful skeletal surface viewer should be able to do, a file consisting of a complete skeleton was read into GRASP. Using the functions available in that program it was possible to isolate specific bones or bone regions, to highlight areas of a bone and to ‚paint' the surface.

The first requirement for the surface viewer was a file of skeletal surfaces which can be displayed and manipulated. These are most easily collected by laser scanning. The CyberWare laser scanner is controlled by a computer, in this case a Silicon Graphics Indigo, coordinating the movement of a turntable on which a scannable object rests. Laser scanners measure an object by moving a scanning apparatus in a circular path around an object – or in the case of the setup available to us, by rotating the object while the scanner is still - to produce a mesh of surface values on a cylindrical coordinate system. The scanner can simultaneously measure surface color, and the color data set has the same resolution as the range data mesh, registered point-for-point (Parke and Waters p. 78). The scanning resolution of the surfaces was initially set to 151 x 151, which results in 151 measurements around the object being taken at each of the 151 horizontal "slices".

The determination of a surface relies on the item in question to be sufficiently reflective to return the laser. In order to minimize spurious data points, the scan must be done in a dark room with nonreflective surfaces nearby. The turntable itself must be covered with a matte cloth. In spite of these precautions, a data set once gathered should not be used directly, but examined and cleaned of polar artefacts, typically present at the top and botton of the scan (Parke and Waters p. 81), removed. Also, because of the high curvature of most bones at the top and bottom of the scan, multiple scans must be taken at different orientations and joined up, or algorithms applied to approximate difficult curvatures, to produce a continuous surface.

The file is saved in the CyberWare proprietary format. Programs are available to convert the file to either Open Inventor (.iv) or VRML formats, and these were used. In order to convert the files to GRASP format, however, the quadrilateral tessellations produced by the scan had to be divided into triangles and the original binary files converted to ASCII. This was performed by a program written for the task, vrml2grasp.

Figure 1: *Surface Viewer in Macintosh 9.x*

When read into the C-language viewer, the converted GRASP file is manipulable in real time. The wireframe mesh primitive of connected vertices underpinning the surface becomes visible via a keystroke command. The surface viewer can also produce a PostScript file or convert the file format to .stl, suitable for stereolithography.

The surface viewer's ability to output a version of a file in .stl file format is potentially very useful to osteoarchaeology. As GRASP is Fortran binary, conversion from an .srf file is a logical one. Stereolithography (or SLA) is a method used in product design for rapid prototyping of a product in engineering or development. A stereolithography machine uses a computer-controlled laser to cure a photosensitive epoxy resin, layer by layer, to create the 3D object. The models can also be used for master patterns to make metal castings off and are easily modified to accommodate changes. Additionally, SLA models are used for photo-optic stress analysis and dynamic vibrational analysis. The objects generated from the resins do not have the physical, mechanical or thermal properties typically required of end-use designs: though research is ongoing into durable materials that will be an acceptable end product, the model shown here is sensitive to moisture and light, though not nearly as friable nor impossible to replace as an archaeological specimen would be.

Figure 2: *a stereolithography scapula*

Other methods of reproducing images as physical models include reductive processes like CNC (computer numeric control), where material is removed from an initial block by shaped bits. Processes that build up the model which are similar to SLA in that excess material is not wasted include SLS (selective laser sintering) in which metal-impregnated compounds are bound together through application of heat.

Finally, to produce static JPEG images of some orientation of the surface, the program sView was written. This is accessible by command line in UNIX and allows the user to specify the orientation of the surface to be used in the image – default is the default orientation. The user can also specify background colour of the JPEG. An example of such an image, from a low-resolution scan of a skull, is shown in Figure 3.

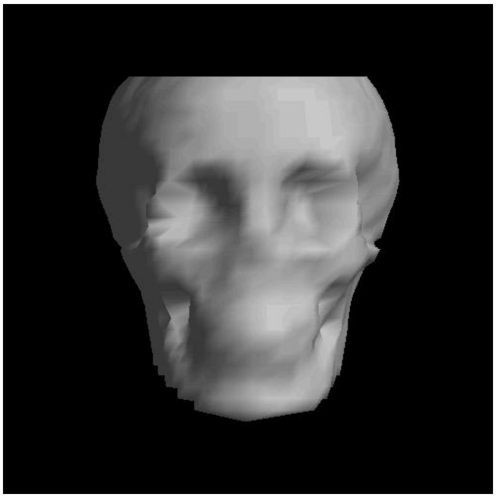

Figure 3: *an sView JPEG*

4. Developments and Future Directions

With a few exceptions such as microhistology and trabecular structure, many of the skeletal features of interest to archaeologists are located on the surface. Therefore it makes sense to adapt programs widely used for surface visualisation to the needs of osteology. Visualisation of molecular surface properties, of concern to medicinal chemistry and other pharmaceutical development areas, provided an excellent analogue for this project. Both GRASP and RasMol are fast and adaptable, making them ideal for the task. The resulting simplicity of the program described here - especially when compared to those in which large scenes or assemblages are manipulated - makes it an ideal tool for many levels of educational applications and for sharing files between academics and other professionals. The sView files, in particular, are of sufficiently small size to attach to email.

Several other projects based on this work were undertaken to explore the viability of offering a Web-based system for accessing osteometric records of skeletal surfaces. These include projects by Xavier Langevin (Langevin) and Rui Tu (Tu) conducted in the Department of Computer Science at the University of Sheffield.

Working from C++ classes of skeletal features based on the recording standards in the *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker) and the basis of the surface viewer, the students adapted the C-language surface viewer to a Java application and Web-launchable applet incorporating data about the skeletal elements and a surface viewer. The important aspect of using such classes is that with the appropriate automatic code generators, parsers, and use of PHP and Cascading Style Sheets, the system can be updated to reflect the needs of a discipline where standards of data recording vary. The user interface was adapted from ARCHERR (Haval), a program for visualising images, surfaces and information about historic buildings.

The laser scanning equipment used for surface collection is widely available, but prohibitively expensive. As most osteometric measures record a chord length between landmarks, it should be possible to recreate through deforming a default model an approximation of a particular bone using the morphometric data. When an image is warped, all positions in an original plane are mapped to positions in a second plane. In two dimensions, this would involve a pair of two-dimensional functions, $u(x,y)$ and $v(x,y)$ that map a point (x,y) in the original image to position (u,v) in the second. The methods of warping images include parametric transformations, such as Procrustes or affine transformations, and non-parametric, such as thin-plate splines and elastic deformation. The difference is in the way smoothness and accuracy of shape match are reconciled, and the methods would have to be explored in order to determine which approach is the best fit for this problem.

All of the work described in this paper has been incorporated into a project that aims to develop a Web-accessible database of archaeological and forensic skeletal human remains (Magnanti). The tools developed here provided a basis for the incorporation of database search and statistical analysis tools into the field of Web-based skeletal examination. When such tools are made available, the sharing of surface images and morphometric information between institutions can increase the body of data available to researchers, thereby improving the development of models of disease, pathology, evolution and taphonomy in human skeletal biology.

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