Three-dimensional modeling of paleoanthropologic tools

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Computer-assisted imaging techniques have revolutionized many fields of research and medicine. In industry reverse engineering based on three-dimensional (3-D) imaging and modeling has been used to create a digital dataset of a complex physical object. These datasets can then be used to produce a virtual or hard-copy representation of the object. These easy-to-handle replicas can be used for a wide range of purposes from inspection to simulation.

Virtual imaging technology has become an increasingly widespread tool for reconstruction and analysis of archeological material. Until now the technique has been applied mainly to fossil hominids. Nevertheless 3D imaging of nonfossil artefacts can provide important clues about the paleoenvironment. Lithic material, e.g., stone tools, holds a wealth of information about cultural evolution. The advantages of 3D modeling of palaeolithic tools are straightforward. In addition to being easier to handle than the original stones, digital images can be copied an infinite number of times and sent over the internet. Replicas of the stone can be reproduced with stereo-lithography.

The purpose of this report is to provide general information about 3D modeling technology and to describe the experience of the FOVEA project (Virtual Excavation of Paleo-Anthropological Environment) (GUIPERT 2003) in developing 3D imaging of palaeolithic tools not only for archival purposes but also for new applications such as automatic indexing or refitting.

Three-dimensional digitizing instruments

Two main types of data acquisition can be distinguished, i.e. passive and active. Passive acquisition does not interact with the object being digitized. It is based on photographic techniques such as photogrammetry or stereovision. The main limitation of passive acquisition is that detail must be extrapolated from different images. This requires precise knowledge of camera settings including focal distance, focal plane, and movements.

Active data acquisition requires some type of interaction between the digitizer and object being digitalized. Interaction can be obtained with or without direct contact. Thus active digitizing instruments are broadly classified as contact and noncontact and include the following:

<u>Contact electro-mechanical arms</u> measure the position of a touch probe in relation to a reference point. In addition to being slow and incompatible with soft materials, this type of digitizer does not allow acquisition of details larger than the probe diameter or of internal or difficult-to-access parts.

<u>Optical scanners</u> are noncontact systems that work on the triangulation principle using a CCD camera to observe a beam of light, e.g., a laser or plain light beam, on the object.

<u>Medical-type scanners</u> are noncontact systems based on time of flight and radar principles using X-ray, tomography, ultrasound scan, and nuclear magnetic resonance. The main advantage of these techniques is to visualize internal parts.

The advantages of medical scanners are that 3D images can be obtained almost immediately and there is an abundance of software available to handle the datasets. The accuracy of medical scanners can reach less than one millimeter but this may not be sufficient to analyze some details of prehistoric tool details, e.g., thin ridges, and the limits of acquisition appear as 'steps' in the 3D model. The main drawback of medical scanners is that they are expensive and must be used in medical establishment where they are located. Similar systems with high definition are available in industry but only for small objects.

Laser scanners have a number of advantages. In addition to being portable and noncontact, the device does not have to be linked directly to a computer and can store data in its own memory. Other major advantages include precision (300,000 apex per shot) and rapidity of the acquisition. However the compromise between noise and saturation is a problem that can only be resolved by performing a high number of detailed passes, thus resulting in longer digitalization times. The inevitable occultation due to the optical system necessitates a long preparation before the digitalization but this problem can be resolved using a revolving table.

Pilot study

In order to obtain the basic references necessary for further development, a pilot study was carried out on casts of two palaeolithic tools, i.e., a chopping tool (122*127*44mm) and a chopper (186/100*32mm). The originals were excavated at Terra Amata, Nice, France and estimated to be around 300,000 years old. These casts selected by a paleontology expert were obtained on loan from the Institute of Human Paleontology directed by Pr. Henry De Lumley.

Casts were made using high accuracy resin. Although sharp edges had been blunted over time, the removal marks were clearly visible: bifacial removal for the chopping tool and unifacial removal for the chopper. Thanks to the quality of the resin the texture or shape of the cast was the same as the original one. The main difference is that the cast is hollow and lighter than the original. By changing surface reflection properties, these factors can have a distorting effect on laser scanning.

Imaging was performed using datasets obtained from three different non-contact 3D acquisition devices, i.e.,

- Siemens® Somaton medical scanner featuring a UFC-detector with 16x0.75mm and 16x1.5mm collimation, prospective ECG-triggering and retrospective ECG-gating (Heart View CT), high frequency X-ray generator and CT X-ray tube StratonTM. Spiral and sequence scanning were performed with the following settings: maximum spiral scan time, 100 s; minimum sequence cycle time, 0.75 s; rotation times, 0.5 s, 0.42 s, and 0.37 s; temporal resolution, up to 92 ms, and maximum power of 60kW and.
- Minolta® Vivid (VI) 900 laser scanner featuring light-stripe triangulation rangefinder, CCD resolution with 640x480 pixels per color, IEC825 class II 690 nm laser, and galvanometer-driven mirror scanning system:
- Minolta® Vivid (VI) 910 laser scanner featuring scanner featuring light-stripe triangulation rangefinder, CCD resolution with 640x480x24bits pixel per color, IEC 60825 class II 690 nm laser, and galvanometer-driven mirror scanning system:

To create the 3D models, we used software developed by a partner in FOVEA project (DELINGETTE 2003). These applications allow extraction of a mesh surface from the image of a structure with a

number of facets that can be predetermined in function of the scanned model and envisage application.
The 3D images obtained using the three systems were compared qualitatively (resolution) and quantitatively (accuracy). For this purpose images were converted to the same graphic format and aligned in the same position using a registration algorithm designed to automatically superpose images. In this way it was possible to calculate the distance between each model and statistical parameters to study the shape discrepancies of each acquisition. The registration algorithm used was an iterative closest point (ICP) algorithm, (HORN 987), (CHEN 1991), (BESL 1992) that has often been for regrading viewpoints of objects obtained by 3D laser modeling. It is based on the following simple process:

1. Initial configuration;
2. Determination of the closest neighbor of m_i belonging to the model M amongst the s_i belonging to S.
3. Determination of the rigid transformation (R,T) of M in S while minimizing application of the transform (R,T) on M:
4. Return to step 2. If the criteria: is inferior to a given threshold or if the maximum iterations is reached.

The main features of this ICP algorithm are good initial configuration, manual tuning or determination of points of correspondence between the model and scene, and slow convergence to a minimum; -A n.log.n complexity, by letting n be the number of points in the model.
For inspection of 3D data we used the Korean software RapidForm that uses an ICP registration algorithm. As a first step a relative table (fig. 4) of the differences was obtained by comparing the different datasets two by two. A “perfect” mean model was created for comparison with the acquisitions.
A comparative study was performed on a detailed zone of the chopping tool, i.e., the cutting edge where the curvature of the tool is the most complex (fig. 6, 7 and 8). This comparison enabled us to study acquisition noise and role of the number of summits and provided a digital reference, i.e., 15,000 summits for the cutting edge (fig. 10). By focusing on a detailed area of high curvature, we were also able to observe that a higher divergence persisted between the models despite the details of acquisition (fig.9). This particularity will have to be taken into account to obtain a faithful model.

***In situ* acquisition**

A second study to determine the feasibility of acquiring 3D replicas of stone tools *in situ* was carried out during the 2004 excavation campaign in the paleolithic cave dwelling site of Arago (450,000 years B.C.) in Tautavel, France. Data acquisition was performed using a portable non-contact 3D laser scanner (Minolta® system). In addition to artefacts that were removed from the ground and cleaned, modeling included casts of the archeo-stratigraphic layers so that the artefacts could be refitted in the archaeological context and changes in a one-meter square zone could be tracked over a one-day period.

A cast was made of the face of the Arago 21 skull (areaC15, layer C7c). It was used to partially straighten the ground in relation to the skull before analysis (SUBSOL 2002). In addition 5 artefacts from the area were digitalized to be reintegrated individually into the model image of the ground area. These objects that give a good idea of what a complete 3D modeling of the ground (THOMAS 2004) would achieve can also be used for educational purposes (virtual excavation) or for museum presentation. Computer-assisted restoration of original characteristics and arrangements of these objects was also performed.

During excavation, the original position of the artefacts was located in three dimensions. Since the different objects overlapped each other in a 3D environment, it was impossible to extract the exact information about their position. A 3D model of the excavation area could be used to replace to the excavation notebook, millimeter scale covering of the area and casts of the archeological level. To assess this possibility under 'extreme' acquisition conditions, a complicated site containing many objects and located against a rock face was chosen and excavation was performed by an experienced excavator whose technique was rapid and precise so as to maximize changes between two acquisitions. A total of 13 shots were made in the morning and 16 during the afternoon.

Conclusion

The results of our pilot and in situ studies provide insight into the advantages and disadvantages of the different digitalization devices. Our results can be extended to all archeological artefacts not requiring internal visualization that would require the use of a medical scanner (too big and expensive for widespread use in the archeological excavation).

The key features of a 3D scanning device for archeological excavation are portability and durability for use under harsh conditions (e.g. high temperature or underwater). The system must be capable of performing more than a hundred thousand points of acquisition in order to have a reasonable precision, possibility of focusing on specific details (e.g. sharp edge of a tools). It must be simple to operate for the variously qualified people who often working at excavation sites. Scanners do not require high overall precision and speed of the digitalization taking less than a minute since the number of objects found per day during an excavation is limited.

The post-digitalization process remains a great challenge for the future as shown by the slow progress in recalibration of the different 3D views (range data), in development of analysis software and 3D imaging.