3-D Digitization Methodologies for Cultural Artifacts

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INTRODUCTION

Historic cultural artifacts are objects of high importance and value. They give evidence of a civilization's culture, heritage, and development over time, and often date back thousands of years and are irreplaceable. Thus, the preservation and protection of artifacts against damage or theft is an issue of importance to museums and other conservation organizations.

Developments made in the fields of computer vision and technology have allowed information about artifacts to be archived digitally. These developments have facilitated the use of electronic models and replicas, and have led to numerous organizations, worldwide, increasing research into methods of artifact digitization . (Surendran, Xu, & Stead, 2007)

The three main methods of digitization can be broadly defined as contact digitization, image-based digitization (photogrammetry), and geometry-based digitization (laser scanning). With the development of the latter two digitization methods, and advanced rendering technologies, virtual displays and museums can now be used widely. (Hung, 2007) Furthermore, recent developments in interactive 3-D computer graphics technology have seen an increased interest in, and use of, 3-D digitization for cultural heritage objects. (Muller-Wittig, Zhu, & Voss, 2007) Technologies for reconstructing or remodeling physical components in 3-D formats are not new in the engineering field, in particular within manufacturing engineering. However, 3-D digitization used for the preservation and archiving of cultural artifacts is relatively recent.

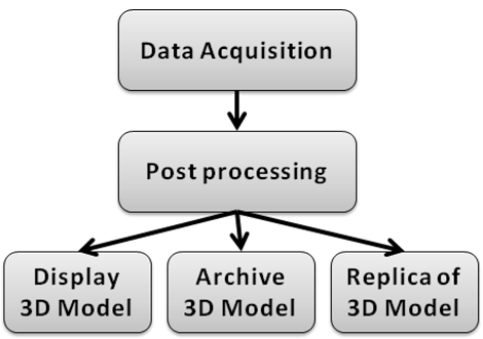
BACKGROUND

Digitization of artifacts is the process of converting spatial and color information into digital formats. 3-D digitization refers specifically to creating a digital representation of an object in three spatial dimensions, that is, Cartesian x, y, and z coordinates. During 3-D digitization, depth, size, proportion, and textural information about the artifact are recorded and stored in electronic form.

There are a wide range of techniques available in the field of 3-D digitization. The specific approach to digitization differs depending on the artifact and the final intended application of the data. The overall process of 3-D digitization involves three broad steps, as shown in Figure 1. Data are acquired using a method of determining and recording the spatial details of the artifact. The raw data are then processed to form complete rendered 3-D models, and then the data are applied to its intended purpose.

3-D digitization of artifacts is an effective method of archiving historic information. It is currently used within museums and other organizations for documentation and security purposes. Furthermore, electronic models give museums the ability to display digital models on the Internet, increasing public awareness and accessibility to the cultural artifacts. The models also facilitate the use of digital interactive displays within museums, allowing viewers to explore objects without risk of damaging the original artifact. Digital information can also be supplied to computer numerical control (CNC) machines to manufacture accurate replicas or

Figure 1. Overall digitization process



support pieces for artifacts. A further application of digitized data is in analysis of artifacts for historical restoration.

CURRENT DIGITIZATION PRACTICES

A number of organizations, worldwide, are promoting research into the digitization of cultural artifacts. These include the Canadian Heritage Information Network (CHIN), the Virtual Heritage Acquisition and Presentation (ViHAP3D) project in Europe, and the Salzburg Research Institute (SRI) in Austria. Some museums are working in collaboration with universities to further research in digitization; in 2004, approximately 35% of museums, worldwide, had initiated developments in some form of 3-D digitization of objects (White, Mourkoussis, Darcy, Petridis, Liarokapis, Lister, et al., 2004). These include the Museum of New York, the Royal Ontario Museum, the Museum of Science Boston, and the American Museum of Natural History. Efforts to establish entire "virtual museums" include The Canadian Museum of Civilization and the National Research Council of Canada collaborating on the production of the Inuit3D Virtual museum, launched in April 2001, and the Computer Science Department of Zhejiang University developing a 3-D Dunhuang cultural relic exhibition system in 2004. (Zhang, Pan, Ren, & Wang, 2007)

The field of 3-D artifact digitization also extends to independent projects, and in several cases, organizations have been assigned specifically to digitize iconic monuments. A project led by Gabriele Guidi, in 2005, involved digitizing the "Plastico di Roma antica," a model of ancient Rome created in the last century. A modulated light scanner was used to provide the accuracy needed to capture the detail of the model's features. The scanner was supplemented by a triangulation scanner to capture the more intricate parts of the model (Guidi, Micoli, Russo, Frischer, De Simone, Spinetti, & Carosso, 2005).

In 2004, the spiral motif at England's Castlerigg stone circle in Cumbria was digitized using the noncontact techniques of laser scanning (using a Minolta 910 scanner) and ground-based remote sensing. No motif was identified through the digitization process, despite the fact that in previous years, the motif image had been observed. This indicated that the spiral was probably painted or had faded due to natural events, and was a novel application of the highly objective methods of 3-D digitization to record the presence of an artifact feature (Diaz-Andreu, Brooke, Rainsbury, & Rosser, 2006).

In 2003, Subodh Kumar, and a team of students from the Johns Hopkins University in Baltimore, undertook the 3-D scanning of ancient cuneiform tablets. Cuneiform documents exhibit writing on three-dimensional surfaces. The team aimed to provide accurate, high-resolution 3-D models of these tablets for scholars' use in their research and for digital preservation of the unique historical artifacts. A laser triangulation scanner was used, using a regular grid pattern at a resolution of 0.025 mm. It was found that conclusive scanning was a challenge using current technologies (Kumar, Snyder, Duncan, Cohen, & Cooper, 2003).

In 2002, David Luebke, and a team from the University of Virginia's Computer Science Department, scanned Thomas Jefferson's Virginia home using a commercial time-of-flight laser scanner, the DeltaSphere 3000. The resultant data from the process was later combined with color data from digital photographs to create the Virtual Monticello, and the Jefferson's Cabinet exhibits, displayed in the New Orleans Art Museum in 2003 (Wang & Luebke, 2003).

The examples described are just a selection of projects that indicate the diversity of applications of 3-D digitization to cultural heritage artifacts.

DATA ACQUISITION TECHNIQUES

The past 15 years have seen the development of different 3-D data acquisition technologies. These include acoustic position trackers, close range photogrammetry, coordinate measurement machines (CMM), holography, laser scanners, magnetic position trackers, and touch probes. The methods of digitization available can be broadly classified as contact or noncontact (mechanical or optical) techniques. (Surendran et al., 2007)

Contact Digitization

Contact digitizing systems work by manually recording points, on the surface of the object, to be digitized. To acquire each data point a probe is activated and runs over the target object. Contact digitizers are commonly used in reverse engineering and manufacturing applications, and are inexpensive and efficient methods for obtaining digital models of objects with low geometric detail. Though these methods could be extended to artifact digitization, in some cases, the process is slower and does not capture as much geometric information as optical techniques. Furthermore, the process of physically touching the object has the potential to damage the artifact itself. For this reason, the two techniques that are predominantly used for artifact digitization are noncontact techniques of laser scanning and photogrammetry (Granero, Sánchez, Micó, Esteve, Hervás, Simón, & Perez, 2007).

Laser Scanning

Laser scanning is a method whereby surface information is captured using laser technology. A 3-D laser scanner is an active system that uses laser light to explore the surface of an object with a process called triangulation, as shown in