3D Acquisition of Archaeological Ceramics and Web-Based 3D Data Storage

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Abstract

Motivated by the requirements of modern archaeology, we are developing an automated system for archaeological classification and reconstruction of ceramics. The goal is to create a tool that satisfies the criteria of accuracy, performance (findings/hour), robustness, transportability, overall costs, and careful handling of the findings. Following our previous work, we present new achievements on the documentation steps for 3D acquisition, 3D data processing, and 3D reconstruction. We have improved our system so that it can handle large quantities of ceramic fragments efficiently and computes a more robust orientation of a fragment. In order to store the sherd data acquired and hold all the information necessary to reconstruct a complete vessel, a database for archaeological fragments was developed. We will demonstrate practical experiments and results undertaken onsite at different excavations in Israel and Peru.

1 Introduction

Archaeology is at a point where it can benefit greatly from the application of computer vision methods, while at the same time provide a large number of new, challenging, and interesting conceptual problems as well as data for computer vision (Martinez 2001). In particular, a major obstacle to the wider use of three-dimensional (3D) object reconstruction and modeling is the extent of manual intervention needed. Such interventions are currently extensive and exist throughout every phase of a 3D reconstruction project: collection of images, image management, establishment of sensor position and image orientation, extracting the geometric detail describing an object, and merging geometric, texture and semantic data. Improvements in rangefinder technology, together with algorithms for combining and processing 3D data, allow us to digitize accurately the shape and surface characteristics of physical objects.

The range and pictorial information of a pottery fragment recorded by the acquisition system serves as the basis for the further classification and reconstruction process (Kampel and Sablatnig 2003a). The profile of a sherd has to be determined by orientation. The term orientation describes the exact positioning of the fragment on the original vessel with the help of the axis of rotation. To automate this process, the profile has to be determined in the same way as in the manual documentation. The generated profile is used to perform the reconstruction and retrieval of fragments of the same type. The reconstruction procedure works if the size of the fragment covers a large part of the original vessel in the vertical direction. The profile is rotated by the original axis of rotation, thus measurements like volume can be estimated.

2 Data Acquisition

The Vivid 900 3D Scanner developed by Minolta used in our setup consists of the following devices:

- one CCD-camera with a focal length of 14 mm and a resolution of 640x480 pixels, equipped with a rotary filter for color separation;
- one red laser with a wavelength of 670 nm and a maximal power of 30 milli-Watts. The laser is equipped with a galvanometer mirror in order to open loop control the laser beam scanning motion.

Figure 1 illustrates the acquisition setup consisting of the Vivid 900 Scanner connected to a PC and the object to be recorded. Optionally, the object is placed on a turntable with a diameter of 40 cm, whose desired position can be specified with an accuracy of 0.1°. The 3D scanner works on the principle of laser triangulation combined with a color CCD image. It is based on a laser-stripe but a galvanometer mirror is used to scan the line over the object. The Vivid 900 is a portable device that does not require a host computer. The optional rotating table is used to index the scanned part and capture all sides in one automated process. Due to its

Figure 1. Scanning of fragments.

weight (11 kg) and size (213 by 413 by 271 mm), it cannot be used as a handheld device, which complicates the acquisition process on an excavation site.

3 Onsite Experiments in Tel Dor, Israel

The traditional method of documentation of an archaeological sherd is a drawing of the profile line, which is a cross-section of the sherd along the axis of symmetry (also called rotational axis). The profile of the fragment can be measured using a profile comb. This comb consists of several movable metal pins that adjust themselves to the surface of the object if pressed on it, as shown in Figure 2. The accuracy of this comb is 1 mm, which is the distance between two consecutive pins. The profile comb is applied to the front and the back of the fragment, the correct thickness is determined by measuring the thickness at the top (ideally the rim) and the bottom of the fragment (in respect to the rotational axis) with the help of callipers. Finding this axis of rotation and drawing the profile line by hand requires expert knowledge and a certain amount of time. It is, therefore, an impossible task to draw all the profiles of a large number of sherds. Another disadvantage is that the hand drawing is dependent on the skill of the draftsperson. It is also very time consuming to manually compare several hundreds of profile lines found in publications.

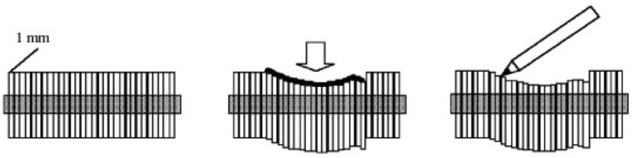

Figure 2. Measuring the profile with a profile-comb (Orton 1993).

A profilograph is a mechanical interface device that can directly acquire and transfer a profile by transferring the 3D coordinates of the profile points to a computer. One disadvantage of this procedure is that the axis of symmetry still has to be found manually, and, also, the time for acquisition of a profile line requires approximately the same amount of time as the manual drawing.

Our group has developed a fully-automated system for acquisition and documentation of archaeological fragments described in Kampel and Sablatnig 2003b. We assume archaeological pottery to be rotationally symmetric if it was made on a rotation plate (Sablatnig and Kampel 2002). We joined the TELDOR Excavation (Stern 1994, Gilboa et al. 2004) in July 2004 together with the Department of Physics from the Weizmann Institute of Science to compare all three methods of documentation with respect to accuracy and performance.

For the comparison of accuracy between hand drawings, profilograph, and 3D scanner, we scanned 35 different sherds that were selected by archaeologists from among the daily finds. The sherds were selected based on the criteria that their size is small and their curvature is low, so that the axis of rotation is difficult to find by manual orientation. The expected failure rate for all methods was high because the sherds contained flat and/or small pieces and pieces with handles. For the performance evaluation we set up the 3D scanner such that we could scan sherds from small (4 by 3 cm) to large size (27 by 20 cm). In order to increase the number of sherds per scan, we placed small and medium sized sherds into a frame. We could then scan up to six sherds per scan, which resulted in a rate of 40 sherds per hour. For a detailed description of the results see (Kampel et al. 2005).

4 Onsite Experiments in Palpa, Peru

The Commission for Archaeology of Non-European Cultures (KAAK) of the German Archaeological Institute (DAI) in Bonn, Germany is conducting a project investigating the pre-Hispanic occupation of the Palpa Valley, Peru. During the field trip in 2005, we brought our 3D scanner to Palpa. The aim of this cooperation was to test the possibilities for documentation of manually manufactured ceramics without the use of a rotation plate by using a 3D-Scanner.

The ceramics for our experiments are from the Nasca Period (200 BC- AD 650) (Reindel and Cuadrado 2001). This material seemed most appropriated for our intentions. During the last nine years of excavations by the KAAK, several thousands of sherds of this period had been recovered from stratigraphic contexts, as well as some one hundred complete vessels from gravelots. Analysis of the Nasca ceramics from Palpa is in process, as is the documentation of the material. The main question of analysis is concerned with the chronology of the Nasca culture. As recent fieldwork has shown, the existing relative chronology of Nasca ceramics is in urgent need of revising (Reindel and Cuadrado 2001; Silverman and Proulx 2002). The possibility of automated documentation by using a 3D scanner is of great interest for the purpose of accurate and fast documentation of the material.

For chronological analysis of Nasca ceramics the decoration of the vessels is of supreme interest. About 40% to 60% of the recovered sherds are decorated fine-ware. The complex decoration themes allow an investigator to make sharp stylistic distinctions that, together with the vessel shape, are the main clues to chronological ordering of the material. For the documentation of decorated sherds, the applicability of the method of automated acquisition to ceramics manufactured without using rotational plates (not wheel thrown) has to be tested. Even more time consuming is the hand-drawing of complete decorated vessels. Therefore, the use of a 3D scanner promises especially accurate and fast results as compared to hand drawing. Furthermore, the high-resolution (< 1 mm) of a state-of-the-art 3D scanner allows the estimation of features regarding the manufacturing process, which are reflected in the symmetry of an object. Analysis of symmetry might help to better understand the manufacturing process of Nasca ceramics and solve the ongoing discussion on the use of rotational plates (pottery wheels) (Wieczorek and Tellenbach 2002; Sackler and Clifford 1983) in South America. Comparison of vessel forms by exactly measured form and symmetry might lead researchers to answer other ongoing questions regarding social, economic, and political organization of past societies.

For our experiments we acquired 38 sherds and 102 complete vessels found in the area. The sherds were used to test the estimation of the axis of rotation using a method of circular template matching (Mara and Sablatnig 2005). This method could be used on NASCA ceramics because they supposedly were not manufactured on rotational plates even though they appear to be rotationally symmetric. The results described in (Mara and Sablatnig 2005) show that Nasca ceramics have not been manufactured on rotational plates. The automated orientation of these sherds does not work because the vessels are not sufficiently symmetrical to the rotational axis.

For our analysis regarding symmetry of NASCA ceramics, we used vessels found during the excavation seasons 2003 and 2004. For each vessel, four 2.5D images of the wall of the objects and one to three 2.5D images of the bottom were acquired to estimate a complete 3D model. The supposed axis of rotation of the 3D model was estimated by fitting circle templates into horizontal cross-sections in the same way as it is estimated for sherds (Mara 2005). To find the orientation for horizontal intersections, the orientation of the object on the rotational plate is used as a first approximation, which is iteratively optimized. Even though these cross-sections can be elliptic; the center of the fitted circle is located between the two foci of the ellipse. Therefore, a line is fitted through the circle centers and assumed to be the rotational axis. Figure 3 shows the horizontal intersections of the vessel 2801-V3 (circular) and 2827-V1 (elliptic). The complete analysis of symmetry is presented in (Mara and Sablatnig 2005).

5 Onsite Experiments in Vienna, Austria

The goals of the project with the Austrian Federal Office for the Care of Monuments were, on the one hand, the digitization (3D scanning) of the entire assemblage of an archaeological excavation and, on the other hand, the development of a user-friendly, computer-aided tool that facilitates the analysis (i.e., measurement) and documentation while shortening the expenditure of processing time when examining archaeological finds. Some distinctive features of the tool are the automatic estimation of the axis of rotation of rotationally symmetric objects, and the extraction and generation of profile lines which are fundamental when dating and publishing archaeological finds. Furthermore, this simple and standardized procedure of generating profile lines allows a uniform representation of different objects. The functionality of the *Profile Analysis Tool* (PAT) will be explained later in this section.

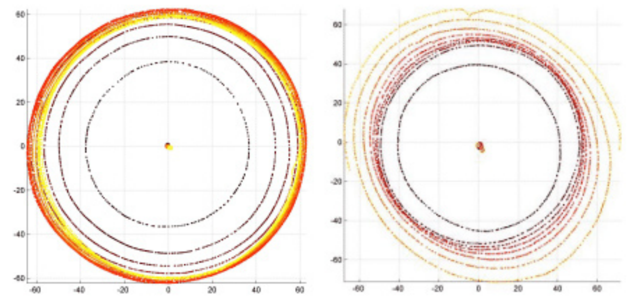

Figure 3. Horizontal intersection of a vessel.

The excavation mentioned above was carried out by the Department of Archaeology in Autumn/Winter 2004-2005 in the courtyard of the so-called *Stallburg*, the winter quarter of the Spanish Court Riding School in the Hofburg of Vienna, Austria. One of the outstanding finds there was a latrine of the late 15th century that contained pottery dating the demolition of the late medieval buildings at this site. The pottery complex contains a large amount of more-or-less whole vessels dating to a very short period of time, i.e., the last quarter of the 15th century, and illustrates the crockery of this period. A total of 217 objects from the latrine were scanned with our 3D scanner and processed with the developed PAT. The group contained 120 vessels and 97 fragments of pottery that were by archaeologists based on their significance.

The central aim of our work was to obtain all required data from each object in as short an amount of time as possible: an entire front view, showing details such as handles, decorations, and grooves, and one or more profiles. According to publication standards, the front view must be in a certain perspective depending on the condition and completeness of the object: handles are usually on right side, the texture surface should be shown as realistically as possible, and the profile has, above all, to show the form of the rim (the main detail for dating pottery) and details like handles or spouts. Furthermore, the profile should be drawn from the most completely preserved part of the object. Figure 4 shows a post-processed 3D model of a jug found in the excavation and a profile generated by the tool developed. Missing parts of the profile are added manually.

With the aid of the 3D scanner and PAT, the average time for analysis and editing of one archaeological object is less than 30 minutes (scanning, pre-processing, and analysis). The digitization, pre-processing, and analysis of the entire assemblage of the archaeological excavation took approximately three weeks.

As mentioned, the emphasis of this project was the development of a user-friendly interface for the automatic determination of the profile line of ceramic archaeological

Figure 4. Table generated from a jug found in the latrine with the developed PAT.

finds. Therefore, we developed a program that satisfies the following points: Wavefront Objects data import; automatic, semiautomatic, and manual determination of the axis of rotation; manual options to align the 3D objects; automatic generation of up to eight profile lines per object; automatic and manual measurement of the objects and profile lines; and database connection to store the evaluated measurements and profiles.

In order to store the 3D data, conventional images of the finds, profile lines, and measurements, we use a MySQL database. Motivated by numerous requests from the archaeological community to share 3D pottery data, and to allow restricted access, we have built database with the following features:

- Web-based interface;
- User management allowing different levels of access;
- Storing of 3D data in various formats (e.g., wrl, obj, dxf);
- Storing of 2D and 2.5D data (Range Data);
- Storing of additional data items depending on the findings to be defined by the user;
- Worldwide access.

In addition to the PAT interface, it can be accessed via a web interface, implemented with Apache/PHP4. The structure of the database allows the storage of an arbitrary number of finds (whole vessels or fragments). Therefore, several fragments can be assigned to one pottery unit, which in turn can be assigned to one specific fabric (archaeological excavation). The data (3D, images, profile, and measurement) obtained with the scanner and PAT can be stored for each object created. There are nine different measurements available to describe the profile: the minimum and maximum wall thickness; the total height and the thickness of the base; the diameter of the base, waist, and rim; the total width of the object; and the diameter of the handle.

Figure 5 shows the simply structured graphical user interface of the main PAT menu. The main menu allows the establishment of a connection to the locally or remotely installed database with the button *Connect*, the import of 3D data with *Open File*, options to align the objects (*Object Rotation*), the creation of profile lines with *Get Profile,* and the closure of generated figures or the program (*Close, Figures, Exit*).

The calculation of the medial axis can be done in three different ways: automatic, semi-automatic, and manual. When using the automatic calculation, the object can be aligned in any way. For the semiautomatic and manual estimation, the 3D object must be aligned to the X-Y plane. When choosing manual alignment, the user must determine the center of the axis manually. The options *Flip Vertical* and *Flip Horizontal* allow a vertical and horizontal flipping of the objects, e.g., when the vessel's handle should be on the right hand side of the profile. *Rotate Z* allows the localization of the starting point for the first profile line, and Y:+1°, Y:-1° can be used for a finer alignment of an off-center base. When the menu button *Measure* is clicked, a new window appears that allows the measurement of the object. For the measurement, the nine different features described above are available. The height and width are extracted

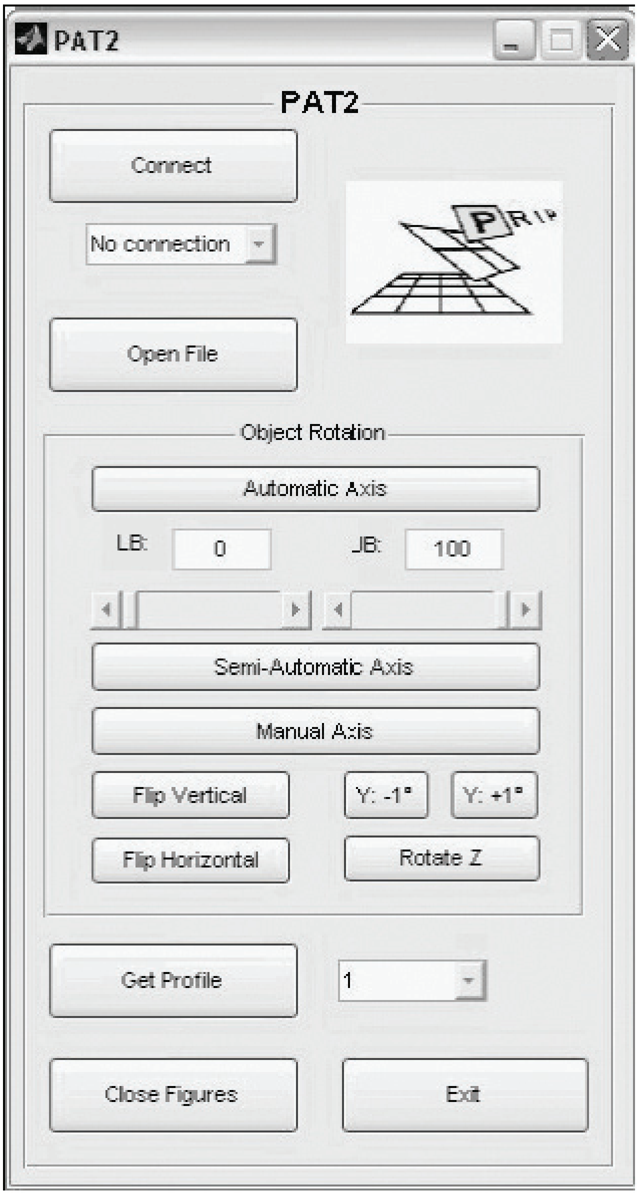

Figure 5. User interface of main PAT-Menu.

automatically; the remainder can be measured interactively by the user.

6 Conclusion

In this paper we presented new achievements on the documentation and, especially, 3D data acquisition of archaeological pottery. We described our research on a systematic comparison of manual versus automated acquisition of ceramics undertaken in Teldor, Israel. Furthermore, we contributed to an ongoing discussion about the ancient use of pottery wheels by an investigation on the ceramics' symmetry in Palpa, Peru. The PAT Tool that we developed, together with the use of the 3D scanner, has the potential to acquire 3D data faster and to analyze the finds in a more efficient way than traditional methods. A considerable advantage is also the 3D digital output, which can easily be accessed via the web. Particularly for complex finds, the 3D scanner and PAT exceed the manual method of drawing and measuring the finds. Further developments of PAT are planned, especially in the direction of automation e.g., automatic determination of measurements of sherd profiles.

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