Measurement of the Density and Granularity of Archaelogical Artifacts by using Industrial Computed Tomography

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***Abstract*—In this paper, we propose a method for easy storing of accurate 3D images of archaeological artifacts obtained with an industrial X-ray computed tomography (CT) device. The obtained 3D image can be used for generating surface models, measuring their thickness and volume, exploring their characteristics, dating earthenware objects, and constructing highly realistic replicas. Since touching artifacts is essential to intuitive reasoning about their historical aspects, the proposed method enables produced replicas to be touched in place of the fragile earthenware artifacts themselves. Our approach makes use of both an industrial CT system and a 3D printer. The surface of the replica is textured while rotating the earthenware artifact by 15° to 30° at a time and taking images along the entire circumference with a digital camera. In this study, replicas were fabricated using a 3D printer and their surfaces were colored by hand.**

Keywords—Digital Archiving; 3D Images; Archaeological artifacts; CT System; Image Processing

I. Introduction

Various applications enable computers to display the shape of archaeological artifacts such as earthenware and stone vessels and figurines. These applications utilize technology for creating survey maps, making precise measurements of the physical parameters of objects, preparing replicas, and creating web content [1,2]. However, since surface measurements are commonly conducted using a laser or a stylus, it is difficult to measure complex surfaces, internal configurations, thicknesses, and volumes [3,4]. In this research which focuses on easily breakable earthenware and stone vessels and figurines, we propose a method for easy storing of accurate 3D images obtained with an industrial X-ray computed tomography (CT) device [5,6]. The obtained 3D image can be used for generating surface models, measuring their thickness and volume, exploring their characteristics, dating earthenware artifacts, and constructing highly accurate replicas.. Precise measurements of the thickness and volume of the artifacts make it possible to estimate when they were created and whether they are real or counterfeit. The ability to touch earthenware artifacts is extremely important to intuitive reasoning about their historical aspects. However, since most earthenware artifacts are fragile, it would be useful to create realistic replicas that can be examined in place of the actual artifacts themselves. Therefore, we propose an approach using both an industrial CT system and a 3D printer. In this study, we took images along the entire circumference of artifacts with a digital camera. Digitizing and modeling earthenware artifacts such as clay figurines makes it possible to create accurate replicas. Here, we used a ZPrinter 250 printer (Z Corporation) with coloring functionality. Since the ZPrinter 250 uses plaster powder, the colors are rather faded. Therefore, we colored the surface of the replica interactively using water-based dyes while referring to the surface color of the original.

II. Digitizing Archaeological Artifacts

A. An Industrial CT System

In order to create a surface model using conventional laser-based measurements, it is necessary to measure both the front and back surfaces, and to subsequently combine the images into a coherent surface model. In this case, it is difficult to match the boundaries between the front and back surfaces, and there is a high possibility of missing certain features. It is also difficult to measure the thickness of the artifacts and their internal configuration. Therefore, we utilized an industrial CT system in order to capture the entire shape as a 3D image. The collection of slice images obtained with the CT system includes information about the thickness and internal configuration. There are two types of CT devices, namely for medical and industrial use. Industrial CT devices have a higher X-ray energy output in comparison with medical CT devices. The most common use of industrial CT devices is for measuring plastic and electrical parts and metal materials, but they can also be used for clay objects. The CT devices used in this study were Micro CT (30~225 kV, Toshiba Corporation), and METROTOM 1500 (225 kV, Carl Zeiss Ltd.) (Fig. 1).

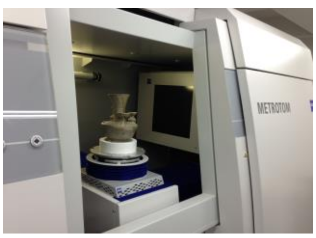

Fig. 1 Digitizing an earthenware artifact

B. *Measurement of clay artifacts*

It is possible to measure multiple pieces of pottery or clay objects simultaneously, as long as they fit together inside the measurement space in the CT device. The images captured are output in an image format, such as BMP, RAW, or DICOM. An efficient approach is to measure several small artifacts together and interactively separate them in the produced images. In addition, there is no need to remove any packaging if the artifacts are measured together, thus avoiding the risk of breaking them during the measurement. Thus, for fragile objects such as pottery, measurements using a CT device are advantageous compared to laser-based measurements.

III. Surface and Volume Modeling

In order to generate a surface model and measure the length, area, and volume of an artifact from a 3D image, we utilize 3D image processing software called Volume Extractor ver. 3.0, which was developed at Iwate Prefectural University [7,8]. Figure 2 shows the interactive extraction process from captured 3D images. Figure 3 shows the surface model created using the isosurface technique [9]. By counting the number of pixels corresponding to the earthenware artifact, we can easily estimate its volume. In addition, by weighing it, the density can be estimated without touching it. Therefore, we also measure the minimum and maximum thickness, as well as the thickness at the center. Figure 2 shows the surface model generated by the isosurface technique, where the volume is estimated from the number of pixels and the thickness is measured interactively.

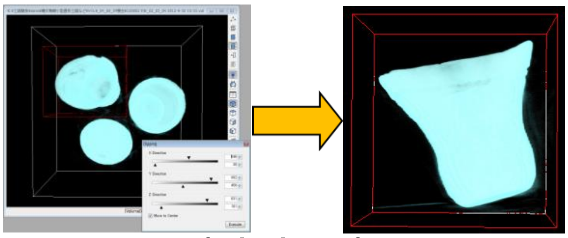

Fig. 2 Extraction of subvolumes from 3D images

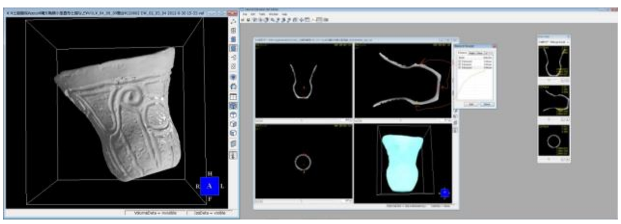

Fig. 3 Generation of a surface model using Volume Extractor ver. 3.0

IV. Evaluation

We selected and measured 16 earthenware artifacts dated from the Jomon to Edo periods (Fig. 4). Table 1 shows the image resolution and pitch of clay artifacts, including tile earthenware, vases, pottery, and figurines, measured using an industrial CT system. The artifacts were dated as follows: 1–3 to the mid-Jomon period, 4–9 to the late Jomon period, 10 to the Yayoi period, 11 to the Heian period, 12–14 to the Nara period, and 15 and 16 to the Heian period. Figures 5–7 show graphs of the weight, volume, and density of the earthenware artifacts summarized in Table 1, respectively. Figures 8 and 9 show graphs prepared by taking the average values for the density and thickness for each period, respectively. In Figs. 5–9 the rows are arranged by age in descending order.

There is a clear trend where the density decreases with decreasing age. After the transition to the Yayoi period from the late Jomon period, the density increases temporarily. This interesting result is assumed to result from a change in the fabrication process in the Yayoi period as well as the different material used for late-Jomon earthenware objects. The weight of each artifact was measured with a scale, and the volume was calculated from the proportion of pixels corresponding to the relevant object in the CT image. The density was calculated from these two values. The averaged values of density and thickness for each period are shown in Figs. 8 and 9, respectively.

As mentioned above, the ability to touch actual earthenware artifacts is extremely important to intuitive reasoning about their historical aspects. Therefore, it is useful to be able to build realistic replicas of these archaeological objects. Here, we propose an approach to replica fabrication using a 3D printer. The surface of the replica was textured while rotating the earthenware artifact by 15° to 30° at a time and taking images along the entire circumference with a digital camera. The images were then connected and blurred the boundary using image editing software, such as GIMP or Photoshop. By pasting the corresponding texture image of the actual artifact on the surface model, it was possible to create a full-scale virtual model.

The texture image was mapped by using Zedit software for texture mapping and coloring (Z Corporation), and the virtual model was constructed using the ZPrinter 2503D printer (, Z Corporation). 3D printers spread a thin foundation of gypsum powder instead of ink and apply binding material while tracing the contours of the input object model. The reusability of the powder material (gypsum) is high, and the ZPrinter 250 can stack contour lines with a width of about 0.1mm. Therefore, layers are less noticeable, and the replica reproduces the original with sufficient accuracy. However, the reproduction of the surface color and saturation were unsatisfactory, and color bleeding was observed. In order to enhance the color, the molding can be colored manually and sprayed with saline solution. This increases saturation, bringing out surface features. Figure 9 shows a replica colored using acrylic paint and dye solution. We colored the replica by hand to bring its color closer to that of the original artifact. As a result, the base model produced by the ZPrinter 250 became more realistic.

V. CONCLUSION

In this paper, we proposed a method for easy storing of accurate 3D images on earthenware artifacts, which were obtained with an industrial X-ray computed tomography (CT) device. The obtained 3D images can be used for dating the earthenware artifacts, measuring their thickness and volume, exploring their characteristics, and constructing highly accurate replicas. In future work, we plan to continue digitizing more earthenware objects from various periods while carefully considering the selection of target objects and learning about their archeological and historical contexts. By increasing the number of examined earthenware artifacts, we can derive more information about their average weight, volume, density, and thickness in each historical period. Since the collected 3D images provide an exact representation of the originals, they can be used for real-time online viewing and replica generation using 3D printers.

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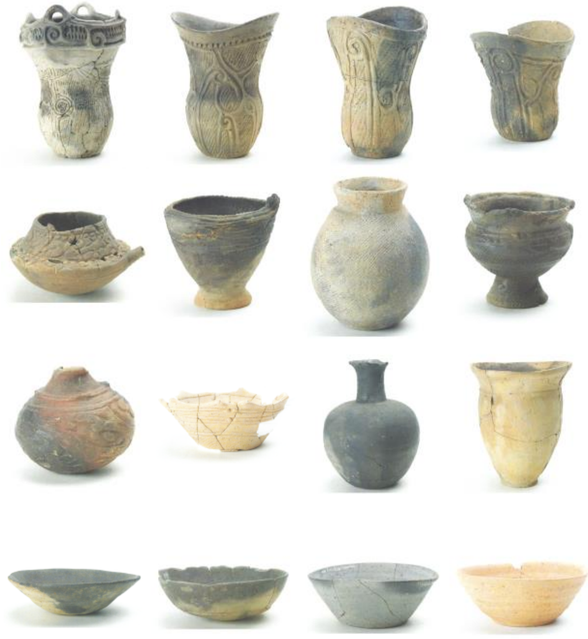

Fig. 4 Measured earthenware artifacts (numbered 1–16 from top left to bottom right.

Table 1 Image resolution for the measured artifacts

Artifact	Image resolution	XY pitch	Z pitch
1	1024×1024×136	0.5859	2.0000
2	1024×1024×1024	0.2329	0.1450
3	1024×1024×1024	0.1848	0.1250
4	976×976×750	0.2188	0.2188
5	1024×1024×890	0.2330	0.1250
6	976×976×980	0.1736	0.1736
7	1024×1024×1024	0.2032	0.1280
8	976×976×750	0.2188	0.2188
9	976×976×750	0.2188	0.2188
10	1024×1024×734	0.2329	0.1250
11	1024×1024×1024	0.2571	0.1900
12	1024×1024×136	0.5859	2.0000
13	1024×1024×669	0.2101	0.1250
14	1024×1024×652	0.2133	0.1250
15	1024×1024×591	0.1981	0.1250
16	1024×1024×591	0.1981	0.1250

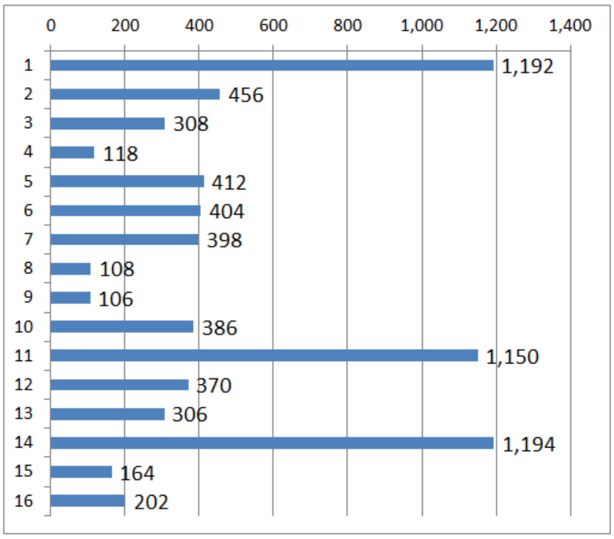

Fig. 5 Measured weight of the earthenware artifacts (g)

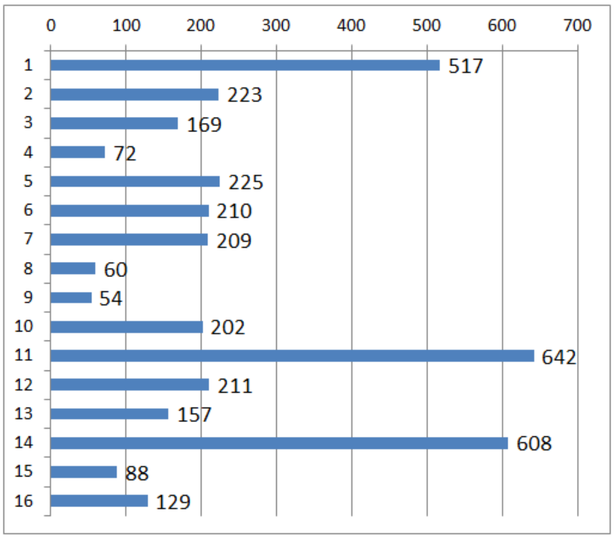

Fig. 6 Calculated volume of the earthenware artifacts (cm^3)

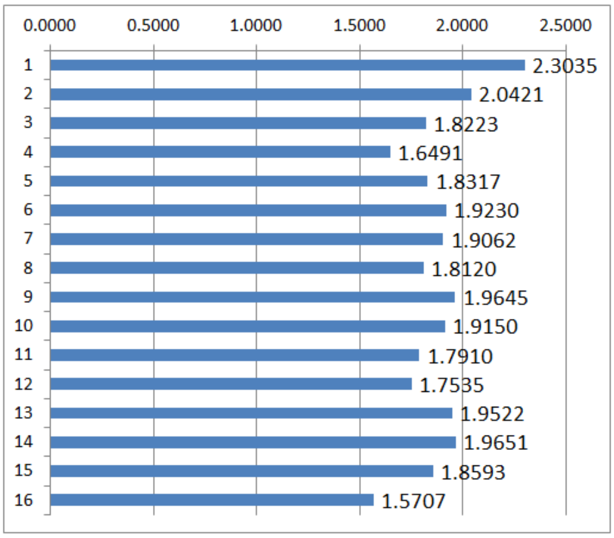

Fig. 7 Calculated density 6 of the earthenware artifacts (g/cm^3)

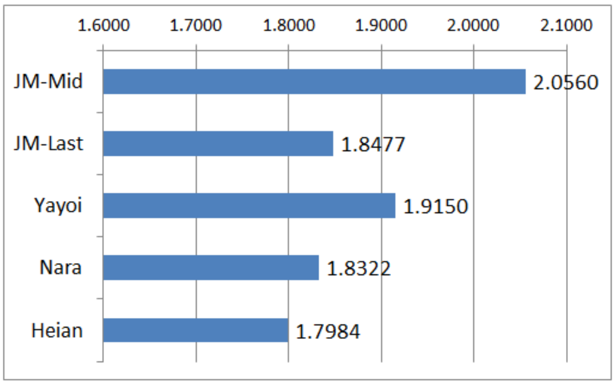

Fig. 8 Average density of earthenware objects from each period

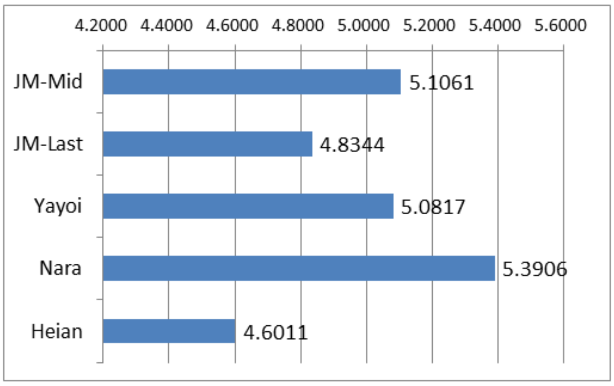

Fig. 9 Average thickness of the earthenware artifacts from each historical period

Fig. 10 Replica fabricated using the ZPrinter 250