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A practical investigation for 3D pottery acquisition

Juraj Sarkisjan[1], Martin Kampel[2]

[1] Charles University, nám. Jána Palacha 2, 116 38 Prague 1, CZ, sarkisjan.j@gmail.com
[2]Vienna University of Technology, Favoritenstr. 9-11/183- 2, A-1040 Wien, AT, martin.kampel@tuwien.ac.at

Small cultural heritage institutions are facing growing problem of the rising amount of unprocessed bulk finds in their depositories. Primary focus of this paper was put on the analysis of the low-cost 3D scanner and on the investigation whether this device might be considered a suitable tool for archaeologists who need to accelerate their task. Secondary aim was to confirm whether all the advantages the high end 3D scanner has to offer are indispensable for the extraction of basic data from the bulk finds. Advantages and disadvantages of both 3D scanners were then analyzed and compared in order to determine which of the two groups is more suitable for the task.

I. INTRODUCTION

The rising amount of unpublished or unprocessed bulk finds in the deposits is considered to be one of the biggest issues of almost every cultural heritage institution with limited depository. The potential of the processed assemblage of the bulk finds, especially pottery sherds and daub, is immense and it might provide information about the trade network of the examined civilization, eating or drinking habits of the group or tell us how advanced the civilization was. However, manual processing of the data is time-consuming and requires manpower, relentless to the repetitive nature of the task.

The development of 3D scanners and automation might prove to be the solution for the cultural heritage institutions, which need to deal with and analyse big amount of data in the fraction of time it usually takes. This paper’s primary focus is the analysis of advantages and disadvantages between two 3D scanner groups which vary primarily in their price category and thus quality of the outputs. The aim of this comparison is to mediate information about the possibilities of the low cost 3D scanners to small cultural heritage institutions, while it is not always possible to afford high-end 3D scanners or technical experts.

Low cost scanners have been considered as a possibility by various researchers for the digitalization of cultural heritage [1], however, most of the models are not accurate enough to provide scan of sufficient quality for the additional research, or 3D printing. Although this issue is considered to be a hindrance for artefacts, which are valuable not only to the researchers, but also to the public, like statues, whole pottery vessels, coins etc., it might not be considered as a critical downsize for plain pottery sherds, daub, or architectural elements, which form a majority of findings in every excavation site. Therefore we added additional criteria to our tests like the time in which the scanner was able to finish the process, technical knowledge needed for further processing of the mesh and overall quality of the scan. Our aim was to discover whether any of the 3D scanners we chose was able to be more efficient than experienced specialists, who are able to extract most of the important information from one sherd in about 3 to 10 minutes, depending on the decoration or complexity of the sherd.

Following chapters of this paper will attend to a brief overview of the 3D scanning technologies, used by both groups of devices. Subsequently, we will introduce the best performing 3D scanners and other 3D scanners used in our research according to the results which were the outputs from these devices. Ultimately, we will compare the outputs from the devices based on other important factors like time of the whole process, technical skills needed and software and hardware requirements, which will reflect in the conclusion of the whole paper.

II. OVERVIEW OF THE 3D SCANNERS USED AND DIFFERENT TECHNOLOGIES

Technologies that can provide the 3D model of an object and are relevant for the archaeology might be divided into broader categories, depending on three main factors.

a) Differentiation between scanners, which need to be in contact with the object or not (Contact type, Non-contact type).

b) Differentiation based on different methods, needed for the data acquisition from the 3D scan.

- Passive devices: object is captured from several angles, the data are subsequently accumulated in order to form a single digitized 3D image

- Active devices: data are obtained from the light, laser or ultrasonic waves reflected from the object using the principle of laser triangulation.
- Mechanical type (measuring arms and CMM machines): object is laid out and fixed on a specific plate, then probed through physical touch.
- Destructive type: the object is broken down in order to get the interior data of the object.

c) Differentiation based on varied range between the scanner and the object.

- Short Range 3D scanner, which is usually defined as one that performs the best within one meter of the object to be scanned.
- Medium and Long Range 3D scanners, come in two major formats – Pulse based and Phase shift. These scanners are able to capture multitude of points by rotating 360 degrees while spinning a mirror, which redirects the laser outward towards the object or areas to be scanned.

Although, there are multiple 3D scanning technologies used today [2], only short-range devices are ideal for this kind of research, which deal with objects smaller than 30 cm. While most of the scans are carried out in closed environments, the optimal range of the device should be less than 1 meter. We worked only with Non-contact types of 3D scanners, because with our current state of technology, the CMM machines are not suitable for daub and irregularly broken edges of the pottery sherd. However, we presume that these devices might be suitable for the extraction of important data like profile and circumference of the pottery sherd.

Throughout our research we used five scanners altogether. Three of the scanners might be included into the low-cost scanner category. They were selected mostly because of the reviews, and speed in which they supposed to scan the object. The other two were a high-end class.

High-end
- Konica Minolta VIVID 900
- Aicon PrimeScan

Low cost
- Scanify 3D Scanner
- Intel SR 300
- Occipital Structure Sensor

First high-end device we used was Konica Minolta VIVID 900, which uses laser triangulation. The objects are scanned by a plane of laser light coming from the VIVID's source aperture. The plane of light is swept across the field of view by a mirror, rotated by a galvanometer. Laser light is reflected from the surface of the scanned object. Each line is observed by a single frame, captured by the CCD camera. The contour of the surface is derived from the shape of the image of each reflected scan line. We used GeoMagic software for the treatment of the 3D scans.

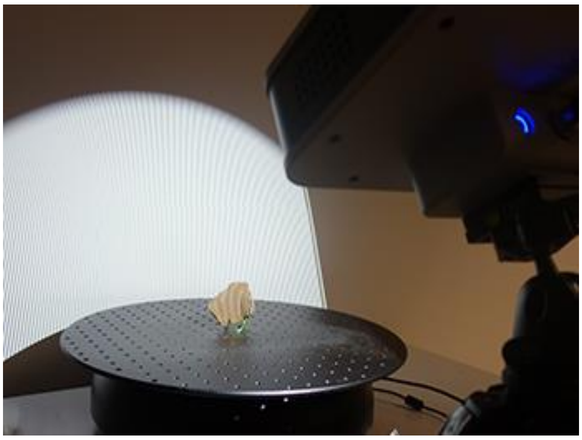

Fig.1 Aicon Primescan during the scanning process

Aicon PrimeScan is based on structural light scanning technology. This 3D scanner also uses triangulation and a camera system, but instead of a laser, it projects a fringe light pattern. The shape of the object is then decoded by calculating the returned patterns of light. The scanner used had FOV (Field of View) 400 (300mm x 275mm) with two 5Mpix cameras with white-light technology for scanning with additional colour information.

PrimeScan works with OptoCat software, which helps the user to align and fuse multiple scans together, thus decreasing the time needed for the entire procedure. (*Figure 1)*

First device, which might be categorized as a low cost scanner, was Scanify. This device scans part of the object by acquiring a series of stereoscopic 2D photographs with several lightning directions. Data fusion is performed to combine the data output of the photometric and geometric processes to produce a single 3D image.

Structure Sensor is a 3D sensing accessory that uses an infrared laser to project structured infrared light into an indoor environment, and captures it with an infrared camera to produce a depth map. Structure Sensor we used was mounted on iPad mini 2 and we used itSeez 3D software for the automatic treatment of the data.

Last one used was an Intel SR300, which is a depth-sensing camera that uses coded-light methodology for close-range depth perception. Camera implements an infrared laser projector system, Fast VGA infrared camera, and a 2MP colour camera with integrated ISP. Camera comes with its own RealSense SDK software.

III. INITIAL STAGE

First step of our research was to determine which low cost scanner is able to capture an object to extent that the user would be able to recognize its basic features and curvatures. We have also tested the ability to capture problematic and most frequently appearing objects for 3D scanners in common assemblage, which are usually considered to be black or very dark, thin and glossy sherds. After the initial scans made on the testing object, which were in our case small dark sherds from the Iron Age, we decided to completely exclude SR300 and Scanify 3D scanner from further research. SR300 was able to capture small and dark sherds, but the error rate was bigger than 3 mm, which is too high considering that some of the sherds are less than 5 mm thick. Scanify was not able to capture small objects properly or at all, and bigger pieces of daub were distorted with multiple dead spots.

Additionally, while both high-end devices, VIVID 900 and PrimeScan, behaved similarly (high quality of the scans, longer time of the entire procedure, technically more demanding), we decided to exclude VIVID 900. Even though the device was used during previous research and evaluated as sufficient [3], the entire procedure, including the editing, took twice as much time on average than with the PrimeScan.

IV. SCANNING PROCEDURE

The testing assemblage consisted of 52 pieces of daub, which were supposed to test the scanners' ability to scan a quantity of objects, and 19 pieces of sherds of different type, which should test the scanners' ability to deal with problematic objects. Both measurements were taken indoors with artificial light, with the exact testing assemblage and by the same person.

A. Duration of the process

First aspect we were testing was the time in which an inexperienced user is able to extract 3D scans of the entire assemblage, excluding the time to install the necessary software. Setting of the environment, where the scanning took place, was relatively straightforward for both devices and both took less than 10 minutes. PrimeScan used motorized rotation table, which was operated directly by the software. In case of Structure sensor, the rotation table caused distortions which were impossible to eliminate, therefore it was necessary to walk around the object. Average scanning process of one object took Structure Sensor less than one minute, while the scanning time of one object took PrimeScan 10 - 15 minutes, mostly because it was necessary to scan the object from multiple sides. Processing of the 3D mash made by the Structure Sensor took itSeez software around 2 minutes and no technical skills were required. Instead some basic skills with 3D software were required during the post processing of the outputs from the PrimeScan. While 3D mashes made from different sides were not aligned automatically. This post processing part took 10 minutes per sherd on average.

Complete process of the data extraction and processing of the 3D scans took Structure sensor less than 6 hours. On the other hand, it took 4 days to finish the processing of the assemblage with the PrimeScan. *(Figure 2)* Although the scanning stage might be substantially lowered by taking a simultaneous scan of several sherds in one scanning procedure (2-8).

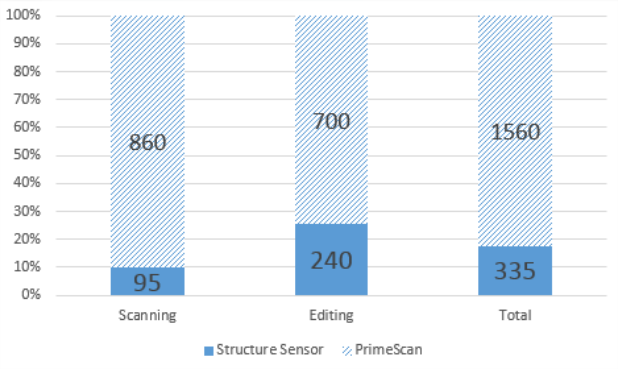

Fig. 2. Comparison between the entire scanning procedures in minutes.

However, this method would not be beneficial for an inexperienced user, while the assembly of a single shard from multiple simultaneous scans would cause that the time saved by this step was lost during the editing of the 3D scans.

The idea of a specifically designed holder which would enable to hold sherds in the air, while the rotating table would move the holder [4], proved to be inefficient for our case. The PrimeScan was able to scan less than two thirds of the surface of the sherd per average, because it was able to capture it only from one angle. Secondary scanning of the sherds from different angles have increased the time needed for the editing (triming, aligning, fusing) exponentially, thus making this method ineffective to be used for a further research.

B. Utilization of the outputs

While it would not be constructive to focus on the comparison between the low cost and high-end scanners in a matter of quality, we examined the outputs of these groups in regards to their potential utilization. Videlicet, whether high quality 3D scans from the high end scanners, might provide supplementary information, which cannot be obtained via traditional method, or whether low quality 3D scans might be used for data extraction.

According to Opgenhaffen et al. [5], high quality three-dimensional models of pottery sherds might provide information on manufacturing methods, technological choices or potter's motor habits. Detailed recording of surface topographies can lead to more accurate analysis of features such as grooves, spiral edges and cracks, commonly examined to assess different shaping techniques (wheel throwing, moulding, coil-building). Likewise, 3D models may establish different degrees of variability in the morphological attributes of a ceramic assemblage, therefore contributing to trace scale and intensity of pottery production. Some of the prepositions might be, however, traceable only in more consistent assemblages, which would contain scannable sherds from a single excavation site. Needless to say, not all sherds might contain valuable information invisible to the human eye.

Color/surface	Structure Sensor	PrimeScan	Calipers
Brown-red/rough	7,32	7,26	7,2
Brown/rough	9,53	9,42	9,4
Black/glossy	5,98	6,02	5,9
Brown/rough	10,24	10,13	10,1
Black/glossy	6,31	6,36	6,2
Brown-red/rough	12,25	12,19	12,2

Fig. 3 Thickness for various pottery sherds in mm

The assemblage which we used proved to be inadequate for us to confirm similar conclusions, mostly because the inconsistency of types of the sherds and their simple characteristics. We faced also an issue with black and glossy sherds where the scanner was not able to capture the entire surface of the sherd, thus we had to apply powdered white chalk, which slightly distorted the data.
However, the 3D scans of daub brought possibilities for the reconstruction of the material to which the clay was attached. Daub proved to be a suitable object for 3D scanning in general, mostly because of the texture and colour, but also because of the quantity of artificial deformities.
Although the limits of the low cost scanners regarding the quality of the outputs are obvious, we wanted to find out whether the error rate was low enough to extract the most important data from the sherds like thickness, radius and profile of the sherd. Our intention was to find out whether it would be beneficial for archaeologists to use these devices as tools for collecting data from the bulk finds, thus substituting profile gauges, calipers and dividers used traditionally for this kind of task.
The initial results from the Structure Sensor exceeded our expectations, while it was able to scan even black and glossy pottery sherds, which were unscannable for both high end devices until the white powdered chalk was applied. The only limitation we encountered was the size of the sherds. The device was not able to track objects smaller then 4cm. The other advantage of the device was that it was able to scan 90-95% of a single sherd in a single attempt. Therefore there was no need to fuse multiple scans together, because we were able to extract the data we required from the first output.
Furthermore, the software itSeez, which we used as a primary tool, was able to run the automated process of editing of the 3D mesh in the background, enabling us to scan additional sherds.

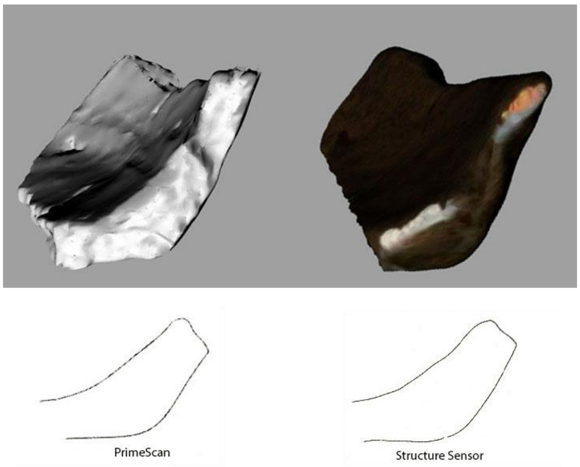

Fig.4 Comparison of the 3D scans and extracted pottery profile made by PrimeScan (left) and Structure Sensor (right)

Processed 3D scans were accessible directly on the tablet we used and on the webpage of the software, no further editing was needed.
After the acquisition of the 3D scans, we started to extract all of the data in Rhino 3D software. The same was done with the 3D scans made by the high end 3D scanner. Values from both scanners were then analyzed and compared with each other. *(Figure 3)*
The results confirmed the visible similarity between scans from both groups and it also proved to be a confirmation that the error rate plays a negligible role for this particular task. (*Figure 4)*

V. CONCLUSION

Primary aim of our investigation was the analysis of the advantages and disadvantages of two different 3D scanners, which differ in their price range and thus in the quality of the outputs.
We concluded that the advantages of a high-end 3D scanner might not be necessary for a considerable part of the bulk finds from inconsistent assemblages. It should be used mainly for assemblages, where the origin is consistent or for selected individual objects, which deformities or unique features might provide valuable insights about the studied civilization. The only possible utilization of a high end scanner we discovered in our assemblage is the potential to bring further insights from daub about the building techniques, by recreating the imprint, which was left in the mud. *(Figure 5)*
Our observations conducted during our work with Structure Sensor proved that even when the precision of the low cost 3D scanners is low, it is sufficient enough for specialists who extract specific data from the bulk finds. This particular low cost scanner was able to capture even black and glossy pottery sherds in time which might be comparable with the speed of a traditional method carried out by an experienced specialist.

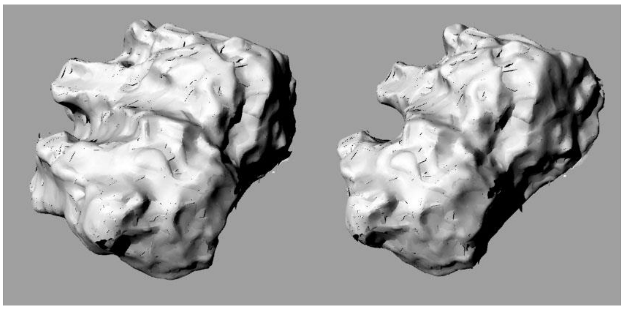

Fig.5 3D model of a daub made by PrimeScan, with 2 deformations caused by branches/sticks

The only limitation which prevented to digitize entire testing assemblage is the incapability of the 3D scanner to capture sherds smaller than 4 cm. However, we presume that continuously developing market with affordable 3D scanners will bring future improvement of the ability of similar devices to capture even small objects and process the mesh even faster.

While the obvious choice for a small cultural heritage institution, interested in the processing of the bulk finds from their depository, would be the low cost scanner, the reason why it is more suitable is not only the price of such a device. The speed of the entire process, portability and overall user friendliness of the software determines better suitability of these devices for the task than high end scanners.

Because of the positive outcome of this investigation and because of the growing possibilities for data utilization, it is probable, that the traditional method for the extraction of data from the bulk finds will face major changes, and specialists might expect to change their profile gauges and callipers for a 3D scanner in the near future.

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