THREE DIMENSIONAL MODELING OF ARCHAEOLOGICAL ARTIFACT USING PHOTOMODELER SCANNER

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Graphical abstract
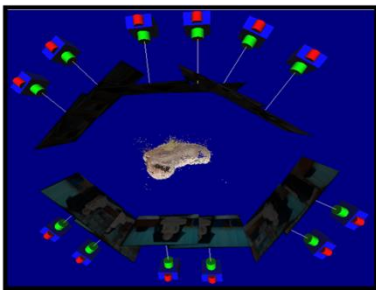
Abstract

This article describes the work of archaeological artifact data recording using close range photogrammetry method. A calibrated stereo camera was used to take the stereo images of the artifacts. Photomodeler Scanner software was used to process the stereo images to produce a three-dimensional model of the artifact. For verification purposes, VIVID 910 laser scanner was used to generate three-dimensional model of the same artifact. The study found that close range photogrammetry method is easy to use, with fast data recording, fast data processing and it is a method which is cheaper than the laser scanning method.

Keywords: Archaeology, artifact, three-dimensional model, photomodeler scanner, low cost

Abstrak

Artikel ini menceritakan kerja-kerja merekod data artifak arkeologi dengan menggunakan kaedah fotogrametri jarak dekat. Kamera stereo yang dikalibrasi digunakan untuk mengambil gambar stereo artifak. Perisian PhotoModeler Scanner digunakan untuk memproses gambar stereo tersebut untuk menghasilkan model tiga dimensi artifak. Untuk tujuan verifikasi, pengimbas laser VIVID 910 digunakan untuk menghasilkan model tiga dimensi artifak yang sama. Kajian ini mendapati bahawa kaedah fotogrametri jarak dekat adalah mudah digunakan, merekod data dengan cepat, memproses data dengan cepat dan merupakan satu kaedah yang murah berbanding kaedah pengimbasan laser.

Kata kunci: Arkeologi, artifak, model tiga dimensi, photomodeler scanner, kos murah

1.0 INTRODUCTION

Cultural heritage and artifacts are a unique expression of history and national identity which enriches our lives and provides a significant foundation to our future national development. Therefore with new technologies and development in automating the documentation of museum collections, this will be a good start towards the continuous preservation of Malaysian heritage.

In the past, the act of documenting artifacts is primarily undertaken to accurately record the status and condition of important physical features. The method that had been used is painting, photography and lithography where we can get a two dimensional

(2D) records. Recently using digital close range photogrammetry and laser scanning techniques, we can achieve three dimensional (3D) data (Bryan et al, 2003). A 3D model allows us to simulate the reconstruction of broken parts, rapid prototyping, research and restoration works.

This 3D model technology will gives a rise and brand new appearance in archaeology field. The automation of documentation and visualization will also gives a fresh and modern environment to museum that often people see as an ancient technology. The artifacts in museum can be modeled and stored as digital copies for documentation purposes. The acquired 3D models can be displayed through museum kiosk and virtual museum website. It is also will help in fostering and increasing public's interest towards our history and heritage in a more interactive way. While archaeologist can easily find any artifacts that they needed for their research rather than wasting time to jump from one museum to another. Besides, it also enables the restoration of excavated relics, architectural reconstruction of historical places and rapid prototyping of artifacts into miniature form for selling purposes and etc.

There had been few approaches in creating the 3D model such as close range photogrammetry, terrestrial laser scanning and some conventional methods for example tape measurements. All of these methods have its own advantages. Laser scanning is a well established method to record and document the artifacts by generating 3D models. The 3D model produced is for visualization and measurement purposes. This output is also suitable to be used in further application such as Geographic Information System (GIS) integration and development of virtual museum that can also enhances our tourism industry.

1.1 Overview of Three Dimensional Modeling in Artifacts

Three dimensional (3D) modeling has been a subject of intensive research for a long time. Mature solutions exist and improvements of their performances have been appearing constantly. In the field of cultural heritage and among others, in archaeology these technologies have been used successfully for many years (Forte and Pietroni, 2009). However, though many impressive results may be found in the literature, 3D modeling remains a sophisticated task which requires specific skills as well as adapted equipment (Al-Kheder et al., 2009).

According to Kadobayashi et al (2003), 3D modeling of sites and artifacts has increased remarkably in recent years. A wide variety of objects (examples small pieces of pottery, statues, buildings and large areas of archaeological sites), have been modeled for such purposes as preservation, reconstruction, study, and museum exhibitions. Many approaches and options have been used and tested to achieve the objectives for modeling due to the range in size of the objects and differences. Laser scanning and digital photogrammetry are two common technologies that have been developed for this agenda.

Advancement of modern technology in 3D laser scanners has set a whole new scene to the recording, preservation and study of historical artifacts. The capability of laser scanners to automatically digitize the 3D coordinates of the complex shape makes it easier to create a detailed 3D model of the object from a point cloud. On the other hand, the quality of the color images obtained from the laser scanners are worse than from the photographs. Therefore, digital photogrammetry method is taken into account to fulfill the best requirements.

Digital photogrammetry using digital cameras has come into practical due to the increased number of pixels available with digital cameras and the development of highly capable personal computers. This method obtained accurate 3D coordinates of objects, create 3D models from 2 or more overlapping photographs while at the same time use it to record and represent the appearance of objects. As Guidi et al (2004) stated to record historical and archaeological sites digitally, the most practical and effective approach is to combine 3D laser scanning and digital photogrammetry.

Both technologies have given a vast impact in historical artifacts and cultural heritage application. It will benefits the documentation system of the artifacts and also dimensional monitoring possibly useful for sculptures that are subject to damage by environmental elements and pollution. Documentation in this field is broadly defined in two main activities which are capturing the information regarding monuments, buildings, and sites, including their physical characteristics, history and problems; and secondly is the process of organizing, interpreting, and managing that information.

Besides that, the resultant 3D models can also be represented via multimedia artwork allowing researchers and public to easily access the museum virtually through the web. This will also help and give rise in the possibility of measuring, selecting and analyzing artwork for the purpose of historical studies. In addition, it also can be used in virtual restoration of artwork available in fragmented form, physical reproduction by rapid prototyping techniques and archiving of artworks (Guidi et al, 2004).

Concisely, 3D modeling plays important roles in the field of historical artifacts. It is very crucial to preserve the cultural heritage and raise public's awareness towards the meaningful history of their countries. Thus, an innovative and creative documentation system is also needed as to support this awareness agenda and foster their interest in historical studies.

1.2 Related Works of Other Researchers

The issue of 3D modeling in archaeology is not new to researchers worldwide. This technology has received a great attention from archaeology community. The International Committee for Documentation of Cultural Heritage (CIPA) was established in collaboration with International Society of Photorammetry and Remote Sensing (ISPRS) and International Council on

Monuments and Sites (ICOMOS). According to CIPA (2010), the main purpose of this committee is to improve the methods for surveying of cultural monuments and sites, especially by synergy effects gained by the combination of methods under special consideration of photogrammetry with all its aspects.

Researchers around the world had gained a lot of benefits through close range photogrammetry technique. They have been used this approach to obtained 3D model and data from the artifacts. Softwares, algorithms and equipments have been used as a method to develop this technique. By using photogrammetry technique, the size of the artifacts can be ranging from small to large objects. Table 1 illustrates briefly on the related works that have been done by other researchers around the globe.

Table 1 Related works of other researchers

YEAR	RESEARCHERS	LOCATION	SUBJECT	METHOD
2009	Alby et al	Strasbourg, France	Limestone	Canon EOS 5D & PhotoModeler Scanner
2009	Koch & Kaehler	Berlin, Germany	Apadana Palace	3D Laser Scanning & CRP PHIDIAS
2008	Ulas Yilmaz et al	Ankora, Turkey	Small artifacts	Close Range Photogrammetry
2008	Ji Zheng et al	Wuhan, China	Skull	Close Range Photogrammetry & algorithms
2007	Tsiligiris et al	Athens, Greece	Monument	Close Range Orthoimage & Digital Camcorder
2005	Duarte & Altrock	Florianopolis, Brazil	Rocks art	Close Range Photogrammetry & Z/I Imaging
2004	Boehler & Marbs	Mainz, Germany	Stone wall	3D Scanning & Photogrammetry

1.3 The Terracotta Buddha Statue

The subject for this study is a terracotta Buddha statue as in Figure 1. According to Bujang Valley Archeological Museum Guide Book, this artifact was found at Site 21 and 22 in Candi Pengkalan Bujang, Mukim Bujang, Kuala Muda District, Kedah Darul Aman. This Candi was found in 1936 on the left bank of Sungai Bujang and re-explored in 1974. Excavations were carried out in 1976. It is built mainly of bricks. Its pillar based were chiseled from granite and its roof was made of tiles. Now the terracotta Buddha statue was placed at Bujang Valley Archeological Museum. The location map of the museum is as Figure 2.

Figure 1 The terracotta Buddha statue

Figure 2 Location map of Bujang Valley Archeological Museum

Apart from the terracotta Buddha Statue, artifacts found here include terracotta elephant statue, terracotta Boddhisatva statue, bronze statue possibly representing the goddess Bhrkuti, Kala head, gold rings, earrings, bricks inscribed with Pallava letters and marked with animal footprints, ceramic sherds, Middle Eastern glass, iron nails and beads. Based on this data, this Candi is believed to have possessed a stupa used by ancient Buddhists. It was probably built during the 11th century A.D.

The Candi ruins from Site 21 were moved to Bukit Batu Pahat, Mukim Merbok and reconstructed in 1976. While, the Candi ruins from Site 22 were reconstructed in its original location at Kampung Pengkalan Bujang the same year.

1.5 Photo-Based Scanning

A new class of 3D scanning technologies called photo-based scanning or photogrammetric scanning is the solution for creating dense 3D point clouds and detailed surface models of physical objects. Nevertheless, this new technology are cost-effective and in efficient manner. This technology uses a standard off-the-shelf digital camera in combination with specialized software that analyzes the digital images and no additional hardware required (Walford, 2007).

In 2008, the influence of modern computers and development techniques brought us to affordable close range photo-based 3D scanning. This technique is based on research and development of photogrammetric topographic Digital Elevation Model (DEM) creation and computer vision stereo matching. This approach brings the accurate measurement mindset from the photogrammetrists and the advance matching algorithm techniques from computer vision. Photo-based scanning system is capable of calibrating cameras and accurately solve for the position and orientation of the camera when it took the photos.

The new approach uses light rays but in a passive way. The ambient light reflected off the object is captured by the camera from two or more positions. The figure below shows how the camera uses external light source in a passive way:
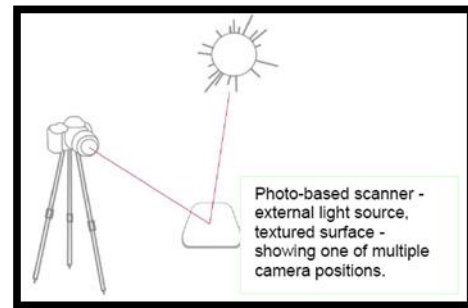

Figure 3 Camera detecting reflected ambient radiation

According to Walford (2007), the photo based scanning software then compares two photos on a small patch by patch basis. It compares the patches across the images to find the best matches. When these optimal matches are found, the already computed position and orientation information for the photographs is used to compute the location of that patch in 3D space. When a regular grid of patches is sampled in image 1, and matched to the optimal image positions in image 2, the result is a dense cloud of 3D points. Figure 4 shows the matching process using patch by patch technique:
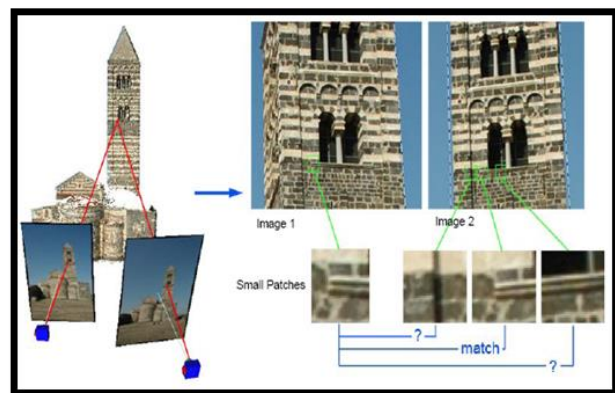

Figure 4 Matching process using patch by patch technique in software

The requirement needed for the matching process to work, the surface being scanned must have a texture. The surface should have random pattern like carpet, rock, and gravel, concrete or human skin. The surface cannot be blank or shiny like paper or clean metal. Figure below is an example of object that has been scanned successfully with photo-based 3D scanning software:
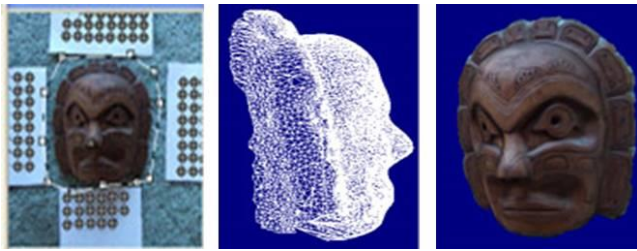
Figure 5 Mask photo, point cloud of mask and 3D model of mask

2.0 METHODOLOGY

This section discussed all the steps involve in generating the 3D model of artifacts. This study is carried out by using two different methods which are digital close range photogrammetry and laser scanning technique. Figure 6 shows the overall flowchart of the stages involved:
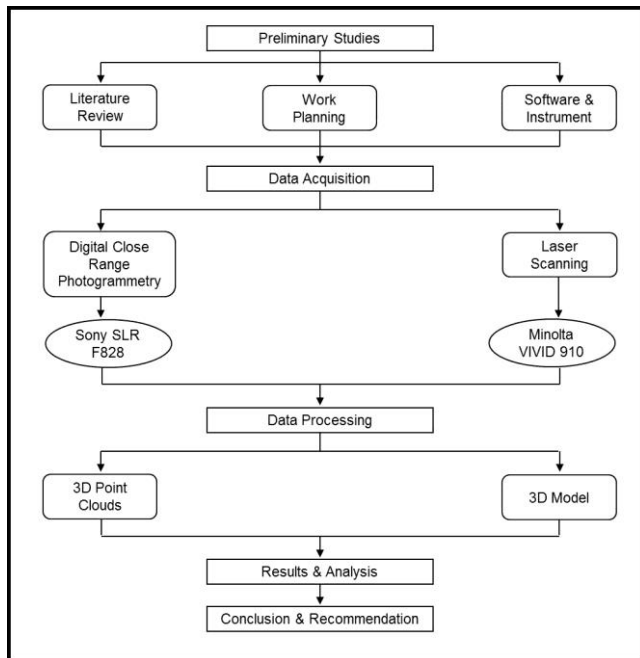

Figure 6 Overall flowchart of research methodology

2.1 Digital Close Range Photogrammetry Technique

This section is sub-divided into few sections which are project planning, camera calibration, data acquisition and data processing in PhotoModeler Scanner software. Figure below are the steps taken and involved in this study:

Figure 7 Flowchart of digital close range photogrammetry technique

2.1.1 Project Planning

Before data was collected, the subject that was going to be used in this study was determined. In this study, the terracotta Buddha statue that was recovered from Site 21 Candi Pengkalan Lembah Bujang, Kedah was used as subject. After that, determine how the photos are taken to make sure all the photos taken are able to meet the requirements. In this research, stereo pair method was used to take the photographs to make sure that photographs are in parallel orientation and overlap on the surface being modeled.

2.1.2 Camera Calibration

Camera calibration is the process of determining the characteristics of a camera so it can be used as a measurement device. PhotoModeler Scanner software needs values for some specific parameters of the camera to use the image information in a photograph. Generally, the minimum properties that required are effective focal length of the lens, digitizing scale or sensor format size, principal point and lens distortions characteristics (PhotoModeler EOS System Inc., 2008). Camera calibration is a method for accurately determining values for these camera parameters. Once a camera is calibrated, it will provide accurate measurements. By using PhotoModeler Scanner, a camera calibration function is includes in the software package. It is a simple procedure for estimating these values by analyzing an array of targets that comes along with calibration grid in PDF file format. The calibration grid can be obtained from the Photomodeler Scanner software installer package as in Figure 8.
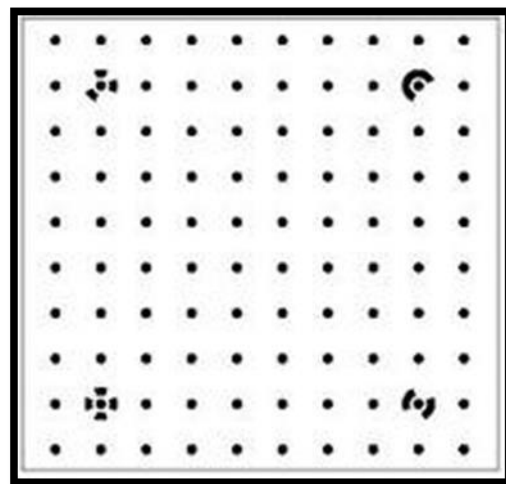

Figure 8 PhotoModeler Scanner's calibration grid

The calibration grid contains doted targets and four coded targets in a grid manner was printed suitable size referred to the object size itself for calibration purposes. The paper was positioned flat on the floor. To obtain the data needed to calibrate a camera, at least six

photographs taken from different angles of a calibration grid are needed. Therefore in this research, photographs are taken from four of the sides where each photo on landscape view and two of the sides where positive 90 degrees roll. The figure below shows the camera location for the calibration purposes:
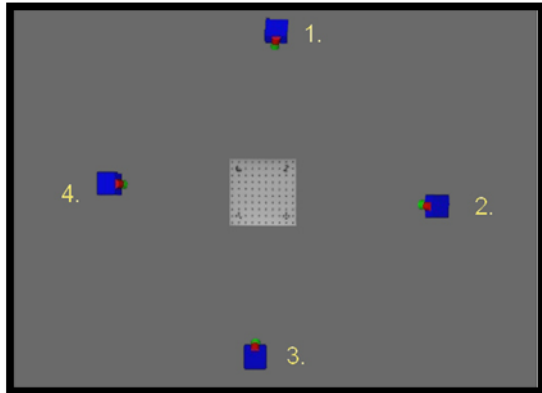

Figure 9 Top down view of camera position during camera calibration

So, there were six photographs (APPENDIX A) as a total number of the grid being captured. The calibration grid remains unmoved at all time as the camera is moving from the four sides to take the photographs. All the photographs are imported into PhotoModeler Scanner to run the automated camera calibration process. Since this research is using stereopair method, therefore there are two cameras need to be calibrated. The steps to calibrate the camera are the same for both cameras and it is calibrated separately. Thus, in PhotoModeler Scanner software there were two cameras in the camera library that were used in this project.

2.1.3 Data Acquisition

The calibrated Sony DSC-F828 SLR camera as in Figure 10 is used to capture the photographs of the objects. One has to work on pairs to obtain a dense point clouds. Therefore, stereopair method is used in this research to obtain stereopair images.

Figure 10 Sony DSC-F828 SLR camera

With the aid of a controller, both cameras can capture photos simultaneously. A tripod and mounting steel camera bar are used to make sure the distance from both cameras to surface is same. The setup of the camera system is shown below:

Figure 11 Camera system setup

The camera positions were approximately one quarter the distance apart compared to the distance of the cameras from the surface. The flexibility of this ratio is between 0.1 to 0.5 bases to height ratio. In this project, camera base was determined at 15cm between cameras and the average distance from cameras to the subject surface was determined at 50cm. So, base to height ratio computed was within 0.3. It is important to work without the zooming capabilities since the calibration corresponds to only one fixed position of the zoom. Lighting conditions should also be controlled. The time taken to capture and acquire all the photographs is less than 30 minutes. The number of photos had been captured were six stereopair photos and that make a total number of 12 photos (APPENDIX B).

2.1.4 Data Processing

Image processing and 3D point cloud generation are done using PhotoModeler Scanner software. All the stereopair images are imported into the software and assigned with the camera calibration file from the camera library. The software will use the internal camera calibration parameters to process the images. Figure 12 below shows the general steps that have been carried out to model the terracotta Buddha statue:
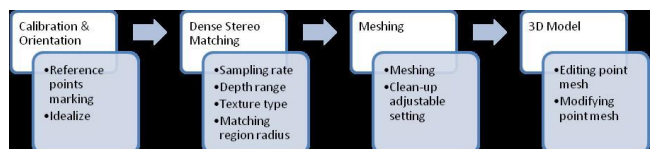

Figure 12 Data processing steps in PMS software

2.1.4.1 Referencing

This study was conducted in a non-contact environment since the object of this study is an artifact. Therefore, there are no coded targets on the statue. Besides, natural targets on the statue itself are being used as aid to mark the reference point. The natural targets are manually marked as precisely as possible on the easily recognizable areas on the images. A unique identification number (1, 2, 3,…) is assigned when a point is marked on an image. The next step is to mark other images with reference to the marked points. The software will reassigned the same identification number as the reference marked point when marking the point. The referencing operation is done manually until certain minimum numbers of points are referenced on all images. In this project, the minimum number of 20 points and maximum of 50 points are referenced on all images. However, to obtain the dense point cloud, it is also necessary to regularly spread points entirely on the object especially on the areas where there are edges.

  Once enough points have been marked, the orientation may be processed. Processing of all the points runs a photogrammetric bundle adjustment algorithm. It results in the spatial location and orientation angles of the camera for the stereopair images. At this stage, all the images are being oriented. The next step is to idealize the image using the Idealize Module. The Idealize Module will take an existing project and use the calibrated camera parameters to produce an idealized camera and images. It will re-map any specified images removing any lens distortion, non centered principal point and any non-square pixels. It will then adjust the existing marks to match the undistorted image and then assign an idealized camera to the project. The result from idealized process can be seen in figures below:
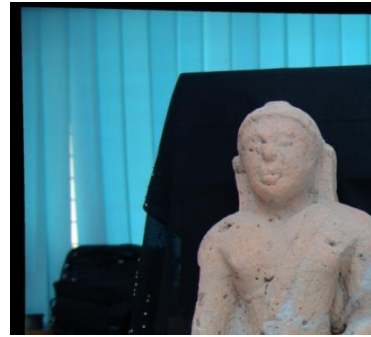

Figure 14 Idealized image

2.1.4.2 Dense Stereo Matching (DSM)

Next is to define the DSM area of interest using DSM Trim tool. DSM Trim is a 2D polygonal region defined on a photo. These trim boundaries restrict the DSM algorithm to search only within the outlined areas of the photos. This allows PhotoModeler Scanner software to focus on DSM in a specific area and can help reduce processing time by reducing the search area, as well as reducing noise and unwanted regions. Then, the matching process can begin with selecting the stereopairs images to process and defining appropriate DSM parameters in DSM Options Dialog. They are sampling rate, depth range, texture type and matching region radius. The DSM process creates an object called a PointMesh which is a set of 3D points with optional triangles connecting them. All meshing tools except the contours in Figure 15 need to be run to convert the PointMesh into a useful surface. Besides, the meshing tools will also register and merge all the points cloud, fill holes, reduce noise and smooth it.
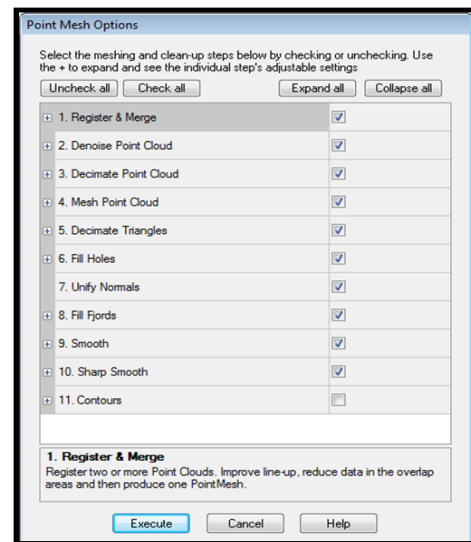

Figure 13 Raw image

Figure 15 Meshing Tools Dialog Options

  After the meshing steps done, the point clouds are converted into a triangulated mesh surface. Now, user can view the 3D model in the 3D Viewer. The last step is

to modify the PointMesh to clean up the noise. The 3D model also can be viewed with a texture on the statue. To do this, turn the surface type to quality texture that will display the point clouds using an individual RGB color extracted from the photo.

2.2 Laser Scanning Technique

As for comparison purposes, the laser scanning technique also involved in this study. However, this study is focused more on PhotoModeler Scanner software but on laser scanning technique still will be explained generally. This section is sub-divided into few sections which are project planning, data acquisition and data processing. Figure below is the steps involved in this study:

Figure 16 Flowchart of laser scanning technique

2.2.1 Project Planning

Konica Minolta VIVID 910 is used to acquire the data from the terracotta Buddha statue. This equipment is using laser scanning principles. This scanner and its rotary table were linked to the desktop using cables. This scanner was interfaced and operated using Polygon Editing Tool software which comes along with the scanner. After setting up the workspace, the scanning process can be done. First of all is to place the object on the rotary table.

Figure 17 Konica Minolta VIVID 910

The advantage of using this rotary table is reducing the scanning time, since operator do not needed to rotate the object manually. Other than that, the rotation axis of the rotary table with respect to the scanner's reference frame can be easily obtained by scanning a calibration pattern which allows for simple, accurate registration of partial scans into a complete model (Isler et al., 2006).

2.2.2 Data Acquisition

There are two primary steps involved in data acquisition which are chart calibration and object scanning. We need the calibration chart because the statue is scan on the rotary table. First step is to scan the calibration chart. Second step is to scan the statue by using the parameters that are already been determined and set. The parameters are including type of lens, distance from scanner to object, intensity, scan parameter, convert parameter, stage parameter and number of scans. Table 2 summarized the settings used to scan the statue:

Table 2 Parameters setting for terracotta Buddha statue

Parameters	Settings
Type of lens	Middle
Distance (mm)	1100
Intensity	None
Scan parameter a) Mode b) Use color	 Fine No
Convert parameter a) Reduction rate b) Fill holes c) Filter d) Remove	 ¼ Off None None
Stage parameter a) Rotation step	 60°
Number of scans a) Step scan b) One scan	 6 (cover sides of objects) 2 (cover upper and bottom part of object)

2.2.3 Data Processing

The partial scans obtained from the object were imported to RapidForm software. The raw data can be imported either points with polygon meshes or points only. The data can be displayed in seven types of mode which are point set, wire frame, hidden line, shaded, shaded with edge, transparent and textured. After import all the data, next step is noise elimination. Then, it is the registration step. This step is taken to register multiple points or polygonal shells using overlapping regions. There were multiple scans taken to cover the whole object and hence those scans need to be aligning properly within the viewpoint to construct the original 3D model. Lastly, is followed by the merging surface steps. This operation merges shells which had been aligned by registration process into one united shell. During this process, overlapped regions between shells were removed and neighboring boundaries were stitched together with newly added polygons. The results and accuracy of shells were still maintained after merging. The 3D model was generated once the

merging process was done. Figure 18 shows the steps taken to process the statue data in RapidForm software:

Figure 18 Data processing steps in RapidForm software

3.0 RESULTS AND ANALYSIS

The final output of point clouds were executed from six stereopairs image. The resultant point clouds were generated from 6 camera stations as in Figure 19. Figures 20 and 21 below show the textured surface 3D model from PhotoModeler Scanner software. While Figures 22 and 23 shows the 3D model from RapidForm software.
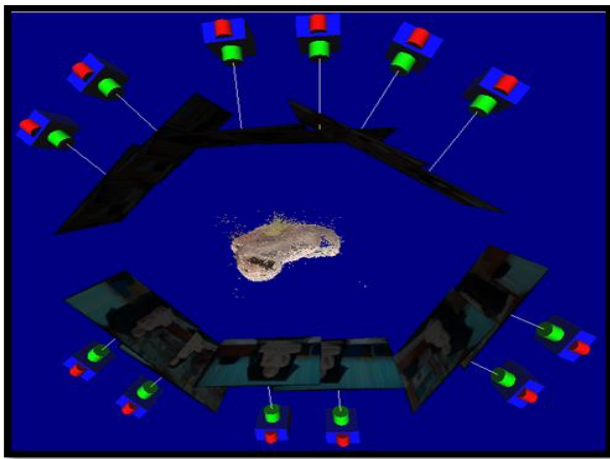

Figure 19 Top down view of camera position during data acquisition

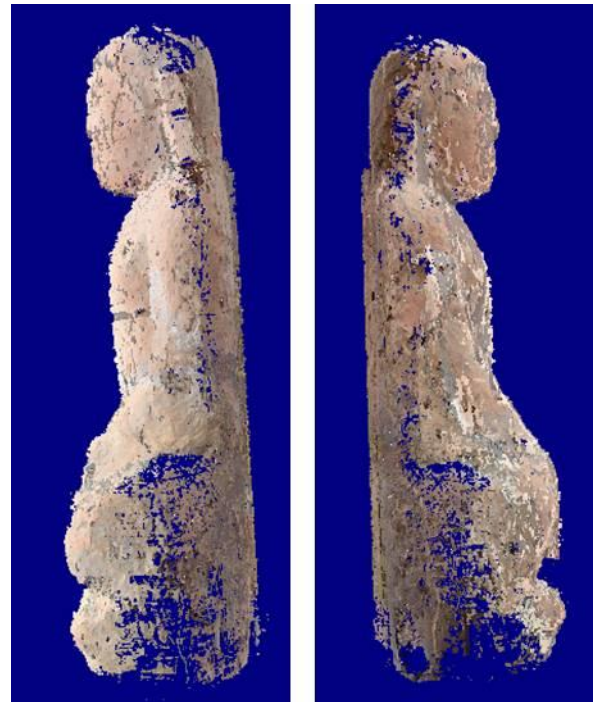**Figure 20** Front view and back view of the 3D model from PMS software

Figure 21 Left view and right view of the 3D model from PMS software

Figure 22 Front view and back view of the 3D model from RapidForm software
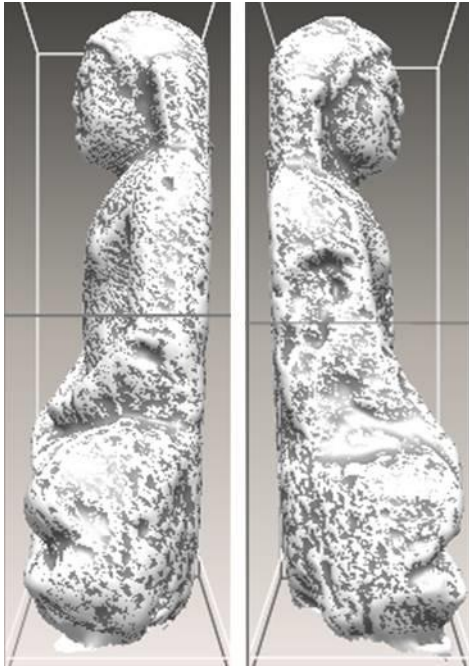
Figure 23 Left view and right view of the 3D model from RapidForm software

From the figures, a 3D model of the terracotta Buddha statue is successfully modeled with the photo-based scanning technique using PhotoModeler Scanner software. However, the points cloud produce are not denser enough as compared to the laser scanning technique. This is due to the quality of the stereopairs images that could not cover the whole object.

3.1 Distance Measurement

As for comparison, few measurements were done on the object to analyze the precision of measurements from PhotoModeler Scanner software. 5 distances were measured on the object as shown in Figure 24. The measured distance values using 2 different techniques are shown in Table 3.

Table 3 Measurement difference between digital close photogrammetry and laser scanning technique

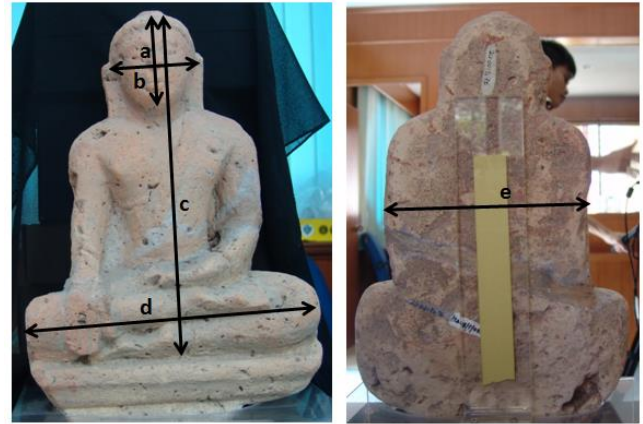| Items	Digital Close Range Photogrammetry (mm)	Laser scanning (mm)	Differences (mm)
a	66.452	64.556	1.896
b	70.571	69.218	1.353
c	259.000	259.535	0.535
d	211.352	211.087	0.265
e	145.307	144.141	1.166

Figure 24 Parts of distance measurement involved

From the table, it can be seen that the maximum differences between both techniques is 1.896mm whereas the minimum differences is 0.265mm. These differences are less than 2mm which can be considered as very small. However, the measurements were done in different software hence the common points for both models were difficult to pick for measurements.

3.2 Comparison Between Digital Close Range Photogrammetry and Laser Scanning Technique

Other than comparing the quantitative results, the system evaluation is also a part of this study. There are several aspects that we look upon making the evaluation. The criteria are mobility of the system, time, versatility and cost. The comparison between two techniques is summarized in Table 4.

Table 4 Comparison of both techniques

Criteria	Digital Close Range Photogrammetry	Laser Scanner
Mobility of the system	Easier with only a camera being used and the process can be done later	Rigorous
Time for data acquisition	Fast recording process	Time consuming
Time for data processing	Tedious post processing	Immediate point cloud viewing
Versatility	Fully adaptable to any object dimension	Restricted by the size of the object
Cost	Low	High

4.0 CONCLUSIONS

In this study, it is showed that 3D modeling is now fully available at low cost and with great efficiency to the community of the archaeologists. However, an initial

learning remains necessary which should be carried out with experts to give an idea to newcomers. Digital close range photogrammetry is more adapted to the world of cultural heritage. Indeed the taking photographs are even easier and the system is adaptable to any object dimension from tiny fragment to whole building. The acquisition stage is fully independent from the modeling stage and may be operated on site. On the contrary, laser scanner returns more accurate and dense 3D model. But the drawbacks are mainly because of the cost, complexity, and time. And these are the reasons that laser scanner does not respond to the needs and cannot comply with archaeological missions.

After completing this study, there are some recommendations can be made to improve the results. The results from this 3D model can be improved by finding a better approach in order to get more detail and denser point clouds. With great accuracy of the point clouds, we can convert it into suface and compare the measurements in the same software. Next, is to build a database that manage and store the 3D model and its related information for documentation purpose. Lastly, by using both methods we can achieve high quality results.

References

[1] Al-Kheder, S., Al-Shawabkeh, Y., Haala, N., 2009. Developing a Documentation System for Desert Places in Jordon Using 3D Laser Scanning and Digital Photogrammetry. *Journal of Archaeological Science*. 36(2): 537-546.

[2] Breithaupt, B. H., Matthews, N. A., Noble, T. A. 2004. An Integrated Approach to Three Dimensional Data Collection at Dinosaur Tracksites in the Rocky Mountain West. *Ichnos*. 11: 11-26.

[3] Bryan, P. G., Barber, D. M., Mills, J. P. 2003. Towards a standard Specification for Terrestrial Laser Scanning in Cultural Heritage Recording. *CIPA 2003 XIX*th *International Symposium Proceedings*. Antalya, Turkey.

[4] CIPA Brochure. 2010. Retrieved March 3, 2011 from http://cipa.icomos.org/objectives.html.

[5] Forte, M., Pietroni, E. 2009. 3D Collaborative Environments in Archaeology: Experiencing the Reconstruction of the Past. *International Journal of Architectural Computing*. 7: 57-76.

[6] Guidi, G., Beraldin J., Atzeni C. 2004. High-accuracy 3D Modeling of Cultural Heritage: The Digitizing of Donatello's "Maddalena". *Image Processing, IEEE Transactions*. 13(3): 370-380.

[7] Isler, V., Wilson, B., Bajcsy, R. 2006. Building a 3D Virtual Museum of Native American Basket. *3*rd *International Symposium on 3D Data Processing and Transmission*. Chapell Hill, NC.

[8] Kadobayashi, R., Kochi, N., Otani, H., Furukawa, R. 2004. Comparison and Evaluation of Laser Scanning and Photogrammetry and Their Combined Use for Digital Recording of Cultural Heritage. *International Archives of Photogrammetry and Remote Sensing*. XXXV(B5): 401-406.

[9] Kersten, T., Mass, H. G. 1995. Photogrammetric 3-D Point Determination for Dam Monitoring. *Optical 3-D Measurement III*. Eds. Gruen/Kahmen, Wichmann Verlag. 161-168.

[10] Matthews, N. A., Noble, T. A., Breithaupt, B. H. 2006. The Application of Photogrammetry, Remote Sensing and Geographic Information System (GIS) to Fossil Resource Management. *New Mexico Museum of Natural History and Science Bulletin*. 34: 119-131.

[11] PhotoModeler, EOS System Inc. 2008. Retrieved on 15/10/2010 from http://www.photomodeler.com/support/glossary.htm.

[12] Walford, A. 2007. *Photo-based Scanning Saves Time and Money – A White Paper*. Vancouver BC, Canada.