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3D documenatation of the petalaindera: digital heritage preservation methods using 3D laser scanner and photogrammetry.

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Abstract. 3D imaging technologies have undergone massive revolution in recent years. Despite this rapid development, documentation of 3D cultural assets in Malaysia is still very much reliant upon conventional techniques such as measured drawings and manual photogrammetry. There is very little progress towards exploring new methods or advanced technologies to convert 3D cultural assets into 3D visual representation and visualization models that are easily accessible for information sharing. In recent years, however, the advent of computer vision (CV) algorithms make it possible to reconstruct 3D geometry of objects by using image sequences from digital cameras, which are then processed by web services and freeware applications. This paper presents a completed stage of an exploratory study that investigates the potentials of using CV automated image-based open-source software and web services to reconstruct and replicate cultural assets. By selecting an intricate wooden boat, *Petalaindera,* this study attempts to evaluate the efficiency of CV systems and compare it with the application of 3D laser scanning, which is known for its accuracy, efficiency and high cost. The final aim of this study is to compare the visual accuracy of 3D models generated by CV system, and 3D models produced by 3D scanning and manual photogrammetry for an intricate subject such as the Petalaindera. The final objective is to explore cost-effective methods that could provide fundamental guidelines on the best practice approach for digital heritage in Malaysia.

1. Introduction
3D laser scanners use laser technology to deliver highly detailed 3D Documentation. 3D images of complex environments and geometries can be generated in mere minutes. It can be used for accident reconstruction, 3D modeling of process plants, architectural preservation tasks, digital factory layouts or deformation monitoring. Photogrammetry is the art and science of using overlapping photographs to reconstruct three dimensional scenes or objects. The practice has been around for over a century, but has become especially popular over the course of the past decade with the proliferation of digital cameras and free or relatively inexpensive, but accurate, processing software.

2. Equipment and Software
2.1. 3D Laser Scanner

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The hardware and equipment used for the 3D laser scanner process are as follows:

i. FARO® Focus3D X130 Scanner
ii. FARO® Freestyle3D Scanner
iii. Microsoft Surface Pro 3 Tablet
iv. Checkerboard
v. Tripod

3D Laser Scanning data processing will mainly utilise two (2) major software, which are FARO SCENE and MeshLab. SCENE is a software specifically designed to process 3D point clouds collected by FARO® FocusS, Focus3D and Freestlye3D Laser Scanners. SCENE processes and manages scanned data easily and efficiently by using automatic object recognition as well as scan registration and positioning. SCENE can also generate high-quality colorized scans very quickly, while providing the tools for automated target less or target-based scan positioning.

MeshLab is an open source system for processing and editing 3D triangular meshes. It provides a set of tools for editing, cleaning, healing, inspecting, rendering, texturing and converting meshes. It offers features for processing raw data produced by 3D digitization tools/devices and for preparing models for 3D printing.

2.2. Photogrammetry

The hardware and equipment used for the 3D laser scanner process are as follows:

i. DSLR Camera
ii. Tripod
iii. Target

Photogrammetry data processing will mainly utilise two (2) major software, which are Agisoft PhotoScan and Autodesk MAYA. Agisoft PhotoScan is an advanced image-based 3D modelling solution aimed at creating professional quality 3D content from still images. Based on the latest multi-view 3D reconstruction technology, it operates with arbitrary images and is efficient in both controlled and uncontrolled conditions. Photos can be taken from any position, providing that the object to be reconstructed is visible on at least two photos. Both image alignment and 3D model reconstruction are fully automated.

Maya 3D animation software offers a comprehensive creative feature set for 3D computer animation, modelling, simulation, rendering, and compositing on a highly extensible production platform. Maya has next-generation display technology, accelerated modelling workflows, and tools for handling complex data.

3. Workflow – 3D Laser Scanner

For this project, two type of 3D laser scanner will be used to obtain the point cloud data. This is decided based on the type and the scanning area of artefact.
The workflow for FARO Focus3D Scanner involves two (2) major step:

i. Scan – Scanning process using checkerboard marker around the artefact.
ii. Data Processing – Post processing to merge the multiple scans.

The workflow for FARO Freestyle3D Scanner involves two (2) major step:

i. Scan – With an intuitive plug and play system, capture real-time point cloud visualisation data effortlessly of almost any surface type in a wide range of environments.
ii. Data Processing – Register and process point cloud data using FARO CAPTURE and SCENE.

3.1. Scanning – FARO Focus3D Scanner
Before starting the scan, set up the workplace placing checkerboard markers on the wall. The checkerboard placement is decided with the visibility to the scanner in mind in order for the software to be able to register the scan placement during data processing. The scanner is set up on a tripod and the settings of the scanner are determined on the quality vs. duration of scan.

Then, the scanning process can begin. During the scan, the scanner must remain in place and no object/person should be blocking the view between the scanner and the artefact and the checkerboards. The scan processes are repeated on several locations surrounding the artefact ensuring there are no blind spot on the scan data.

It is recommended to have 3 to 5 metres of buffer area around the artefact for comfortable work area. On several occasion the scanner will be place on the ground or the tripod is boosted on a stool to capture low-level area or high-level area respectively.

Figure 1. Checkerboard markers area.

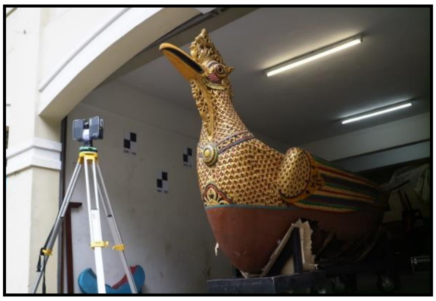

Figure 2. Scanning process.

3.2. Data Processing – FARO Focus3D Scanner
The data processing for the FARO Focus3D Scanner is done in FARO's own software, SCENE. The multiple scan points that has been captured on site are merged together to form a point cloud model of the scanned object. The software used the checkerboard markers scanned together with the object as reference points to merge the multiple scan points into one. The software also offers tools to manipulate the point cloud such as deleting unwanted data and colorising the point cloud model.

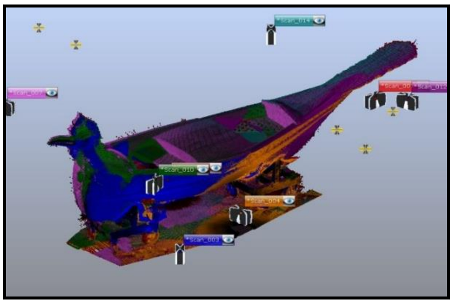

Figure 3. Cloud point model of Petalaindera.

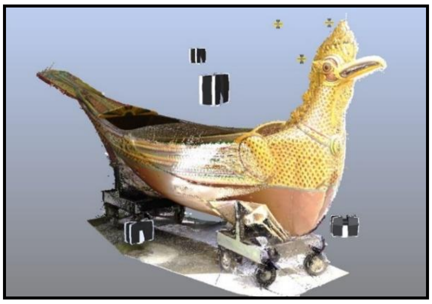

Figure 4. Colorize result in 3D view.

3.3. Scanning – FARO Freestyle3D Scanner
With the faro scanner freestyle, you can capture effortlessly almost any surface type simply by pointing the handheld device to the surface of object. Through the real time visualization on the tablet, the intuitive user interface and the lightweight (less than 1kg) of the scanner, the data acquisition process scan is fast and can easily be done even by semi-trained operators.

Figure 5. Scanning process of Freestyle3D.

Figure 6. Scanning process Freestyle3D.

The scanning is done by pointing the scanner toward the artefact and steadily and slowly moving to cover the whole scan area. The scanned data can be viewed in real-time within the tablet to ensure all data are collected. The data that have been fully captured will be displayed in green cloud.

It is recommended to finish the scanning process in only one scan as multiple scans may impose deviation in data when merging them together. The scanner can be calibrating for scanning distance between 0.5-3 metres depending on the artefact size, for a large sized artefact like the ***Petalaindera***, a 3-4 metres buffer zone surrounding the artefact is required for a comfortable workspace and optimal scanning process.

3.4. Data Processing – FARO Freestyle3D Scanner
Similar with Facos3D Scanner, Freestyle3D Scanner data are processed in the software SCENE. All of the unwanted scan data are removed and the cloud point are processed into a cloud point model.

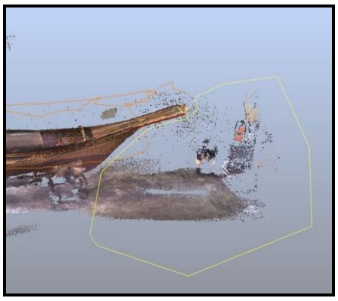

Figure 7. Deleting unwanted point clouds.

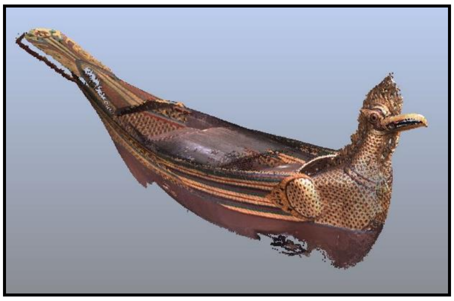

Figure 8. Result in 3D view.

3.5. Combining Focus3D and Freestyle3D Scan Data
Once both of the scanned data are processed, the next step is to merge them together. This is also done inside SCENE, by marking several matching reference points on the both scan data the software will be able to identify and merge the point cloud models into one.

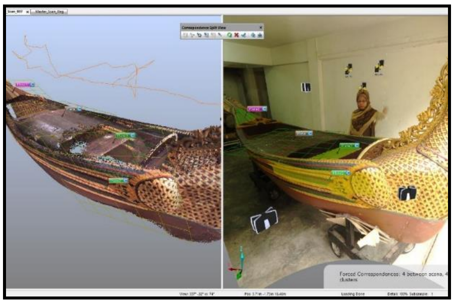

Figure 9. Mark references on both scan data.

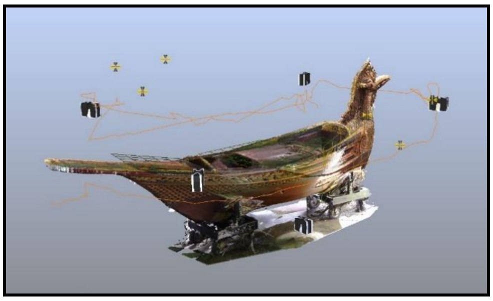

Figure 10. Final result of the merge.

3.6. Building Mesh Using MeshLab

MeshLab is an open source, portable, and extensible system for the processing and editing of unconstructed 3D triangular meshes. The scan data from SCENE are imported into MeshLab for mesh construction. The software works by identifying the individual points in order for surface reconstruction in the form of triangular faces. It also provide multiple tools to clean and edit the mesh. The mesh can then be exported as various formats for further actions including STL (STereoLithography) file format for 3D printing.

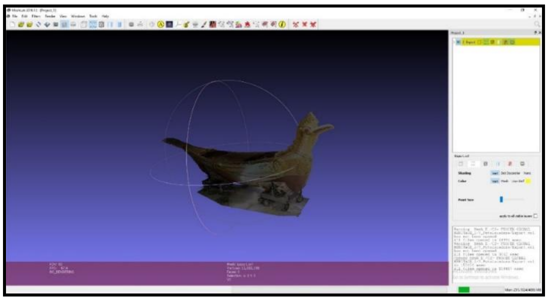

Figure 11. Imported scan data in MeshLab.

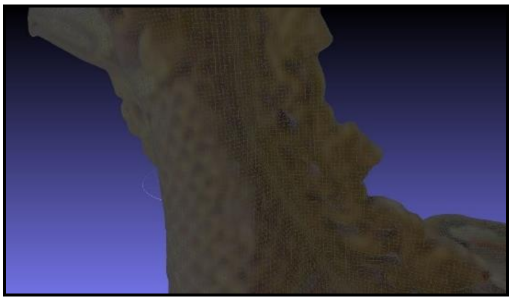

Figure 12. The completed mesh.

4. Workflow – Photogrammetry

The workflow for Photogrammetry involves two (2) major step:

i. Photography – Capturing multiple subsequence overlapping photographs of the artefact.
ii. Data Processing – Processing the photos into point cloud and then into mesh model.

4.1. Capture Overlapping Photographs

The following figure represent several typical capturing scenarios:

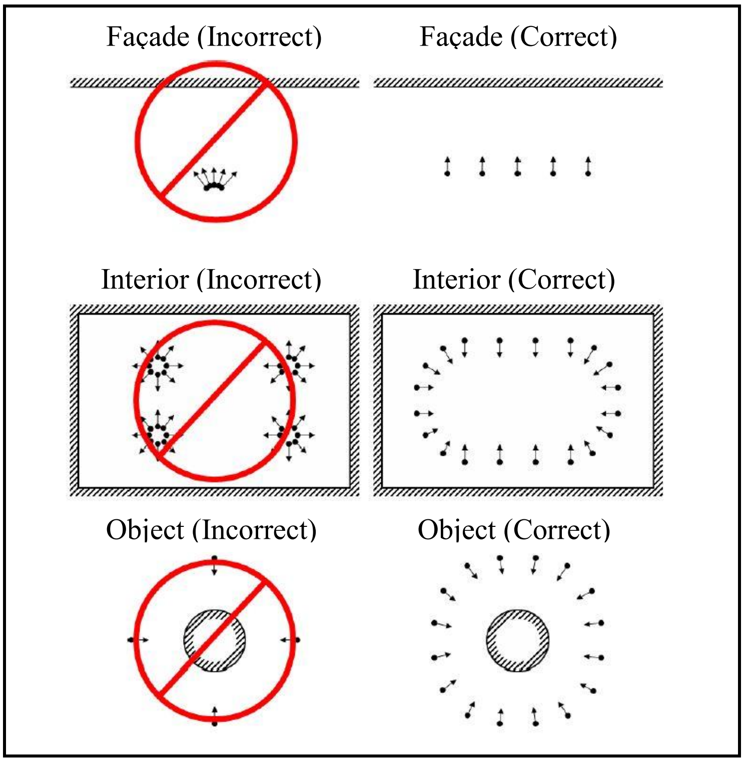

Figure 13. Photography capturing method.

Before start taking photos, set camera mode to manual mode and set a fixed exposure level to get a consistent sharp image with little or no noise. After that, shoot 100 - 300 photos of artefact depend on size. Take photos with different level such as eye level, below and above or many angles possible. It is quite possible to generate usable 3D data by taking two overlapping photographs. The more data will make better to take a sequence of images, according to the size and detail of the subject.

There are some ground rules when taking images for photogrammetry. The photos must overlap by no less than 60%, the camera must be kept at consistent distance for each shot, and must keep the camera perpendicular to the subject. As an example, a single footprint might take 3 shots with 60% overlap at the first pass with the camera in its normal orientation, back to the original and rotate the camera -90 degrees and take 3 more, rotate the camera 180 degrees and take the next sequence.

Figure 14. Setup place.

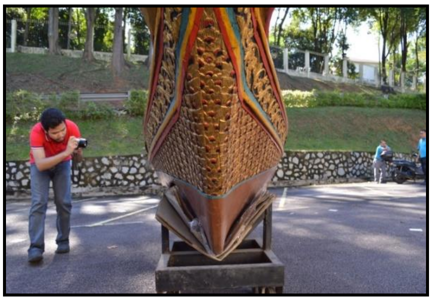

Figure 15. Taking photos of artefact.

4.2. Data processing – Photogrammetry

The software PhotoScan makes the order of operations easy to follow via its Workflow menu. Basic operations can be accomplished by stepping through the menu and performing each of the following tasks in turn.

i. Add Photos (or Add Folder containing all photos)
   - This first step loads all of raw images into the software's interface.

ii. Align Photos
   - The first processing step compares the pixels in the photos to find matches and estimate camera locations and 3D geometry from them

iii. Build Dense Cloud
   - Once satisfied with the alignment, the sparse point cloud (a mere fraction of the total data) is processed into a dense cloud in which each match able pixel will get its own X, Y, Z location in 3D space

iv. Build Mesh
   - This step connects each set of three adjacent points into a triangular face, which combine seamlessly to produce a continuous mesh over the surface of your model

v. Build Texture
   - In the final step, the original images are combined into a texture map and wrapped around the mesh, resulting in a photo-realistic model of original object.

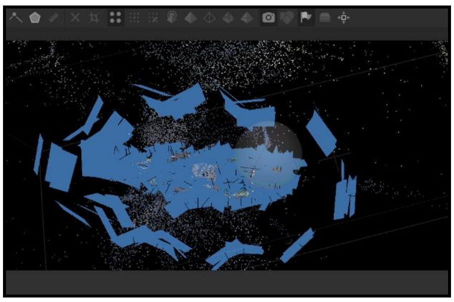

Figure 16. Photo alignment.

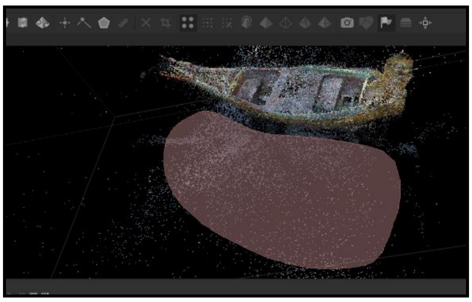

Figure 17. Deleting unwanted points.

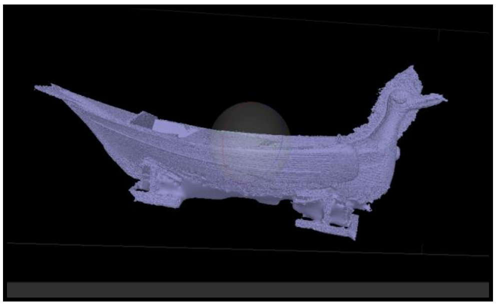

Figure 18. Color-stripped point cloud.

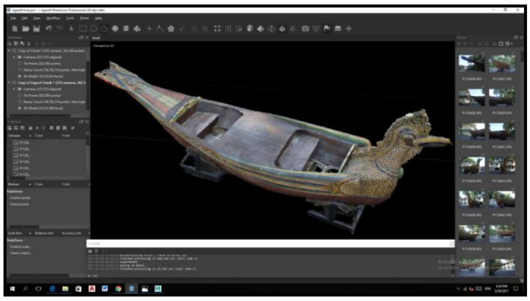

Figure 19. Final 3D Model after meshing.

The finished model can be exported in various formats for display or import into other 3D analysis suites, animation software or game engines. Common formats are:

1. 3D PDF: an interactive format that is widely accessible, as the model can be viewed, manipulated and even measured using the ubiquitous and free Adobe Reader.
2. Wavefront (.obj) and Collada (dae) are the most portable 3D mesh formats. If you are working with other animation platforms like Blender or game engines like Unity 3D, these formats can be easily added as assets to your project.
3. Pointcloud (LAS, .txt, etc.) these formats are probably the most future proof for long term storage, and also offer many options for secondary analysis in other tools like Geomagic and Meshlab.

The model can also be can be transferred to Autodesk Maya for 3D development and final adjustment. Apply lighting and texturing to artefact to enhance the 3D model. The 3D model can also be manipulated to add or subtract any of its elements using this software.

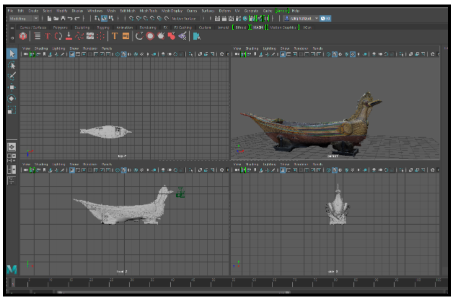

Figure 20. The 3D model in Autodesk Maya

5. Discussion and conclusion

Cultural heritage is very core of a nation's self-respect and identity and without it, the history can be influenced for reinterpretation or even rewritten. However, many of these heritage assets are left undocumented and unknown to the public. Thus, the awareness for the preservation of cultural heritage had brought exploration of new sustainable methods, one of them being digital heritage. There are many methodologies in digital documentation; 3D laser scanner and photogrammetry are two examples of the most current technology available in the industry.

In term of the availability and accessibility of these methods, each stand on the end of the spectrum respectively, where photogrammetry is on the cheaper side while 3D laser scanner in on the expensive side. This is because for hardware, photogrammetry utilises the standard everyday DSLR camera, while 3D laser scanner requires its own specialised expensive equipment. Software wise, there are numerous freeware available online for photogrammetry and some paid version for extra tools and features, while 3D laser scanner requires specialised software that are compatible with the data captured by the scanner. While both benefits from processing data in a high-end computer, processing 3D scanner data are a lot more demanding than photogrammetry.

Photogrammetry also have a low skill ceiling in comparison to 3D laser scanner as it can be done by semi-trained personnel and there are numerous how-to guide available online for those who want to experiment at home. 3D laser scanning however requires trained personnel to handle both the scanning and the data processing as the workflow are lot more complicated than photogrammetry.

However the output from 3D laser scanner does justify its high demand as it produce a lot more refine and accurate data compared to photogrammetry. The output from photogrammetry is more suitable for light usage, such as animation for display, 3D printing for souvenirs, etc. While the data produced by 3D laser scanners are more versatile in which they can be used for both research and managerial sector, as the data can produce measured drawing, used in simulation, digital to real restoration, etc. This is because the data obtain from the 3D laser scanner are measurable and to scale with around ±2mm accuracy with the scanner model used, while photogrammetry data requires manual scaling.

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