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Comparison of low-cost techniques for digital cultural heritage preservation of an original Egyptian temple*

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Abstract. The research covers a method to map archaeological objects (cultural heritage) in 3D in an accurate, detailed way with low-cost equipment. This paper deals with a preliminary step, testing the method on an ancient Egyptian object, the temple of Taffeh (Raven, 1996) in the Rijksmuseum van Oudheden (National Museum of Antiquities) in Leiden, the Netherlands. Mapping the temple is a preparation step for accurately and detailed mapping and geo-referencing an ancient Egyptian subterranean tomb. The research was to compare two different techniques on reliability and precision, together describing the accuracy. The proposed techniques in the method are photogrammetry with a full-frame digital mirrorless camera and using an iPhone with LiDAR capability. For this first step, the mapping of the temple, a third technique was added: a more advanced mobile laser scanner (a ZEB Horizon), not being low-cost but interesting for comparison and possibly validation. Of all three techniques the point density was measured to give a first indication of the level of detail. The research shows the method to be promising for use in Egypt. The photogrammetry model was the most accurate, presenting sub-centimetre details of the object while the iPhone LiDAR model was less accurate and lower in point density but faster.

Keywords. MLS, iPhone LiDAR, digital cultural heritage, digital archaeology, archaeology, photogrammetry.

1 Introduction

Capture it now, preserve it forever. By creating accurate copies of archeological findings it is easier to do research, to record, maintain, preserve, and restore monuments (Remondino, 2011). By capturing heritage with the newest capturing techniques, we can reach centimeter or even millimeter accuracy. This enables researchers to examine heritage in a many ways, for example by examining small elevation differences in carvings in walls.

Digitally capturing monuments offers opportunity to do wholistic research in areas with a high archeological density. Here, it makes sense to capture findings within a global geographical context instead of a local grid. Wholistic approaches ask for scanning both indoor and outdoor environments into a singular 3D object as well. This enables us to analyze archeological landscapes where lots of archaeological projects are located in close geographical proximity, yet in different excavation projects that can be years apart.

Although capturing archaeological findings in a digital way holds many benefits, there are some challenges to overcome. 3D scanning equipment can be expensive, vulnerable and unhandy (Jalandoni et al., 2018). For remote archeological surveys in harsh environments, we propose an approach that uses low-cost (costing less than 2.500 EURO) equipment and is flexible in itself to scan monuments in 3D and accurately geo-reference findings in global coordinates, while still getting enough detail to analyze distantly. Capturing Cultural Heritage is in need of using low-costs methods, optimizing between cost and accuracy (Teppati Losè, 2022). In this research (Teppati Losè, 2022) it is concluded that the technology is promising and emerging, both from a hardware and a software standpoint.

* This paper is available in preprint at http://www.gdmc.nl/publications/2023/AGILE2023Submission9107final

2 Methodology

This paper compares three techniques for obtaining a digital 3D model of both exterior and interior of historic monuments. Two of the techniques are chosen for their low-cost and low footprint properties, making them suitable for travelling to remote locations. The other, more costly technique is chosen for comparing it with the with the results of the low-cost techniques.

2.1 Data acquisition

Photogrammetry data was obtained with a Canon EOS R5 full-frame digital mirrorless camera with a Canon RF 24-105mm F4-7.1 IS STM lens. For all photos the widest view of 24mm is used to allow short-range, high-overlap photogrammetry which is required in the narrow spaces found in heritage locations.

For the temple dataset, 3000x images were obtained with 80% overlap in both lateral and vertical direction. A distance of 1 meter to the object wall was maintained. For geometric robustness several overview images have been taken from a larger distance. In-camera HDR is applied to increase dynamic range of the images (maximal distinguishable difference in light and dark areas).

Low-cost LiDAR data was obtained with an Apple iPhone 12 Pro. This phone is equipped with a laser time of flight sensor which measures the depth on 576 points (Leutzenberg et al. 2021). The angle of view of the sensor is equivalent to 26 degrees. As with photogrammetry a distance of 1 meter to the wall has been maintained. The temple dataset is obtained in one single recording session with the software standard settings.

A third dataset of the temple has been obtained with a GeoSLAM ZEB Horizon mobile laser scanner, which is a more costly LiDAR system. This mobile laser scanner obtains 300.000 points per second in a 270 degree by 360-degree angle of view. This dataset is acquired for comparison purposes and does not necessarily fit the low cost, low footprint pattern.

For reference, digital laser distance measurements have been acquired of the floor plan of the temple. These 5 measurements are used for an independent accuracy comparison between the three models.

2.2 Software

Photogrammetry data has been processed using Reality Capture 1.2.0 on a HP zbook G5 x360 workstation.

iPhone LiDAR data has been obtained and processed by the Apple iPhone app called "Scaniverse Pro" version 2.0.3.

ZEB Horizon MLS data has been processed using the GeoSLAM Connect v2 software.

Comparing the data was done using CloudCompare v2.13.alpha

2.3 Referencing

As photogrammetry on its own delivers a result up to an arbitrary scale, reference points have been used to scale the models for real world measurements. As with the data acquisition methods a low-cost solution has been found, in this case in the form of a two meter long wooden plank with a carefully measured length and painted segments. This ruler has been included in the data acquisition to be reconstructed in the 3D model. Within the Reality Capture software, key points in the 3D model have been selected corresponding to the model of the ruler. These key points have then be scaled according to the real world dimensions of the ruler.

As both the iPhone and ZEB Horizon datasets are scaled using their laser measurements, this method has only been applied to the photogrammetry dataset.

2.4 Comparison

For comparison, each model is compared against the other two to quantify relative precision. The open-source software application CloudCompare is used to calculate the cloud-to-cloud distance between each set. In preparation, CloudCompare is used to align the three models. Starting with a manual alignment based on selected features. The final alignment is done with the use of the Iterative Closest Point algorithm (ICP).

Cloud-to-cloud distance measurements calculate the per-point-distance of a reference point-cloud to a candidate point-cloud. For each point in the reference point-cloud, first the nearest neighbour of the candidate point-cloud is found. To this nearest neighbour the distance is calculated in each (X, Y, Z) direction which gives a signed distance. Also, the total (absolute) distance is calculated from these components.

Because the distance is calculated from each point in the reference point-cloud, the result from point-cloud A to B will be different to the result from point-cloud B to A. Therefore, both results are discussed.

For comparison, three key parts of the model have been selected, shown in figure1:

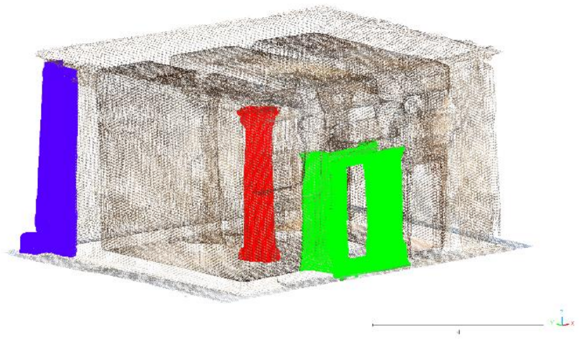

Figure 1 - The three sections used for accuracy estimation: Door (green), Column (red) and Corner (blue)

The three sections (doorway, column and corner) are each compared on point density, mean distance and the spread of the distance. Point density is determined by counting the points within each section and gives an indication of the (theoretical) ability to register details in the model.

Mean distance and spread of the distance are results of the cloud-to-cloud distance calculation in CloudCompare. The mean distance is a quantification of the difference between the reference and target dataset. Because this can be skewed by outliers the spread of the distances assists in explaining the quantification with the means of a histogram.

Also, in CloudCompare, measurements are taken in each model, corresponding to the laser-distance measurements of the temple. This gives an indication of the accuracy of each model. The distances are determined using the distance tool in CloudCompare. Because the exact point is hard to select in a point-cloud, the measurement is repeated three times and averaged.

3 Results

To be able to use the proposed techniques in Egypt we used them on an object which is also from ancient Egypt: the temple of Taffeh (Raven, 1996) as on display in the Rijksmuseum van Oudheden, Leiden, The Netherlands. This gave us the opportunity to do scanning inside an object with the added options of validating the data because we could also scan the outside parts together with the internal. This object also has many small details on its surface, such as graffiti incised into the temple walls and unevenness. Since this object is on display inside a building it would not be possible to geo-reference it.

From the temple we made 3 different point-clouds (iPhone, DSLR/photogrammetry and MLS-based). Several distances along the floor are measured with a calibrated laser distance meter (Bosch GLM 250 VF Professional (accuracy specified as 0.05 mm/m)) to be able to use as validation for all three point-clouds. The 3 different point-clouds are compared against each other (3 comparisons) with the standard ICP method of Cloud Compare so find the differences. Capturing the roof (outside parts) of the temple with iPhone turned out not to be possible because of the maximum reach of 5 meters, reaching it from above was not possible as well as from sideways was difficult because of the need of using a ladder to get from one spot to the next one. For the comparisons only the parts until the roof edge are used, including all the internal parts.

In all cased standard and closed source software has been used. One of the goals of this project is to find easy to learn methods with as simple equipment as possible building our own open-source software for photogrammetry, registering a LIDAR point-cloud and using the iPhone LIDAR did not fit well in this goal. A floorplan of the temple is provided as appendix.

Processing times were a few minutes for the iPhone model, less than an hour for the MLS model and approximately a day for the photogrammetry model.

3.1 Reliability (vs. laser distance meter)

At seven locations distances along bottom parts of the temple and of the ruler have been measured with the laser distance meter, bringing some ground truth and compared against the camera, ZEB-Horizon and iPhone.

Table 1 - Camera distance measurements

Part of temple	Measured distance	Difference with reference
Ruler 170-180 line	0.101 m	+ 0.001 m
Ruler 10-170 line	1.599 m	- 0.001 m
Front	8.456 m	+ 0.006 m
Front-left of door	1.354 m	+ 0.004 m
Left side	6.750 m	+ 0.031 m
Front-right of door	4.892 m	+ 0.001 m
Door opening	1.362 m	+ 0.001 m

Table 2 - ZEB-Horizon distance measurements

Part of temple	Measured distance	Difference with reference
Front	8.465 m	+ 0.015 m
Front-left of door	1.364 m	+ 0.014 m
Left	6.725 m	+ 0.006 m
Front-right of door	4.898 m	+ 0.007 m
Door opening	1.377 m	+ 0.016 m

Table 3 - iPhone distance measurements

Part of temple	Measured distance	Difference with reference
Front	8.191 m	- 0.259 m
Front-left of door	1.349 m	- 0.001 m
Left	6.949 m	+ 0.230 m
Front-right of door	4.620 m	- 0.271 m
Door opening	1.429 m	+ 0.068 m

3.2 Precision

Three sections as shown in figure 1 have been used to quantify precision differences between each model. These are discussed per model combination of which the results are shown in a table and some figures.

iPhone vs Camera photogrammetry

Table 4 - iPhone and Camera model comparison per section

Section	Reference	Target	Mean distance	Standard deviation
Door	iPhone	Camera	0.034 m	0.024 m
	Camera	iPhone	0.033 m	0.025 m
Column	iPhone	Camera	0.037 m	0.027 m
	Camera	iPhone	0.040 m	0.024 m
Corner	iPhone	Camera	0.066 m	0.030 m
	Camera	iPhone	0.055 m	0.029 m

Table 4 shows the found distances and their spread for the different sections of the iPhone and Camera point-clouds. The smallest distances between both models can be found in the door section, also shown in figure 2.

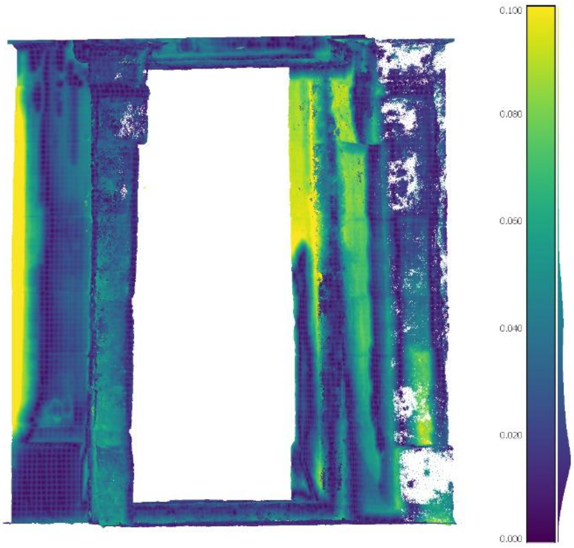

Figure 2 - Door section point-cloud coloured based on the distance between the iPhone and Camera model

Zeb-Horizon vs DSLR/photogrammetry

The calculation with the ZEB-Horizon as reference shows consistently larger distances than the calculations with the camera model as reference. Figure 3 shows the distances found on the column section, also some scan lines can be seen.

Table 5 – ZEB-Horizon and Camera model comparison per section

Section	Reference	Target	Mean distance	Standard deviation
Door	ZEB-Horizon	Camera	0.010 m	0.008 m
	Camera	ZEB-Horizon	0.005 m	0.002 m
Column	ZEB-Horizon	Camera	0.009 m	0.007 m
	Camera	ZEB-Horizon	0.005 m	0.002 m
Corner	ZEB-Horizon	Camera	0.009 m	0.007 m
	Camera	ZEB-Horizon	0.008 m	0.004 m

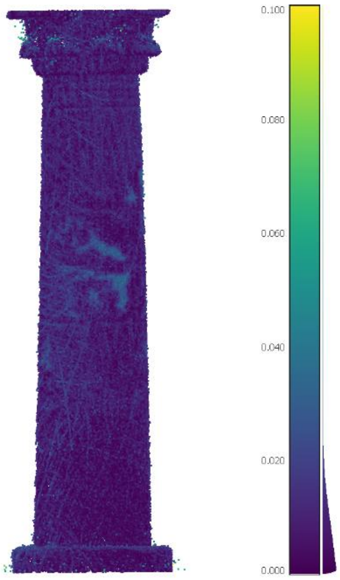

Figure 3 - Column section point-cloud coloured based on the distance between the ZEB-Horizon and Camera model

iPhone vs Zeb-Horizon

The distances between the iPhone and ZEB-Horizon models are similar to the distances between the iPhone and Camera models. With the exception of the door section with iPhone as a reference, which is considerably lower. Figure 4 shows the corner section with the highest distances found.

Table 6 – ZEB-Horizon and iPhone model comparison per section

Section	Reference	Target	Mean distance	Standard deviation
Door	ZEB-Horizon	iPhone	0.032 m	0.022 m
	iPhone	ZEB-Horizon	0.017 m	0.017 m
Column	ZEB-Horizon	iPhone	0.032 m	0.020 m
	iPhone	ZEB-Horizon	0.023 m	0.021 m
Corner	ZEB-Horizon	iPhone	0.060 m	0.030 m
	iPhone	ZEB-Horizon	0.060 m	0.033 m

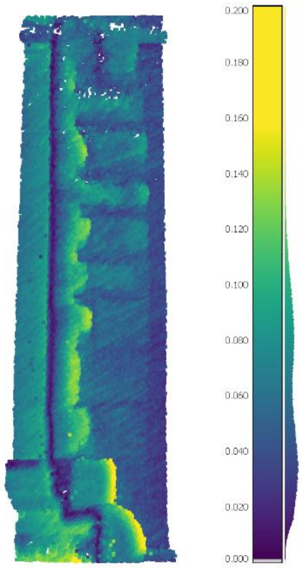

Figure 4 - Corner section point-cloud coloured based on the distance between the ZEB-Horizon and iPhone model

3.3 Point density

For the 3 already used parts and of the entire model the numbers of points were counted (in Table 7 and 8), showing the highest density in the photogrammetry model and the lowest with the iPhone.

Table 7 – Number of points per section

Model	Door	Column	Corner
Camera	9,783,429	5,713,638	4,612,312
iPhone	23,824	12,601	13,418
MLS	1,014,291	462,870	153,255

Table 8 – Number of points in total

Model	Total
Camera	207,292,537
iPhone	570,596
MLS	16,428,897

3.4 Conclusions

Three different techniques of acquiring a point-cloud of a heritage object have been compared on both reliability and precision.

The laser distance measurements indicate the camera photogrammetry model to be the most accurate with a sub-centimetre difference for all but one measurement. Second is the ZEB-Horizon model. Measurements on this model suffer from noise in the point-cloud which causes spread in the measured distances. Finally, the iPhone model shows the largest errors but also has a accurate result for the Front-left measurement. This model is sparse compared to the other two, and appears to suffer from rounding of interpolating on the edges, which influences the accuracy measurements.

The sections comparison shows similar results, with sub-centimetre differences between the photogrammetry and ZEB-Horizon model and several centimetres between the iPhone and other models. The corner section indicates again the smoothing of surfaces in the iPhone model, showing larger distances on sharp corners compared to flat surfaces. The mean reason in the differences between the photogrammetry and ZEB-Horizon models in believed to be the beforementioned noise in the ZEB-Horizon and some not reconstructed areas in photogrammetry due to a lack of light or features, as visible in the column in figure 3.

The handmade wooden ruler of 2.00 m with a precise scale is also visible in the photogrammetry part. Using the ruler shows good results both for going through narrow parts of the object and for scaling the results.

Figure 5 - Ruler and measurement points on the ruler

Going back to the goals (low-cost, reliable and precise) of the research the following conclusions are taken. Capturing Cultural Heritage objects with high reliability and precision is possible with non-expensive equipment in such a way that study is possible in many ways with using only the datasets.

Combining indoor and outdoor parts of the objects will be sensible to circumstances like accessibility and ways for transferring scale and geo-reference between the two parts. The usage of the wooden ruler showed to offer benefits both for the transfer of scale and for the continuity in the photogrammetric processing.

Comparing the distances measured with the laser distance meter with the three point-clouds it shows that in this project the photogrammetric point-cloud offers the best results (only one distance of 6.75 m is 3 cm wrong while all other errors are significantly smaller). The iPhone point-cloud does not offer enough detail to do this comparison, and the MLS point-cloud has a lot of noise, hampering the comparison.

Although the iPhone LiDAR gives good results in capturing Cultural Heritage (Teppati Losè, 2022) it is still limited in both precision and reliability also because of its low range. In this case we could not capture the top side of the roof.

3.5 Recommendations / future work

Lighting was stable because it was either artificial or artificially shaded because of the special fence above the temple to prevent direct light. This turned out to be helpful for the photogrammetry part. Geo-referencing the temple being erected inside a building would only have been possible with taking the outdoor coordinates inside with a total station. First this was not possible in a public museum during opening hours also in this stage of the work was not necessary.

In the next stage, capturing an ancient Egyptian subterranean tomb in Egypt, both items had to be taken into account again. The tomb, having an opening to the outdoor world, in a most of the time sunny environment would require a plan to deal with the moving sun light.

The tomb being located in an open sky environment would make it better possible to geo-reference all data. First of all, this is to solve issues like finding back subterranean archaeological spaces in the future but more importantly relating several projects, located in each other's neighborhood to each other geospatially. Since to planned project is in environment without already availably reference points with coordinates in a global grid it was needed to use a GNSS-data logger and use PPP-corrections over a longer period of time. These data loggers are expensive equipment so it has been decided to build one based on open source, opening that goal again.

A third and final recommendation is that un subterranean situation requires another way of validation of measurements. Getting ground truth is different because the object is not directly and evenly spread connected to an outdoor world and since it consists of 1 outdoor area and 4 indoor parts that are only connected to the outdoor area on one location. The use of special markers and measuring the distance between these will have to be considered.

4 Acknowledgements

This project has worked closely together with the Rijksmuseum van Oudheden, Leiden, the Netherlands and wishes to thank Dr. Daniel Soliman, curator of the Egyptian and Nubian collection for his very kind collaboration and organization of all the logistics in the museum. Also the project thanks Mr. Edward Verbree for his extensive help in acquiring the ZEB-Horizon dataset.

5 Data Availability

All data as captured of the Taffeh Temple is available in https://rlvoute.stackstorage.com/s/UJzwS4STKnSnOzat .

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Appendix

Appendix 1: Floorplan of Taffel Tempel with laser distance measurements and ruler position indicated